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10246-1, Session 1

Multiscale numerical study on ferroelectric nonlinear response of PZT thin films

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PZT thin films have excellent performance in deformation precision and response speed, so it is used widely for actuators and sensors of Micro Electro Mechanical System (MEMS). Although PZT thin films outputs large piezoelectricity at morphotropic phase bounfary (MPB), it shows a complicated hysteresis behavior caused by domain switching and structural phase transition between tetragonal and rhombohedral. In general, PZT thin films have some characteristic crystal morphologies. Additionally mechanical strains occur by lattice mismatch with substrate. Therefore it is important for fabrication and performance improvement of PZT thin films to understand the relation between macroscopic hysteresis response and microstructural changes. In this study, a multiscale nonlinear finite element simulation was proposed for PZT thin films at morphotropic phase boundary (MPB) on the substrate. The homogenization theory was employed for scale-bridging between macrostructure and microstructure. Figure 1 shows the proposed multiscale nonlinear simulation [1-3] based on the homogenization theory. Macrostructure is a homogeneous structure to catch the whole behaviors of actuators and sensors. And microstructure is a periodic inhomogeneous structure consisting of domains and grains. Macrostructure and microstructure are connected perfectly by homogenization theory and are analyzed by finite element method. We utilized an incremental form of fundamental constitutive law in consideration with physical property change caused by domain switching and structural phase transition. The developed multiscale finite element method was applied to PZT thin films with lattice mismatch strain on the substrate, and the relation between the macroscopic hysteresis response and microscopic domain switching and structural phase transition were investigated. Especially, we discuss about the effect of crystal morphologies and lattice mismatch strain on hysteresis response.

10246-2, Session 1

Fluid-structure interaction modelling of the roof tile-shaped modes in piezoelectric plate microresonators

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The use of micromachined resonant devices to monitor liquid properties is of interest to many different fields, such as automotive industry, biology or food analysis[1,2]. For liquid media applications, the use of high order out-of-plane modes, in particular the roof tile-shaped modes, have recently revealed their suitability due to a high quality factor and reasonably low resonant frequency[3]. Modelling the in-liquid behaviour of these modes is of utmost interest not only for the understanding of the physical phenomena responsible of their overwhelming properties but to overcome with the limiting factors[4].

In this work, roof tile-shaped modes of piezoelectric plate microresonators (fig. 1a) with different designs are studied using analytical and simulation models. Here, we present the results for a 2524x1274x20 μm3 cantilever. The analytical modelling is based on Sader's theory for beams and thin plates immersed in incompressible[5] and compressible[6] media. With the help of these models, it was possible to explain the change in the dominant mechanism of losses from viscous to acoustic while varying the geometrical dimensions or increasing the order of the mode[4] (fig. 2). However, in order to reach more accurate estimations of the quality factors for devices that do not meet the theoretical models' hypothesis, a FEM (Finite Element Method) simulation model is required.

In the first approach, a 2D CFD (Computational Fluid Dynamics) model (fig. 1b) was used[7]. As it can be seen from fig. 2, the CFD model gave lower Q-factors for high order modes, which may suggest that the dominant mechanism of losses, i.e. the acoustic damping, was not properly modelled. In a more realistic but computational expensive approach, a full FSI (Fluid-Structure Interaction) model (fig. 1b) in which the whole coupled system is simulated was used[7], giving the results shown in fig. 2. With this approach, the increasing trend in the measured Q-factor was reproduced even for modes up to the 4th order (15-mode) and the errors to the experimental values reduced in comparison with the analytical models.

10246-3, Session 1

Optimization of a Piezo-fiber scanning architecture

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Piezo-based fiber scanning probes have emerged as low-cost and compact tools for various optical imaging modalities, allowing access to tissue sites that are hard to reach. These instruments exploit scanning of a fiber optic cable via a piezoelectric element, which is driven at the mechanical resonance of the extended fiber piece. However, the dynamics of the piezo-scanning structure is often neglected, resulting in an inefficient electromechanical conversion. This work presents a methodology, together with experimental evidence, to collectively optimize the geometries of the piezo-scanner and the extended fiber optic cable to achieve maximum displacement for a given drive voltage. Our findings suggest that matching the individual resonances of the fiber optics cable and the piezo-scanner alone, leads to optimum electromechanical conversion efficiency. Simulations, circuit model, and experimental results reveal more than x2 improvement in the achieved fiber displacement when piezo and fiber resonances are matched, as opposed to the unmatched (i.e., when piezo element length is varied approximately by ±20% from its optimal value) case. Besides offering lower power consumption for the actuation of the piezo-element, our findings paves the way for safer (electric shock-free) minimally-invasive procedures using the piezo-based fiber scanning probes, which is crucial for patient safety.

10246-4, Session 1

Optimal design of a microgripper-type actuator based on AlN/Si heterogeneous bimorph

David Ruiz, Alex Díaz, Univ. de Castilla-La Mancha (Spain); Ole Sigmund, Technical Univ. of Denmark (Denmark); José Carlos Bellido, Alberto Donoso, José Luis Sánchez-Rojas Aldavero, Univ. de Castilla-La Mancha (Spain)

In this work we show a systematic procedure based on the topology optimization method [1] to design robust microgrippers with piezoelectric actuation. The topology of the gripper and the polarization profile are simultaneously optimized with the objective of improving its in-plane deformation while the out-of-plane displacement is kept below certain limit. The fabrication techniques used to manufacture the piezoelectric layer lead us to overcome an important issue: only one piezoelectric layer is usually placed over the host structure due to the complex process

required to deposit a second piezoelectric layer on the bottom face of the silicon structure. This asymmetric laminate generates a bending that spoils the behaviour of the device as a gripper in the plane of the substrate. The main novelty introduced in this work is the suppression of this out-of-plane deformation at some points of interest in order to get a genuine microgripper-type actuator.

In addition, a robust formulation [2] is used with two objectives. The first is controlling the minimum length-scale of the design to prevent the appearance of hinges. The second one is minimizing the effect of manufacturing errors in the behaviour of the gripper.

This work is intended as a continuation of the work presented in [3] and it is the previous case of a more general and interesting problem that involves big displacements.

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10246-5, Session 1

Topologically optimised flexure hinge based XY stage

Adil Han Orta, Bogazici University (Turkey); Evren Samur, Cetin Yilmaz, Bogaziçi Univ. (Turkey)

The purpose of this study is to develop a millimeter scale two degree of freedom planar actuation mechanism (XY stage) with flexure hinges that can generate micrometer scale motion at high frequencies. To amplify the micro scale motion in X and Y directions, two identical levers are used. According to the analytical and computational results, a prototype is developed for experimental purposes. Operation of the prototype is demonstrated with experiments. Piezoelectric actuators are used in the system because of their compactness and large force capacity. The levers in the XY stage are topologically optimized so that the first resonance frequency of the system is maximized, which enlarges the operation range of the system.

10246-6, Session 2

Modeling high signal-to-noise ratio in a novel silicon MEMS microphone with comb readout

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Strong competition within the consumer market urges the companies to constantly improve the quality of their devices. For silicon microphones, excellent sound quality is the key feature in this respect, which means that improving the signal to noise ratio (SNR), which is strongly correlated with the sound quality, is a major task to fulfill the growing demands of the market. MEMS microphones with conventional capacitive readout suffer from noise caused by viscous damping losses arising from perforations in the backplate. Therefore, we conceived a novel microphone design based on capacitive read-out via comb structures, which is supposed to show a reduction in fluidic damping compared to conventional MEMS microphones. In order to evaluate the potential of the proposed design, we developed a fully energy-coupled, modular system-level model, taking into account the mechanical motion, the slide film damping between the comb fingers, the acoustic impact of the package and the electrical energy domain (capacitive read-out, bias voltage, and ASIC). All submodels are physically based scaling with all relevant design parameters and are properly calibrated and validated by numerical simulations and measurements, which ensures the predictive power of the models and the significance of the obtained results. By carrying out noise analyses we were able to discriminate the noise contributions of different parts of the microphone and to identify design variants of this concept which exhibit a SNR of up to 78 dB(A). This is superior to conventional and at least comparable to high-performance variants of the current state-of-the art MEMS microphones. Hardware realizations of comb microphones have been fabricated and will be evaluated w.r.t. to the predicted performance.

10246-8, Session 2

An FE model of a cellular polypropylene: exploring mechanical properties

Pavlos Sgardelis, Michele Pozzi, Newcastle Univ. (United Kingdom)

Most piezoelectric sensors and actuators are made of piezoelectric ceramics, notably PZT, which is dense and brittle. For applications where high strain and mechanical flexibility is required, PZT is not among the optimal choices. A novel alternative is offered by flexible electromechanically active polymers. Among these, cellular polypropylene (C-PP) was found to exhibit a pseudo-piezoelectric behavior when functionalized in high fields. On the contrary, their dielectric response is non-linear and depends on the mechanical load applied.

Several suggested analytical models describe the changes in the electromechanical properties due to the charging process. However, there is a limited number of studies considering the non-linear dependence of the piezoelectric effect d33 on the mechanical load applied. One of the main reasons for this non-linearity is the stiffness of the film which increases proportionally to the mechanical load applied. Moreover, this kind of approach does not consider the distribution of enclosed voids, which is an important parameter of the electromechanical properties.

In this work, the geometry of a 3D Finite Element (FE) model of C-PP is designed on the basis of analytical Splines. Both the manufacturing procedure of these films (bi-axial stretching) and the pressure expansion treatment were simulated in order to account for a realistic void distribution. The mechanical response is analyzed theoretically based on different applied mechanical loads. The load-deflection curves obtained from the analysis are then compared to the experimental results acquired via Dynamical Mechanical Analyzer (DMA) to validate the model. Four types of Cellular PP films expanded at different pressures are available in this validation. The aim is to develop a model that describes the effect of morphological parameters on the stiffness of the films.

10246-9, Session 2

Efficient fluid transport by a bionically inspired micro-flapper: fluidic investigations using fully coupled finite element simulation

Regine Behlert, Gabriele Schrag, Gerhard Wachutka, Technische Univ. München (Germany)

Cooling by efficient fluidic mass transport is a key issue in many (micro-) electronic devices in consequence of the increasing degree of integration in conjunction with continuously shrinking feature sizes and, thus, higher power densities. Therefore, we proposed the concept of a bionically inspired, integrated piezoelectric micro-flapper for cooling and venting applications. The fin-like design is deduced from the undulation-based locomotion of fish and small insects, which evolved to be one of the most effective principles for fluid transport in nature. The undulatory, wave-like motion of such a design is supposed to generate vortex chains in the surrounding fluid resulting in a directed jet stream and, hence, enhanced mass convection and heat transport inside the fluid. In this work, we studied the fluid-structure interaction (FSI) underlying the function of this bionically inspired micro-flapper. Fully-coupled finite element (FE) simulations have been carried out to investigate the fluid transport induced by such an excitation in order to assess the efficiency of the concept. The challenges we have to cope with are the strong interaction between moving structure and surrounding fluid as well as

the large aspect ratio of the mechanical structure (about 1:100 to 1:500). The moving boundary of the fins necessitates a moving mesh inside the fluid model with very poor convergence properties. Therefore, as a first approach to a detailed understanding of undulatory motion, we approximated the flap motion by the combined translatory and rotatory motion of an ellipsoid of comparable dimensions. The results show that there is a significant higher net flow for undulation compared to the simple, beam-like up-and-down motion of the flap, which conforms with the theoretical expectation and, thus, corroborates the feasibility of the proposed design. The next steps focus on the adaptation of the model to the true twin flap geometry, the optimization of the transport efficiency, and the validation by measurements.

10246-10, Session 3

Development of a lab-on-chip electrochemical immunosensor array for detection of Polycyclic Aromatic Hydrocarbons (PAH) in the environmental

Shifa Jameel A. Felemban, Patricia Vazquez, Tyndall National Institute (Ireland); Eric Moore, Tyndall National Institute (Ireland) and Univ. College Cork (Ireland)

This work shows how the integration of immunoassay techniques in combination with electrochemical detection can provide a portable and very accurate solution for detection of water pollutants that are detrimental for human health. In particular, we focus our work in the quantification of PAH in drinking water. Our integrative approaches takes advantage of microfluidic technology in order to facilitate a real-time detection of this family of toxic compounds. Additionally, the use of a lab-on-a-chip platform delivers a portable solution that could be used in a household and avoid the dependency of costly equipment that is currently used in specialized laboratories.

By optimizing a displacement assay that targets the presence and concentration of Benzo[a]pyrene in water, we have obtained, thanks to the miniaturization of the platform compared to standard ELISA plates, a fast-result, highly accurate system that also provides a limit of detection comparable to the existing state-of-the art. It also presents a linear range useful for the application of PAHs in water as recommended by the European Drinking Water Directive (DWD).

10246-11, Session 3

Gravimetric humidity sensor based on ZnO nanorods covered piezoresistive Si microcantilever

Jiushuai Xu, Maik Bertke, Alaaeldin Gad, Hao Zhou, Hutomo Suryo Wasisto, Erwin Peiner, Technische Univ. Braunschweig (Germany)

Humidity monitoring is very important in a wide range of fields, such as agriculture, food processing and biomedical devices. In this contribution a new portable, highly sensitive and stable zinc oxide (ZnO) nanorods-covered self-sensing piezoresistive silicon microcantilever gravimetric humidity sensor was designed and fabricated. The piezoresistive silicon microcantilevers were fabricated using silicon bulk micromachining based techniques (i.e., photolithography, dopant diffusion and ICP cryogenic dry etching), and in this development the microcantilever was equipped with a full Wheatstone bridge on its clamped end as a piezoresistive element working based on the strain-to-resistivity change for reading the sensor output signal.

The geometry of the resonant microcantilever (1 mm x 170 μm x 10 μm) was designed to obtain high sensitivity and Q-factor. ZnO nanorods which were used as sensing material, were grown on the microcantilever by chemical bath deposition (CBD), based on a sputter-coated nanocrystals seedlayer. An extended area of uniform and aligned coverage of the cantilever with ZnO nanorods of 566 ± 86 nm in length and 157 ± 50 nm in diameter at a density of 17 ± 1 μm-2 was observed after the CBD process. Then the ZnO- covered piezoresistive microcantilevers were operated in their second bending mode for humidity sensing, whose spectral shape was fitted using a simple harmonic oscillator (SHO). Measurements and experiments showed that ZnO-nanorods-covered piezoresistive Si microcantilever sensors are almost independent of temperature, and have a high sensitivity value of 101.5 ± 12 ppm/% (quality of water adsorbed 36.9 ± 4.4 ng/% RH response) at 20 °C from 20 % RH to 70 % RH. Further researching indicated that both good short-time stability (?Sshort = 1.97± 1.34 ppm/%) and long-term stability (after 100 h full operation, ?Slong = 48.5 ppm/%) were achieved, subsequent measurements at decreasing RH levels revealed that only a slight hysteresis occurred.

10246-12, Session 3

MEMS-based array for hydrogen sulfide detection employing a phase transition

Benedikt Bierer, Cem Dinc, Haitao Gao, Univ. of Freiburg (Germany); Jürgen Wöllenstein, Univ. of Freiburg (Germany) and Fraunhofer-Institut für Physikalische Messtechnik (Germany); Stefan Palzer, Univ. of Freiburg (Germany)

Here we present a technique for quasi-continuously and selectively detecting hydrogen sulfide (H2S) concentrations using a percolation phase transition in copper (II) oxide (CuO)-based metal oxide gas sensors. It makes use of the hydrogen sulfide (H2S) induced transformation from semiconducting CuO to copper sulfide (CuS) at temperatures below 200°C. Because CuS features high electrical conductivity a huge drop in the resistivity of the layer is the result and this may be observed after a concentration dependent time of H2S exposure. For temperatures above 400°C the reaction is reversible, i.e. CuS is converted back to CuO even in the presence of H2S. This allows us to use a thermal modulation protocol to operate the sensor and measure the time until the reaction to CuS takes place to infer the H2S concentration instead of measuring the resistivity of the gas sensitive metal oxide layer. While this scheme offers advantages as compared to standard, resistivity-based read-out techniques in terms of reproducibility and selectivity, it makes continuous H2S concentration determination difficult. To address this issue we use 15 individually temperature-controlled CuO layers to determine the H2S concentration in the range between 0.1 – 20 ppm in a quasi-continuous fashion. The CuO layers are produced via inkjet printing of a water-based dispersion containing nano-sized Cu2O spheres with an average diameter of 300 nm. Using an on-chip annealing techniques the Cu2O spheres are converted to CuO and subsequently used to detect H2S. The temperature of the gas sensitive layer is controlled by a microcontroller which also processes the sensor data. The design of the sensor is such that it may be applied to detect a hydrogen sulfide filter breakthrough in biogas plants.

10246-13, Session 4

Direct measurement for organic solvents diffusion using ultra-sensitive optical resonator

Amir R. Ali, Catherine Elias, The German Univ. in Cairo (Egypt)

In this paper, novel techniques using ultra-sensitive chemical optical sensor based on whispering gallery modes (WGM) are proposed through two different configurations. The first one will use a composite micro-sphere, when the solvent interacts with the polymeric optical sensors through diffusion the sphere start to swallow that solvent. In turn, that leads to change the morphology and mechanical properties of the polymeric spheres. Also, these changes could be measured by tracking the WGM shifts. Several experiments were carried out to study the solvent induced WGM shift using microsphere immersed in a solvent atmosphere. It can be potentially used for sensing the trace organic solvents like ethanol and methanol. The second configuration will use a composite beam Nitrocellulose Composite [NC] structure that acts as a sensing element. In this configuration, a beam is anchored to a substrate in one

end, and the other end is compressing the polymeric sphere causing a shift in its WGM. When a chemical molecule is attached to the beam, the resonant frequency of the cantilever will be changed for a certain amount. By sensing this certain resonant frequency change, the existence of a single chemical molecule can be detected. A preliminary experimental model is developed to describe the vibration of the beam structure. The resonant frequency change of the cantilever due to attached mass is examined imperially using acetone as an example. Breath diagnosis can use this configuration in diabetic's diagnosis. Since, solvent like acetone concentration in human breath leads to a quick, convenient, accurate and painless breath diagnosis of diabetics. These micro-optical sensors have been examined using preliminary experiments to fully investigate its response. The proposed chemical sensor can achieve extremely high sensitivity in molecular level.

10246-14, Session 4

Inkjet-printed dissolved oxygen and pH sensors on flexible plastic substrates

Ana Moya, Miguel Zea, Instituto de Microelectrónica de Barcelona (Spain); Enrico Sowade, Technische Univ. Chemnitz (Germany); Rosa Villa, Eloi Ramon, Instituto de Microelectrónica de Barcelona (Spain); Reinhard R. Baumann, Technische Univ. Chemnitz (Germany); Gemma Gabriel, Instituto de Microelectrónica de Barcelona (Spain)

It is well known that inkjet printing technology is attracting great interest in a wide range of applications, since it is an additive and non-contact approach that allows the mask-less deposition of different functional materials on rigid and flexible substrates. Although the main field is printed electronics, the interest of this technology in the micro-sensor area is increasing. The aim of this work is to demonstrate the potential of inkjet printing technology for the area of micro-sensors by substitution of standard microfabrication techniques for the manufacturing of dissolved oxygen (DO) and pH sensors with a multiple micrometer sized electrodes on a flexible film for monitoring at high temporal and spatial resolution. The DO sensor has been fabricated using commercially available gold ink and the pH sensor with platinum ink in PEN and Kapton substrates. The inks are specially designed formulation which allows their sintering at low-temperature, which is a key point in the development of low-cost sensors made on plastic and paper substrates. We have printed the basic elements of the sensors; in detail a working electrode (WE) and a counter electrode (CE) with the gold or platinum ink, and a pseudo-reference electrode (RE) with a silver ink. In order to delimit the active area of the electrodes, we printed the dielectric SU-8 as passivation layer. The four used inks have been completely characterized in terms of printability, morphology, conductivity and resolution. The performance and characterization of the flexible DO and pH sensors in sensitivity, response time, stability, reversibility, repeatability and selectivity confirm the suitability of the inkjet-printed microelectrodes for electroanalytical applications. This proposed manufacturing strategy is very attractive due to its simplicity and rapidity. The low-cost electrochemical platforms presented here potentially enable novel devices in a broad range of applications such as analytical sensors, biosensing and medical applications.

10246-15, Session 4

Wax microfluidics light-addressable valve with multiple actuation

Maria Diaz-Gonzalez, Gerard Boix, Cesar Fernandez-Sanchez, Antonio Baldi, Instituto de Microelectrónica de Barcelona (Spain) and Consejo Superior de Investigaciones Científicas (Spain)

Microvalves are one of the key components of microfluidic devices. The design, fabrication and performance of a novel light-actuated wax microvalve is described in this work. This valve has a fast response (< 500 ms) and a very low energy-consumption (< 1 J). The valve exhibits reversible open–close behaviour for up to 30 actuation cycles in air and 15 in water. The valve is also inherently latched in both open and close states and is leak-proof to at least 80 kPa.

This phase-change microvalve is actuated by simply using a white LED without requiring any electrical connection. The valve can be easily fabricated as a fully integrated element of wax microfluidic devices using a low-cost and fast prototyping process. This fabrication process is also compatible with temperature sensitive biocomponents since the chip assembly is performed at 40 ºC.

The chip comprises one structured wax layer (160 μm-thick) sandwiched between two transparent polymer films. The top polycarbonate layer includes the holes for fluid access. The bottom polyester film incorporates the printed line that opto-thermally actuates the valve. The valve structure comprises a 500 μm-length wax barrier located in a microfluidic chamber. The black ink line printed on the substrate is positioned perpendicular to the wax barrier extending on both sides of the wax structure. Wax valve is designed for opening at pressures ≥ 3 kPa and for closing when no pressure is applied to the system. Both opening and closing of the valve occurred when wax is melted using the heat released by the printed line upon LED irradiation.

This valve notably improves current drawbacks of paraffin microvalves in terms of response time, energy consumption, multiple-actuation and complexity of the fabrication processes. Furthermore, the wax microfluidic technology described here is highly promising for mass production of single-use, fully-integrated lab-on-a-chip devices.

10246-16, Session 4

Development of biosensors for non-invasive measurements of heart failure biomarkers in saliva

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Heart failure (HF) is a chronic cardiovascular disease which affects mainly elderly people, and for this reason is rapidly increasing in western societies, in view of the aging population. For contributing to an m-health environment for monitoring and improving the adherence and management of patients suffering from heart failure, we are developing biosensors for the detection of HF biomarkers in saliva. Typical relevant biomarkers for HF are cytokines such as interleukin-10 or the tumour necrosys factor-alpha (TNF-α).

The biosensors are based on metal microelectrode transducers. The chips consist on an array of eight gold working electrodes, a gold counter electrode and a silver quasi-reference electrode. Interconnects have been made of gold or platinum. The metals have been deposited on silicon dioxide over a silicon substrate, and silicon nitride has been used as a passivation layer. To obtain an adequate reference electrode behavior, the silver microelectrodes are chlorinated by immerging them in a 3 M KCl solution. The gold working electrodes are activated electrochemically. The electrochemical behavior of the microelectrodes was characterized by cyclic voltammetry measurements.

For the detection of cytokines, the working microelectrodes are functionalized with monoclonal antibodies. The antibodies are modified with diazonium, which allows the antibodies to be electroaddressed to specific gold microelectrodes and immobilized on them. Electrochemical impedance spectroscopy (EIS) has been used for the measurement of the biosensor response. We report the EIS results for concentrations of TNF-α in the 1-15 pg/mL range, which is the clinically relevant one for HF monitoring. A high sensitivity for the detection of the HF biomarker molecule has been obtained.

10246-500, Session Plen

MEMS microphone innovations towards high signal to noise ratios

Alfons Dehé, Infineon Technologies AG (Germany)

After decades of research and more than ten years of successful production in very high volumes Silicon MEMS microphones are mature and unbeatable in form factor and robustness. Audio applications such as video, noise cancellation and speech recognition are key differentiators in smart phones. Microphones with low self-noise enable those functions. Backplate-free microphones enter the signal to noise ratios above 70dB(A). This talk will describe state of the art MEMS technology of Infineon Technologies. An outlook on future technologies such as the comb sensor microphone will be given.

10246-17, Session 5

MEMS direction finding acoustic sensor

Gamani Karunasiri, Fabio Alves, William Swan, Naval Postgraduate School (United States)

The conventional directional sound sensing systems employ an array of spatially separated microphones to achieve directional sensing. However, there are insects such as Ormia ochracea fly that can determine the direction of sound using a miniature hearing organ much smaller than the wavelength of sound it detects. The fly's eardrums that are coupled mechanically with separation merely by 0.5 mm have remarkable sensitivity to the direction of sound. The MEMS based sensor mimicking the fly's hearing system was fabricated using SOI substrate with 25 micrometer device layer. The sensor consists of two 1.2 mm x1.2 mm wings connected in the middle by a 2.7 mm x 30 micrometer bridge. The entire structure is connected to the substrate by two torsional legs at the center. The frequency response of the sensor showed two resonance frequencies at approximately 1.1 kHz (rocking) and 1.7 kHz (bending). The resonance at 1.1 kHz is due to rocking of the wings by twisting the legs and the other at 1.7 kHz is due to bending of the bridge. The sensor response was probed electronically using comb finger capacitors integrated to the edges of the wings and with the help of MS3110 chip. At the bending resonant frequency an output voltage of about 25 V/Pa was measured. The directional sensitivity of the sensor was found be within a couple of degrees depending on the bearing of the incident sound. These findings indicate the potential use of the MEMS sensor to locate sound sources with relatively high accuracy.

10246-18, Session 5

A multi-functional MEMS-SPM for quantitative characterisation of nano-objects

Zhi Li, Sai Gao, Uwe Brand, Physikalisch-Technische Bundesanstalt (Germany); Karla Hiller, Technische Universität Chemnitz (Germany); Nicole Wollschläger, Bundesanstalt für Materialforschung und -Prüfung (Germany); Xianghui Zhang, Universität Bielefeld (Germany)

For the purpose of extending the capabilities of commercially available atomic force microscopes (AFMs), in recent years based upon the micro-fabrication technology, a series of MEMS scanning probe microscopes (MEMS-SPM) have been developed in the national metrology institute Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig. In comparison with those traditional AFMs, our MEMS-SPM features generally (1) a vertical deflection up to more than 10 μm with a resolution of 0.2 nm and a nonlinearity less than 0.03% [1], (2) a testing force up to several mN with a force resolution down to ~nN by means of a capacitive displacement sensing technique and down to ~15 pN/Hz1/2with an in-chip fiber interferometer [2]. As a result, these MEMS-SPMs have already been successfully applied in the field of nanomechanical metrology.

Another important feature of the MEMS-SPMs is that conventional AFM-cantilevers can be used as probes for the MEMS, further extending the applications of our MEMS-SPM.

A prerequisite for measurements with small uncertainty, especially force measurements, is the stiffness calibration of the MEMS-SPM. A MEMS stiffness calibration setup has been developed, which utilizes a long-stroke piezo-stage to engage and drive the MEMS force actuator and a precision compensation balance to quantitatively measure the reaction force of the MEMS after contact. A stiffness calibration uncertainty less than 4% can be achieved.

In this paper, the reliability of the new cantilever clamping mechanism is characterized with the aforementioned setup. The experimental results indicate that the new micro-cantilever gripper attached to the MEMS works well, even if the probing force is increased up to tens of micro-Newtons.

First profile measurements with a prototype of the MEMS-SPM are demonstrated in this manuscript, verifying the metrological capabilities of the MEMS-SPM.

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10246-19, Session 5

Asymmetric resonance response analysis of a thermally excited silicon microcantilever for mass-sensitive nanoparticle detection

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The asymmetric resonance responses of thermally actuated silicon microcantilevers for a portable, cantilever-based nanoparticle detector (Cantor) are analysed. For the measurement of airborne nanoparticle concentrations, the cantilever is excited in the first in-plane resonance mode by an integrated p-type heating actuator. The resonance frequency (f0) of the cantilever shifts due to the deposition of nanoparticles (NPs) on the cantilever surfaces. A homemade phase-locked loop (PLL) circuit is developed for tracking of f0. To optimize the collecting efficiency and the sensor sensitivity, different cantilever geometries were designed and manufactured by bulk silicon micromachining techniques. Besides the thermal actuator they contain an integrated piezo-resistive Wheatstone bridge (WB). The fabricated cantilevers were characterized by their frequency responses. The most significant characterisation parameters of our application are f0 and the quality factor (Q). Regarding the asymmetric resonance behaviour, a new fitting function based on the Fano resonance and a method for calculating Q by the fitting parameters are developed. To obtain a better understanding of the resonance behaviours, we analysed the causes of the asymmetric line shapes. Due to a good correlation of the theoretical and measured asymmetric line shapes, we had performed the studies using the theories of the Fano resonance behaviour. Therefore, we compared the frequency response of the on-chip thermal excitation with an external excitation using an in-plane piezo actuator. We found the heating influence as the origin of the asymmetry. In correspondence to the Fano effect, we can reconstruct the measured resonance curves by coupling a signal with constant amplitude with the expected signal of the cantilever. Moreover, the phase of the measurement signal can be analysed by this simulation, which is important to understand the locking process of the PLL circuit. Using the described analysis method, decent results to optimize a next generation of Cantor are expected.

10246-20, Session 5

Thermoelectric bolometers based on silicon membranes

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State-of-the-art high performance IR sensing and imaging systems utilize highly expensive photodetector technology, which requires exotic, toxic, materials and cooling. Cost-effective alternatives, uncooled bolometer detectors, are widely used in commercial long-wave IR (LWIR) systems. Compared to the cooled detectors they are much slower and have approximately an order of magnitude lower detectivity in the LWIR. We present uncooled bolometer technology which is foreseen to be capable of narrowing the gap between the cooled and uncooled technologies. Thermoelectric bolometers suitable for fast and sensitive detection of weak levels of thermal power are presented. These bolometers are fabricated by patterning a 40 nm thick silicon membrane into 50 x 50 μm2 and 100 x 100 μm2 areas suspended by beams. The thermal signal is transduced into electric voltage using thermocouple consisting of highly-doped n and p type Si beams. The devices operate in a Johnson-Nyquist noise limit with the measured noise equivalent power below 30 pWHz-0.5, voltage responsivity in the order of 1000 V/W, and thermal time constant in the range of 1-10 ms. Reducing the thickness of the Si membrane improves the performance (i.e. sensitivity and speed) as thermal conductivity and thermal mass of Si membrane decreases with decreasing thickness. This and other performance improvements and use of these devices in optical applications, such as LWIR sensing, are discussed.

10246-22, Session 6

Oscillator circuit for monitoring the gas damping effect of piezoelectric microresonators

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Real time monitoring of the physical properties of gases is an important subject in different markets such as aerospace, automotive, healthcare or pharmaceutical industry. Microelectromechanical systems have been widely employed in gas sensors, pressure sensors and flow meters1,2. Resonant microstructures may be a precise and compact solution for tracking other physical properties of gases such as viscosity and density3,4. In this work, an aluminum nitride based piezoelectric resonator (05-mode5) was fabricated and characterized to study how various factors, such as pressure, gas composition, the resonator geometry or the order of the vibrational mode, influence the resonant frequency (fr) and quality factor (Q-factor) of micro resonators.

In order to track these parameters, an interface and oscillator circuit were designed for the measurement of the oscillation frequency (fosc) and the gain of the interface circuit (Gosc) from which the quality factor and resonant frequency were deduced. The effect of viscosity and density of the gases under test on the resonance parameters can be determined through a calibration process similar to the one previously reported for liquids 6. The calibration process was developed using different gases, an impedance analyzer and theoretical values of density and viscosity reported in the literature.

Our results demonstrate the performance of the resonator in different gases (Air, N2, Ar, CO2 and He) and pressures (0.1-950 mbar) by developing and applying specific experimental setup (Figure 1). The Q-factor measured was around 200 at 950 mbar and 1350 at 0.1 mbar. Depending on gas species different gas damping effects in the molecular, viscous and transitional flow regimes may be observed (Figure 2). However, as the resonant mode number increases and therefore fr, the acoustic wavelength reduces, the contribution of acoustic effects on the energy loss cannot be neglected any more in comparison with viscous effects. In the final paper, a comparison for different vibration modes, resonators and geometries will be presented.

10246-23, Session 6

Comparative assessment of PVDF and PVDF-TrFE piezoelectric polymers for flexible actuators applications

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In the recent years, there has been an increasing interest in the use of piezoelectric organic materials for the actuation of flexible devices. Poly(vinylidene fluoride) (PVDF) and its copolymer with trifluoroethylene (TrFE) are some examples of these alternative materials [1]. They exhibit excellent electroactive properties, such as piezo-, pyro- and ferro-electricity. However, the achievement of high piezoelectric coefficients together with compact and plain layers, requirements for electronic manufacturing, are challenging. A promising alternative for processing is the phase separation at low temperature. In this process, a viscous solution is first cast on a suitable support and then immersed in a non-solvent bath. A piezoelectric layer, characterized by a significant presence of ?-phase, is formed by polymer precipitation.

The aim of the present work is to make a comparison between PVDF and PVDF-TrFE films in terms of piezoelectric response. Solutions of PVDF and PVDF-TrFE in either DMF (N,N-dimethylformamide) or DMSO (Dimethyl sulfoxide) solvent were prepared. The solutions were deposited via spin-coating on different substrates [2]. For the post-processing, special interest was paid to phase inversion at different temperatures. Other protocols, such as baking for removal of solvent and crystallinity enhancement were also considered.

Basic characterization techniques such as differential scanning calorimetry (DSC) and Fourier transform infrared spectroscopy (FTIR) were used to determine the crystalline phase present in the films. Figures 1 and 2 show the results, which confirm the presence of the piezoelectric beta phase for low temperature phase inversion. A step further is the deposition of metallic contacts (by inkjet technology, for example) for the subsequent electrical and mechanical characterization to determine the capacitance and resistivity of the films at different voltages, as well as the displacement due to the piezoelectric properties. The effect of the different processing conditions on the results of the dielectric and piezoelectric characterization will be discussed.

10246-24, Session 6

Thin film system with integrated load and temperature sensors for the technical application in deep drawing process

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In these days industry 4.0 resounded throughout the land and means the fourth industrial revolution. The industry has to tackle the task of a flexible and customer-oriented production. Therefor the need of sensor systems for the measurement of temperature and load, the two most important categories in production, is rising. For getting the real specification during the production process the integration of sensor elements in high load regions of machinery is very important. The direct application of these multifunctional thin film sensor systems on the complex shaped surface of blank holder tools is the aim. Therefor a combination of plasma activated vapour deposition (PACVD) processes with physical vapour deposition (PVD) processes and structuring thechnologies like photolithography, chemical wet etching and also laser structuring is nessecary. During the deep drawing process simultaneously the measurement of load and temperature distribution is possible. These multilayer systems based on a piezoresisive hydrogenated carbon layer combine excellent wear resistance with sensory behaviour. The sensor data will lead to a deeper

process understanding, to optimization of simulation tools, to reduction of rejects and to an improvement of flexibility in production.

10246-40, Session PTue

Anti-collision radio frequency identification system using passive SAW tags

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Modern multi sensor systems should have high-noise immunity, high operating speed, resistance to climate impacts. Some radio frequency systems use passive SAW tags for identification items and vehicles. These tags have application in industry, traffic control systems, and railway traffic control systems. Every tag has unique code which can be recognized by SAW RFID reader. SAW technology and ultra-high frequency of SAW RFID devices with low power allows creating devices and solve issues for different application. These systems allow remote control and detect different objects and also they can measure vehicle speed and temperature. In the base of RF instruments was an integrated principle of work which based on piezoelectric properties of materials that provides high operational speed, the high level of environmental friendliness and safety in comparison with the existing systems of identification. However, collision of the passive SAW RFID tags hinders development passive RFID SAW technology in Industry. The collision problem for passive SAW tags leads for incorrect identification and encoding each tag. When several tags are placed at the same time in the read field, response signals cover each other in time domain. It causes problems in identification and encoding each tag. In our researching we suggest approach for identification of several passive SAW tags in collision case. Generally SAW RFID tags readers define identification code using time delay. Time delay depends on tag topology and the reflector placement on it. Variety of reflector placement in slots determines quantity of unique identification codes. However, in the case when the reader interrogates simultaneously several passive tags, it increases the probability of coincidence of the code groups, resulting in misidentification. As example this case can occur with freight cars and goods. During our research of SAW RFID tags we combined OFC coding and time position coding.

10246-41, Session PTue

Mini- and microgenerators applicable in the MEMS technology

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The article presents certain general conclusions obtained from the investigation of a vibration-powered milli- or microgenerator functioning as a harvester. In this context, the authors summarize the parameters that are critical in designing optimal generators to retrieve the residual energy contained in an electromechanical system and transferred through the vibrations of an independent structure. The discussion exploits the results proposed within paper [1], which theoretically defines the properties characterizing the models of individual basic configurations of a generator based on Faraday's law of induction [2]. A large number of approaches to the actual generator design are tested and analyzed within, for example, [1] and [3].

10246-42, Session PTue

Design and development of microfluidic pH sensor created using RF sputtering technique

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In recent years, Circulating Tumor Cells (CTCs) has attracted high attention as a potential biomarker for early cancer identification. It is well known fact that, there is a direct relation between cancer and pH of the blood cells. Hence, there is huge possibility to identify CTCs from blood using pH values. Therefore, in this research work, to measure the pH of the blood cells, a microfluidic pH sensor was designed and fabricated. RF magnetron sputtering was used to deposit the working (Sb) and reference electrodes (Ag/AgIO3) on glass substrates. As a novelty of this work an electrolyte free reference electrode (Ag/AgIO3) was developed and successfully utilized. Structural and morphological properties of both thin films were investigated using X-Ray Diffraction (XRD), Scanning electron Microscope (SEM) and Laser Microscopes. Both Sb and Ag/AgIO3 thin films exhibited crsyalline nature. Polydimethylsiloxane (PDMS) based microfluidic mask with the channel length and width of 140 μm and 70 μm respectively was prepared by conventional photolithographic processes. Finally the glass substrates with electrode and the microfluidic channel was bonded via. Plasma bonding. pH measurements were done at ambient atmosphere at room temperature. Standard buffer solutions were taken for testing and pH sensitivity was found to be -48 mV/pH with good linearity for the flow rate of 45 μL/min. Sensitivity, stability and effect of low rate was investigated and presented.

10246-43, Session PTue

Modeling the microstructure of surface by applying BRDF function

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The article presents the modeling of the microstructure of surface material by applying new algorithm based on selected elements of two models BRDF function (Bidirectional Reflectance Distribution Function). The BRDF function has full information about reflective properties of flat surfaces, thereby share of specular, direction and diffuse component in reflected light stream can be specified. The authorial software which utilizes elements of the Torrance-Sparrow model and HTSG model has been made. In the Torrance-Sparrow model it is used to generate the test surface microstructure, wherein the distribution and geometry microwalls, micropeak and microcavities determine the direction of the specular reflection. Anisotropic surfaces may be generated by autocorrelation function and the mean square deviation of microsurfaces. Orientation of microwalls towards the incidence angle of the light stream is described by the Gaussian distribution. HTSG model uses a Kirchhoff's scalar theory of diffraction, which allows for a full description of the phenomenon of the light reflection from a particular surface. The software was created to analyze surface mirror of the solar concentrator of photovoltaic systems. The concentrator directs the reflected light radiation on the photovoltaic surface, increasing the value of incident stream energy. The analysis of the distribution component in light stream reflected from the various surfaces made of the steel polished electrochemically, the silver-plated steel and the steel polished mechanically was performed. The results showed that the share of directional and specular component in the stream reflected from the steel polished electrochemically is almost three times larger as compared to the diffusion component. Such a component share provides very good light technical parameters because the shape of light stream reflected from the mirror of the solar concentrator is similar to the specular reflection, which is desirable in photovoltaic systems. The simulation results are consistent with the results of measurements in 98.3%.

10246-44, Session PTue

Actuation control of a PiezoMEMS biomimetic robotic jellyfish

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Recently there has been significant interest in developing robots that can mimic the actuation of living animals or organisms. The development of MEMS based micro-robotics is particularly interesting as there are numerous applications and environments where these robots could function that are not currently feasible. Development of a MEMS robot that can function and move in 3 dimensions in a liquid environment is one such application. MEMS robots that can move and function in a liquid environment would allow for them to be used in applications such as: liquid pipe diagnosis and repair without the need to stop flow like in nuclear power plants. In the future it is envisaged that these devices could be implanted in the body to help diagnose or to treat disease at the target site, thus reducing unwanted side effects like in cancer treatment. This paper investigates the development of a piezoelectric based biomimetic robot that mimics the movement of a jellyfish. There are numerous challenges associated with the development of a MEMS robotic device, but one of the key challenges that is investigated within this paper involves controlling the actuation of the robot so that it can move in 3 directions.

The paper describes a 3D design of a MEMS robot that resembles a jellyfish and uses a piezoelectric polymer substrate to perform the actuation. The robot consists of a tethered centre with six extending piezoelectric legs that can be controlled independently. A Finite Element Model was developed that investigated the control actuation of the robot in a liquid environment. Results demonstrated that a quick excitation pulse followed by a slow recovery allows the robot to maximise thrust and velocity. The FEM model also demonstrates the ability of the robot to move in 3D by stimulating the individual beams independently.

10246-45, Session PTue

MEMS-based seed generator applied to a chaotic stream cipher

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In this work, we have used a cryptosystem based on a combination of a Skew Tent Map (STM) and a Linear Feedback Shift Register (LFSR). Due to the ergodic property of the chaotic systems, any chaotic map such as the STM is expected to generate pseudorandom sequences. However, when a chaotic map is digitized, the period length of the generated sequences is usually very small which results in poor randomness. The LFSR guarantees that the period length of the generated sequences is big enough improving considerably the quality of the cryptosystem.

In order to generate the seeds, we have acquired the signal produced by an ADXL 335 MEMS accelerometer at rest by means of a low-noise real-time digital oscilloscope. Then, we have used this signal to generate the initial parameters of the STM-LFSR system. Our motivation comes from the fact that previous researches have shown that MEMS accelerometers are capable of generating good random numbers. Furthermore, MEMS accelerometers are cheap and are present in many wireless devices (such as cellphones, laptops, vehicles, etc.).

The stream cipher has been implemented in a Xilinx Virtex 7 FPGA VC707 Evaluation Kit and has achieved a throughput of 200 Mbps using 390 LUTs. In order to test the security of this system, several sequences have been generated and have been subjected to the National Institute of Standard and Technology (NIST) randomness tests. All of them have passed the tests proving that the proposed system is secure. Furthermore, we have tested the randomness of some sequences generated using the STM only. These sequences have failed some of the test, proving that the inclusion of an LFSR results in improved randomness.

10246-46, Session PTue

Analyses of electromagnetic and piezoelectric systems for efficient vibration energy harvesting

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The paper deals with analyses and evaluation of vibration energy harvesting systems, which are based on electromagnetic and piezoelectric physical principle of electro-mechanical conversion. Energy harvesting systems are associated with wireless sensor networks and condition base monitoring or reporting systems of engineering objects (aeronautics, automotive, civil structure, etc.). The most of these engineering objects operate with unwanted mechanical vibrations. However, vibrations could provide a source of ambient energy which is converted to useful electricity. The level of vibrations is usually very low and the harvested electrical power is in a range of microwatts up to several milliwatts. Therefore, the harvested electrical power could be used for ultra-low power electronics.

The harvested power depends on the several parameters of energy harvesting system. The fundamental part of the vibration energy harvester is a resonance mechanism. This mechanism is based on spring suspension of a moving seismic mass. This resonance mechanism is excited by ambient mechanical vibrations and it provides kinetic energy of the mass relative movement.

The harvested power is maximal in resonance operation and the power is proportional with seismic mass and quality factor, is square proportional with amplitude of vibration and inversely proportional with operation frequency. Further the harvested power depends on parameters and efficiency of electro-mechanical converter. Due to high power density the electromagnetic and piezoelectric vibration energy harvesters are used for wireless sensors applications.

Parameters of electromagnetic and piezoelectric vibration energy harvesters are analyzed and evaluated for the choice of the most efficient system. The character of used mechanical vibrations and the required output power are input parameters into analyses. Simulink models of typical electromagnetic and piezoelectric vibration energy harvester are used. The volume and mass of the energy harvesting systems are evaluated and the paper provides recommendations about using of electromagnetic or piezoelectric vibration energy harvester.

10246-47, Session PTue

Gold/polypyrrole nanorods for gas sensing application

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Gold nanostructures have attracted a great attention due to their potential application in chemical and biochemical sensing, such as detection of volatile organic compounds (VOCs), medical diagnostics and therapeutics, and biological imaging because of their unique optical and electrical properties [1,2]. In order to enhance the sensing properties of gold in terms of sensitivity and selectivity, the material can be functionalized with other compounds such as biomolecules, conductive polymers, etc. In our work we focused on polypyrrole, because it is one of the most promising p–type conductive polymers thanks to its unique features such as high conductivity, fast charge-discharge mechanism, high energy density and good thermal stability, and last but not least easy and low cost way of the preparation [3]. This work describes a preparation of gold/polypyrrole nanorods (AuPPy NRs) by combination of following techniques: (1) electrochemical anodization, (2) pulsed galvanic deposition, and (3) electropolymerization. For the fabrication of the AuPPy NRs, we used the anodized alumina oxide (AAO) template

prepared via electrochemical anodization of thin aluminium layer, with an advantages of the subsequent deposition of two different materials into the pores, namely an inorganic one (gold) and an organic one (PPy). The pulsed galvanic deposition of the gold into AAO template was performed using aqueous electrolyte based on potassium dicyanoaurate and boric acid. The electrochemical polymerization of pyrrole was carried out using acetonitrile solution containing pyrrole monomer and tetraethylammonium tetrafluoroborate in a potentiostatic regime and two–electrode system. The tunable morphology of AAO template gives a possibility to synthesize the structures with defined length of metal and polymer parts, by controlling the number of applied pulses passed during the the pulsed galvanic deposition of the gold, and setting the optimal reaction time in the case of the electropolymerization of pyrrole. The detailed topography of the nanostructured surfaces was characterized by scanning electron microscopy (SEM). The fabrication process of the sensor was provided by the connection of the sensitive layer with the heater, and connection of the platinum wires to the sensitive layer using the silver paste. In this work we measured the sensor response to NO2.

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10246-48, Session PTue

Four segment piezo based micropump

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In recent years, micropumps have been investigated by various researchers as drug delivery and disease diagnostic devices. Many of these micropumps have been designed, taking into account, primarily, available micro fabrication technologies rather than appropriate pump performance analysis. Piezoelectric based micro pumps are more popular as compared to other smart materials being explored. In this paper, four segment piezoelectric actuator as shown in figure 1 is presented and compared with single disc piezoelectric actuator based pump. The static and transient behaviors under various electric fields have been analyzed by finite element method using ANSYS 12.1®. The deflection of the actuator at 5 volt is observed as 230 nm with four segment piezo actuator as compared to 1.78 nm in for single disc piezoelectric actuator under static analysis. This shows that dividing the actuator in segment can amplify the deflection. Results are summarized in table 1.

For dynamic analysis, a sinusoidal voltage is applied as given in Eq (1).

Applied Voltage=V Sin (2*ϖ*f*Time) (1)

V= Applied voltage

f= Applied frequency

Time= Applied run time for actuator

The comparison of the fluid flow analysis in the two cases is summarized in the table 2. It can be observed that segmented piezoelectric actuator shows better performance and results in reduction of applied voltage to 5 volt as compared to 20 volts for getting approximately same fluid flow velocity in the pump.

10246-49, Session PTue

Computational model and simulation for the whispering gallery modes inside micro-optical cavity

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A computational model for the whispering gallery modes inside a microsphere resonator is presented. In the archetypical microsphere resonator sensor, a tunable laser light beam is injected into an optical fiber and coupled with the resonator's cavity. The resonant optical coupling is achieved by bringing the fiber in the vicinity of the cavity's evanescent field. The transmission spectrum is then observed to detect the WGM shifts. In this paper, two-dimensional models of a single laser source put near the equator of a microsphere are simulated using COMSOL Multi-physics 5.1 electromagnetic waves, beam envelopes library. Afterwards, a three-dimensional model of two laser sources put near the horizontal and vertical equators of a microsphere is computed. The transmission spectrum of both simulations was taken and cross correlation was performed on them. Results show a big similarity between both simulations and could bring a breakthrough in the area of optical sensors.

10246-50, Session PTue

Thermal analysis of magnetic trapping with alternating magnetic fields

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The work aims at the development of a novel therapeutic drug monitoring point-of-care-testing device by converting concentration changes of the analytes in detectable luminescent signals. The integration of point-of-care assays can be facilitated by using actuated magnetic nanoparticles (MNP) to perform testing in less expensive settings, enabling to deliver cost-effective care. MNP provide large surface-to-volume ratio, can be suitably biofunctionalized and can be manipulated by magnetic fields diminishing the difficulties posed by mixing at low Reynolds numbers or by the high flow resistances at small scales. A microconcentrator using MNP as drivers to form clusters or to induce surface binding is a viable approach to concentrate such biomarkers, increasing the sensitivity and the specificity of the test at the same time avoiding interference before testing. Moreover, if the microconcentrator working mode is based on current flowing across coils (resistances), the magnetic field can be modulated by varying the current flowing through the device. However, Joule heating will become an issue if tests need to be performed under strict temperature ranges. This study aims at investigating effects of heat dissipation induced by current flowing through thin film metallic magnetic traps while generating alternating magnetic fields. Two different strategies were developed and tested for surface and volume nanoparticle microconcentrators based on magnetic traps for biological assays. The experimental magnetic force field qualitatively matched simulated results and effective volume and surface particle trapping was achieved with separation between a electromagnet and the fluidic channel height deriving from simulation results. In addition, two cooling devices were successfully designed for an efficient heat removal (30-100W.cm-2) and a narrow thermal control window of 28-37ºC. Results show power dissipation is a function of frequency and duration of magnetic actuation and alternating magnetic fields cause different thermal behavior. This innovative integrated approach permits a fast and optimized response for the dosage of the respective therapeutical drug.

10246-51, Session PTue

Influence of binding material of PZT coating on microresonator's electrical and mechanical properties

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Microresonators are fundamental components integrated in a hosts of MEMS applications: covering the automotive sector, the telecommunication industry, electronic equipment for surface/material characterization and motion sensing, etc. The aim of this paper is to investigate chemical, mechanical and electrical properties of PZT film fabricated with three binding materials: polyvinyl butyral (PVB), polymethyl methacrylate (PMMA), and polystyrene (PS) and to evaluate applicability in control of microresonators' Q factor. Micro particles of PZT powder were mixed with 20% solution of PVB, PMMA and PS in benzyl alcohol. Chemical composition and morphological properties of the created materials were tested using Scanning Electron Microscope Quanta 200 FEG with integrated Energy Dispersive X–Ray Spectrometer detector X–Flash 4030, Fourier Transform Infrared Spectroscopy (SPECTRUM GX 2000 RAMAN), X–ray diffractometer D8 Discover (Bruker), and Atomic Force Microscope NT–206. For investigation of mechanical and electrical properties multilayer cantilevers were made. Obtained PZT and polymer paste was screen printed on aluminium (thickness 300 μm) using 32/70 (layer thickness 68 μm), 48/70 (layer thickness 60 μm) and 140/34 (layer thickness 25 μm) polyester monofilament screen meshes and dried for 30 min at 100oC. Electric dipoles of the PZT particles in composite material were aligned using high voltage generator (5 kV) and a custom–made holder. Electric field was held for 30 min. Dynamic and electrical characteristics of the multilayer cantilevers were investigated using laser triangular displacement sensor LK-G3000. The measured vibration amplitude and generated electrical potential was collected with USB oscilloscope PicoScope 3424. As the results showed, these cantilevers were able to transform mechanical strain energy into electric potential and v.v. However, roughness of PZT coatings with PMMA and PS were higher, what could be the reason of the worse quality of the top electrode. However, the main advantage of the created composite piezoelectric material is the possibility to apply it on any uniform or non-uniform vibrating surface and to transform low frequency vibrations into electric potential.

10246-52, Session PTue

Colorimetric sensor for bad odor detection using automated color correction

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Colorimetric sensors offer a convenient approach for the quantitative measurement of different gases with color-changing dyes. An integrated, mobile colorimetric sensor can be particularly helpful for occasional chemical sensing measurements, such as informal air quality checks for bad odors. One relevant gas contributing to bad odors is ammonia (NH3). In these situations, the main requirement is high availability, easy usage, and high specificity towards one single chemical compound, combined with cost-efficient production. In this contribution, we show how a well stablished colorimetric method can be adapted for easy operation and readout, making them suitable for the untrained end user.

As a first example, we present the use of pH indicators for the selective and reversible detection of NH3 in air using inkjet-printed gas-sensitive layers. Our results show that the method can be adapted to detect NH3 concentrations down to 50 ppb, with measure-to-result times in the range of minutes. We will demonstrate that the color measurement can be carried out with the optical signals of RGB sensors, without losing quantitative performance. We will present a new tool and a protocol to determine the true color composition of an RGB signal, acquired with a conventional color camera. As an application example, we will show how this automated color calibration procedure can be used to determine quantitatively the presence of NH3 with the colorimetric method described above. In summary, all this demonstrates an easy to use methodology to carry out highly specific chemical sensing with colorimetry in everyday life, with simple and inexpensive tools, opening a whole new strategy for ubiquitously available test kits for bad odor detection.

10246-53, Session PTue

Temperature simulation at ZnO surface processed by laser interference lithography

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ZnO is a wide band gap and n-type semiconductor with hexagonal wurtzite crystal structure widely used in several applications such as solar cells, transparent electronics, optoelectronics and thin film chemical sensors. The research community has deeply studied ZnO because of its numerous properties: good transparency, high electron mobility, large exciton binding energy and non-toxicity.

Laser interference lithography (LIL) is a technique that uses interference patterns generated from two or more coherent laser beams to structure materials. Without the need of a mask, nanopatterning with LIL is a fast and simple technique that can be applied at wafer level during the device fabrication process.

In this work, zinc oxide sputtered thin films have been processed on alumina substrates using the laser interference lithography tripled Q-switched Nd:YAG laser source with an output wavelength of 355 nm in a 2-beam configuration. The aim is to obtain periodic structures on the surface, varying the fluence of the laser in order to control the surface area processed and compare with ZnO thin film thermal annealed at 600ºC, 700ºC and 800ºC degrees during 4 hours in synthetic air.

The structural characterization has shown that two-dimensional patterns have been obtained and also that the material changes its morphological properties (for example a stress release is observed in the (002) direction, when compared to as-grown ZnO).

In order to understand the periodic structure generated on the surface with this technique, the temperature profile on the surface of the ZnO has been simulated using Matlab. For this purpose optical properties of the films have been measured and used in the simulation of the heat transfer equation at the surface of the ZnO. Temperature evolution with time and distance at different laser fluences have been simulated and compared to morphological results obtained. For fluencies around 165 mJ/cm2 in as grown samples, the results show up temperatures up to 1800 K few nanoseconds after the laser pulse is sent.

10246-54, Session PTue

Innovative metal thermo-compression wafer bonding for microelectronics and MEMS devices

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In microelectronics the development towards heterogeneous device and materials integration primarily intends to electrically connect two different substrates via wafer bonding. Besides the mechanical stability, and the high thermal as well as electrical conductivity requirements, the bonding interface additionally might ensure hermetic or vacuum

sealing for microelectromechanical systems (MEMS), or is functioning as a mirror for light emitting diodes (LEDs). So far, often a via-last approach including fusion or adhesive wafer bonding has been used. However, due to the demand of increasing interconnect density a via-first approach utilizing wafer level metal (or hybrid) bonding is often the process of choice. Metal wafer bonding can be categorized into three main groups: metal thermo-compression, eutectic and solid liquid interdiffusion (SLID) bonding. Within this work representative processes of these different approaches are explained and their main benefits, drawbacks and challenges are compared (see Fig. 1).

From a physics point of view the fundamentals of the individual approaches are described, and frequently-used material combinations are discussed. Besides the actual wafer bonding process, also the influence of deposition and surface pretreatment are incorporated. Furthermore, experimental results of selected material combinations, e.g. Cu-Cu (see Fig. 2), are presented and considered for the discussion.

Finally, the characteristics of the different approaches are summarized in TABLE I.

10246-55, Session PTue

Characterization of oscillator circuits for monitoring the density-viscosity of liquids by means of piezoelectric MEMS microresonators

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Monitoring the physical properties of liquids is of practical interest in different markets such as automotive, healthcare or chemical. In the case of the automotive industry, the real time monitoring of lubricating oils properties is of utmost importance to determine its performance. Resonant microstructures are playing an important role in the determination of rheological properties of liquids such as density and viscosity. In this work, an aluminum nitride based piezoelectric resonator, based on a roof tile shaped mode, 15-mode1 in figure 1, was fabricated and utilized in a closed loop circuit. The effects of the temperature, sensor calibration process, vibrational mode and measurement setup, were studied regarding the application of microresonators as density-viscosity sensors.

An interface circuit was designed to cancel the resonator parasitic. Two types of oscillator circuits were designed based on this interface circuit; one closing the loop with a Phase-Locked-Loop (74HCT4046) and an alternative scheme based on discrete electronics with an automatic gain control (AGC). Both configurations have been characterized in terms of final sensor performance, showing similar resolution. In order to determine the resonant parameters of interest (resonant frequency and quality factor), gain of the interface circuit and oscillation frequency were monitored, from which the viscosity and density of the liquid under test can be determined through a calibration process2. This was developed using different lubricant oils, and a commercial density-viscosity meter with theoretical models reported in the literature3.

Our results demonstrate the performance of piezoelectric MEMS resonators in lubricant oils up to 100 cP (SAE 0W30) where the quality factor measured at 25 ºC was around 25. In the final paper, a comparison for different vibration modes, resonators and liquids will be presented, demonstrating the implementation of a real time monitoring system based on a microcontroller coupled to the oscillator circuit.

10246-56, Session PTue

Radio link design framework for WSN deployment and performance prediction

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For an easy implementation of wireless sensor and actuator networks (WSAN), the state-of-the-art is offering single-chip solutions embedding in the same device a microcontroller core with a wireless transceiver. These internet-on-chip devices support different connections: Bluetooth, ZigBee and Bluetooth Low Energy at 2.4 GHz, Wi-Fi at 5 GHz, sub-GHz links at 868/915 MHz or 315/433 MHz. The used microcontroller cores range from 8-bit 8051 for low-power short-range solutions to 32-bit Cortex-M ARM ones. The max. sustained bit-rates are from 250 kb/s (sub-GHz links) to 4 Mb/s (Wi-Fi). For example, in case of TI cc254x and cc31xx devices, there are different trade-offs between receiver sensitivity (from -74 to -100 dBm) and maximum transmitter power (from 0 to 5 dBm). These performance parameters lead to different link distances, but also to different power consumption levels, from few mW to several hundreds of mW. A range extender device can be added, e.g. the TI CC2592, to improve RX noise figure (few dB) and TX power (up to 22 dBm), but for a power overhead of 480 mW.

Although a large set of embedded devices for WSANs exist, one limit for their application is the missing of an easy-to-use modeling and simulation environment to plan their deployment. The need is to predict, before installing a network, at which distances the sensors can be deployed, the real achievable bit-rate, communication latency, outage probability, power consumption, and hence battery duration. To this aim, we have developed the H2AWKS (Harsh environment and Hardware Aware Wireless linK Simulator) environment, which allows the planning of a WSAN taking into account:

- environment constraints, e.g. Bit error rate (BER), presence of time-dispersive and frequency-selective channels, shadowing and occlusion, propagation losses wit/without line-of-sight (LOS/NLOS), single or multi hop, outdoor or indoor, in presence of interference sources in the same band;

- hardware parameters, e.g. RX noise figure and sensitivity, TX power, operating frequencies, gains;

- network parameters, e.g. network topology, modulation and channel coding scheme (MCS), packet size.

The details about the set of models and equations used within H2AWKS will be shown in the full paper. Just for an example the path loss (PL) between two communication nodes is modeled as a random variable whose mean value depends on distance d, attenuation exponent, measured attenuation PL(d0) (at a distance d0 of 1 m, beyond it near-field phenomena can be neglected), whereas the variance depends on shadowing/occlusion phenomena modeled through a Gaussian process. The values used for the parameters during PL analysis are obtained from real measurements, some published in state-of-the-art, considering indoor and outdoor scenarios, both LOS and NLOS.

In case of a multi-hop network, the maximum node distance is obtained multiplying the maximum number of hops N with the maximum distance of a single hop. Implementing on the processor (embedded within the nodes of the WSAN) a decode and forward technique in the digital domain, the BER after N hops can be calculated as N times the BER in a single hop. Instead, the latency for multi hops is TMH = N·(+ Tenc + Tdec), where is the average latency for a successful transmission of a packet, and Tenc and Tdec are the times to run the encoding/decoding algorithms on the digital processor of each node.

H2AWKS can also model i) PU the useful power at RX as a function of multi-path, PL model, TX transmitted power, antenna gains, receiver noise, MCS, bit-rate; ii) Preq the minimum PU required to achieve a given quality of service, e.g. a BER and an outage probability below proper thresholds. Once fixed these values, the model allows determining also the PER, the connection latency for N hops, the goodput and the power consumption.

By applying the set of H2AWKS models, once fixed the parameters depending from the operating environment (e.g. from values measured in the field or available in literature), several graphs can be obtained, predicting the achievable performance of the WSAN as a function of the characteristics of the device.

For example, see in the attached file, Fig. 1 shows Preq as a function

of the bit-rate, for a stringent requirement of BER of 10-10, in different operating environments. Fig. 2 shows the bit-rate as a function of distance for different operating conditions, TX power, values of the TX and RX antenna gains. Figs. 3A and 3B show the connection latency and goodput vs. the BER when transmitting, for a single hop, packets of 1 kbit, at 4 Mb/s, using an ARQ (Automatic repeat request) technique with max. 8 retry. To be noted that 4 Mb/s is the maximum bit-rate sustained by devices for WSAN by TI. As conclusion, H2AWKS is an easy to use simulation environment that allows design exploration of the system performance of a WSAN as a function of the operating environment and of the hardware parameters of the used devices.

10246-57, Session PTue

User centered integration of internet of things devices

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This paper discusses an IoT scenario where the whole data chain, from field devices to their final users, can be easily and quickly customized, in order to produce effective applications for a wide range of sectors, such as home, industry and environment.

The “far-end”, i.e. the IoT device itself, is developed using a Model Based approach, which does not require programming; the TaskScript technology is used, which provides a choice of physical boards/boxes equipped with TCP-IP interfaces and a range of Input and Outputs, and a graphical IDE which allows the development of applications by working at graphical level only.

The “near-end”, i.e. the User Interface through which users can interact with their IoT devices, is implemented using commercial messaging applications, and implements the Bot approach. Through Bots, (i.e. automated responders) users can ask their devices about their state and also provide specific commands; moreover, the remote devices can send Alert messages upon crossing of pre-set thresholds on the read values. The Telegram messenger is used, for this availability on both desktop and mobile devices.

A lightweight Publish/Subscribe message Broker has been implemented, with built in capability to process incoming messages according to a rule based specification; the Broker is able to store messages coming from the devices, process them, forward possible alerts to the subscribed users, and possibly store permanently data; finally, is able to hand user commands back to the sending device.

A comprehensive web based console allows configuring the Broker, hence personalizing how each and every device is logically connected with their owners; processing rules and thresholds can be set up as well.

The resulting scenario is a user friendly environment, where users can “chat with their devices”, i.e. ask for information, provide commands, and receive notifications in case of alerts, through standard smartphones and messenger apps.

Several Bots have been set up for industrial applications; such “Mobile Dashboards” are presently used by managers and technicians to keep track of their machines and plants.

10246-58, Session PTue

Identification of squid species by melting temperature shifts on fluorescence melting curve analysis (FMCA) using single dual-labeled probe

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Real time PCR, quantitative PCR, is a standard method for identification of species. One of limitations of the qPCR is that there would be false-positive result due to mismatched hybridization between target sequence and probe depending on the annealing temperature in the PCR condition. As an alternative, fluorescence melting curve analysis (FMCA) could be applied for species identification.

FMCA is based on a dual-labeled probe. Even with subtle difference of target sequence, there are visible melting temperature (Tm) shift. Therefore, dual-labeled probe based FMCA could substitute for conventional qPCR to identify species.

One of applications is distinguishing organisms distributed and consumed globally as popular food ingredients. Their prices are set by species or country of origin. However, counterfeiting or distributing them without any verification procedure are becoming social problems and threatening food safety. Besides distinguishing them in naked eye is very difficult and almost impossible in any processed form. Therefore, it is necessary to identify species in molecular level.

In this research three species of squids which have 1-2 base pair differences each are selected as samples since they have the same issue. We designed a probe which perfectly matches with one species and the others mismatches 2 and 1 base pair respectively and labeled with fluorophore and quencher. In an experiment with a single probe, we successfully distinguished them by Tm shift depending on the difference of base pair.

Furthermore, it is expected that FMCA could be applied to qPCR chip and detect fluorescence with higher sensitivity and resolution compared to pre-existing qPCR chip. Its would enable molecular-level detection in smaller scale. If the results could be analyzed with smart phone like point-of-care testing(POCT) kits for blood-sugar level, POCT for food safety would be realized.

10246-25, Session 7

Low cost nanomechanical surfaces stress based sensors fabricated by hybrid materials

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Nanomechanical surface stress based transducers have become an emerging and promising technology for sensing and biosensing applications, due to their small size, fast response, high sensitivity and their compatible integration into “lab-on-a-chip” devices. However, the multiplexed capability for monitoring several transducers still present some limitations related mainly to the integration of the read-out system when working with an array of sensors (alignment, power,...).

To solve this limitations we present the fabrication of nanomechanical surface stress based sensors by using the nowadays knowns as smart hybrid materials to achieve a power-free array of sensors that change their reflective color depending on the surface stress change induced on each sensor. Nanocomposite materials of elastomeric polymers and ordered nanoparticles embedded inside of the polymer were chosen for the fabrication process. These composite materials, besides being cheap and easily fabricated in mass production, present a mechanochromic behavior producing a color change of the material when applying a deformation process mainly due to the change in the distance between nanoparticles. Any modification on the transducers surface will induce a change on their surface tension, producing a deformation of the sensor and therefore a variation in the distance between the nanoparticles inside the structure of the sensor.

We have fabricated arrays of mechanochromic membranes and cantilevers by infiltrating colloidal photonic crystals of polystyrene nanoparticles with Polydimethylsiloxane (PDMS). Hybrids PDMS and 3D or 2D colloidal photonic crystals were prepared, and compared its sensitivity to strain changes. The color, due to the Bragg diffraction (3D) or light scattering (2D), was analyzed by UV-visible spectrometry and image RGB analysis. We performed a study of the optimum transducers dimensions to maximize both the mechanical response and the color change associated when a transducer deformation is produced.

10246-27, Session 7

Zirconium diboride thin films for use in high temperature sensors and MEMS devices

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Sensors and MEMS devices operate in high temperature environments can provide valuable diagnostic/prognostic data for improved process efficiency and condition-based maintenance of complex machinery. However, there remains a materials challenge in creating stable thin films with high electrical conductivity for use as electrodes, bond pads, and other electronic components. Metal films undergo agglomeration and other morphological changes as thermodynamic driving forces drive instability over long times. Zirconium diboride (ZrB2) is an ultra-high temperature conducting ceramic with a melting point of 3245oC, and has very low atomic diffusion rates compared to other materials, suggesting that ZrB2 films may remain morphologically stable during exposure to temperatures in the range of 500-1200oC. In this work, ZrB2 thin films were synthesized on r-sapphire substrates using electron-beam co-evaporation of elemental Zr and B sources, and film stability was characterized after thermal treatments in both reducing (vacuum) and oxidizing (air) environments. ZrB2 films deposited at room temperature are amorphous, but have short range order characteristic of ZrB2 bonding as determined by EXAFS measurements. ZrB2 films grown at 850oC are polycrystalline with predominant <10-10> and <10-11> grain orientations. After long term (55 hours) annealing in vacuum, negligible grain growth or morphology changes occur, and film electrical conductivity remains in the 105 S/m range. Annealing in air, however, leads to ZrB2 film decomposition into ZrO2 and B2O3 phases, the latter of which is volatile and evaporates from the surface. In situ X-ray diffraction indicates that an amorphous boron nitride (BN) capping layer grown on ZrB2 films via magnetron sputtering hinders the oxidation, but the films eventually transform to ZrO2. These results indicate that ZrB2 films are extremely stable and useful for sensors and MEMS devices operating in reducing environments, and can be used over short times in high temperature oxidizing environments when covered with a BN capping layer.

10246-28, Session 7

FT-IR analysis of high temperature annealing effects in a-SiC:H thin films

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There is a continuously growing interest in the integration of silicon carbide (SiC) thin films into MEMS/NEMS-based devices whenever high robustness is required for operation in harsh environments beyond the applicability of standard silicon technology. Hydrogenated amorphous SiC (a-SiC:H) is especially attractive for these applications due to a low achievable deposition temperature below 400°C, while at the same time retaining superior properties like enhanced robustness compared to silicon to some degree. In previous publications, it was demonstrated, that the properties of a-SiC:H thin films can be tailored over a wide range by changing the table excitation power P_T using a dual plasma source process. In this work, the annealing behaviour of these thin films under argon atmosphere is investigated by using Fourier transform infrared spectroscopy (FTIR) for chemical analysis. The latter results are correlated with material properties like film shrinkage and density.

All investigated layers show a decrease of hydrogen containing bonds (X-H_x) and an increase of Si-C bonds with increasing annealing temperature in the FTIR spectrum. This behaviour is directly correlated to the effusion of hydrogen from the thin films at elevated temperatures. In addition, films deposited at higher P_T values show more X-H_x and less Si-C bonds, indicating a higher hydrogen amount in those films. All layers shrink with increasing annealing temperature due to the effusion of hydrogen with a stronger shrink at higher P_T values caused by the increased hydrogen amount. This shrink also leads to a densification of the thin films.

10246-29, Session 8

Micro solid oxide fuel cells: a new generation of micro-power sources for portable applications *(Invited Paper)*

Francesco Chiabrera, Iñigo Garbayo, Nerea Alayo, Albert Tarancón, Institut de Recerca en Energia de Catalunya (Spain)

Batteries, with inherent limited capacity, have dominated the power supply of small devices for decades. However, despite the fast evolution in the field, the energy gap between the capacity of the current battery technology and the power requirements is increasing year by year. This energy divergence brings a great challenge on portable generation that opens new opportunities for technologies beyond Li-ion. In this new scenario, a major breakthrough on the miniaturization of uninterrupted and efficient generators is crucial.

The dream of miniaturizing one of the most efficient known generators, i.e. a fuel cell, has been unsuccessfully pursued for years until recent advances in silicon integration of Solid Oxide Fuel Cells (μSOFCs) converted this disruptive technology into a serious candidate to power next generations of portable devices. The current technology allows stable operation between 350-450 ºC. However, extending this range to high temperatures (>600ºC) is mandatory for portable applications based on easy-to-handle and available (liquid) hydrocarbons.

In this talk, we will present the integration in mainstream silicon technology of SOFC devices and ethanol micro-reformers able to operate at high temperatures. Micro and nanotechnology helped in reducing the size and thermal mass of the μSOFC devices allowing quick and low energy consumption start-ups, crucial for portable applications. Full system modelling will be presented for supporting the feasibility of the whole power source into real scenarios.

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10246-30, Session 8

Alkaline fuel cell with nitride membrane

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This work presents the fabrication of nitride membranes with Si-MEMS-technology as a platform to build up new membrane-electrode assemblies for alkaline fuel cells. Fuel cells are known as eco-friendly energy conversion technology and the recent focused type polymer-electrolyte-membrane fuel cell uses protons as charge carriers (acid fuel cell system). The use of platinum as catalyst material causes high manufacturing cost. In alkaline systems this material can be replaced by cost-effective non-noble metals. Because of deficient catalyst stability of these platinum-free catalysts development of new material compositions is required.

The embedded electrolyte membrane is selective to OH--ions. Instead of silicon, nitride based materials are preferred as membrane materials with the better chemical stability in alkaline environment. The patterned membrane is subsequent coated with conductive layer and catalytic material in order to form a membrane-electrode assembly. The mechanical stability of the nitride membrane has to withstand the mechanical influences while the whole fabrication cycle and while the characterization. Evaluated LP and PECVD-processes at IMS Chips were used to fabricate the 10x10 mm? nitride membrane (incl. frame) with 5x5 mm? microchannel area. The mechanical stress inside of membrane could

be adjusted successfully by introduction of subsequent ion-implantation or by changing of process parameters while nitride deposition. Nearly 100% yield of separated membranes each 6-inch wafer were achieved.

For alkaline fuel cell application the hydroxide-ion permeable electrolyte was deposited by dip-coating inside the micro-channels and onto the surface of the nitride-membrane. Electrodes acting as anode and cathode were printed on both sides by ink-jet technology using silver and carbon-based inks. Platinum catalysts on carbon black were applied in combination with additional electrolyte. This construction of a self-supporting nitride stabilized membrane has the advantage of direct visible catalyst centers, which makes direct, fast and parallel characterization of the catalyst centers by IR-thermography possible.

10246-31, Session 8

Parameter identification from frequency response of MEMS energy harvesters

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This work presents a method to extract complete parameter sets for certain vibration energy harvester models. The unknown or uncertain parameters of the electromechanical model are obtained by a fitting procedure to a single frequency-sweep data set.

For complicated transducer structures, only some of the fundamental parameters can be estimated from prototype design and there are challenges in extracting the remaining parameters with sufficient accuracy. Mechanical and electrical losses are difficult to find by either simulation or measurements. In addition, beam stiffness can be difficult to estimate for nonlinear devices. Investigations of the Duffing oscillator using the harmonic-balance method show that it is hard to approximate several parameters at the same time or it requires numerous measurements with increasing and decreasing frequency sweeps.

The parameter identification is based on a least-squares minimization in the frequency domain combined with a fourth-order Runge-Kutta method to solve the state-equations. This method is simple, but robust, and independent of model representation or transducer architecture. For a standard overlap-varying electrostatic generator, there are four first-order differential equations. The identification process can also be applied to a simpler two-port model with fewer degrees of freedom without compromising the accuracy.

Comparison with model simulation data shows that the approach can accurately recover the specified model parameters for all studied cases both in the linear regime and in the nonlinear regime. It even works when the sweeps exhibit the jump phenomenon. This is encouraging for further investigations on a larger variety of energy harvesters and should be a useful tool for experimental validation.

10246-32, Session 8

Powering a leadless pacemaker using a PiezoMEMS energy harvester

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MEMS based vibrational energy harvesting devices have been a highly researched topic over the past decade. The application targeted in this paper focuses on a leadless pacemaker that will be implanted in the right ventricle of the heart. A leadless pacemaker requires the same functionality as a normal pacemaker, but with significantly reduced volume. The reduced volume limits the space for a battery; therefore an energy harvesting device is required. This paper describes a MEMS based piezoelectric energy harvester that can harvest energy from the mechanical vibrations of the heart.

Traditional energy harvesting applications operate with a continuous sinusoidal acceleration; however, the heart behaves like a series of impulse vibrations. Since the heart is not continuously vibrating the damping of the energy harvester is important as this will significantly affect the average power that can be harvested. Typical MEMS energy harvesters are fabricated from silicon cantilevers which dampen and cause energy to be harvested for only 100-300 ms, so for a normal heart beat of 60 bpm the harvester will not function for 700-900ms which significantly reduces the average power. This paper describes an alternative method of optimizing the average power by using a polymer based cantilever, which has a lower damping factor. This paper investigates optimizing the energy harvested for this application using Finite Element Modelling and experimental validation. Aluminium nitride piezoelectric material was used throughout the paper, and the results demonstrate that the average peak power of AlN/polymer is lower than AlN/Si, but the average power can be increased due to the damping factor. Experimental results demonstrated an average power of up to 3 μW at 1 g acceleration for the AlN/Si devices. FEM results demonstrate that the estimated average power of an AlN/polymer device would be about 3-5x higher because of the reduced damping effects.

10246-33, Session 9

Designing, modelling and testing of vibration energy harvester with nonlinear stiffness

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This paper is focused on design of piezoelectric energy harvester with additional nonlinear stiffness. Linear generator has very narrow resonance frequency bandwidth, which makes the resonance mechanism sensitive to tuning up of the resonance frequency. Thus, it means that it could be tuned only for one narrow vibration peak. The main reason why to use the vibration energy harvester with nonlinear stiffness is to make resonance frequency bandwidth wider, which allows harvesting from wider bandwidth of excitation vibrations. The harvester will be universal and average output power will be higher.

For simulations and experiments was piezoelectric generator Midé V21BL used. The additional nonlinear stiffness was designed by using permanent magnets. Result of this design was bi-stable generator with nonlinear stiffness around two stable positions. A model of this generator was made in Matlab/Simulink software and the generator was simulated with different excitation vibrations and electric loads. Simulations show two modes of oscillations. The first mode was oscillating around one stable position and the second mode was bifurcation between two stable positions. Oscillating mode depends on amplitude of excitation vibrations, on speed of changing excitation frequency and on electric load.

The last part of research was a construct of the prototype and making measurements. The prototype was constructed with magnets from previous design, which was simulated. One magnet was fixed with possibility to change distance between magnets to tune nonlinear stiffness. An experiment with the first mode of oscillations was made and the result was wider resonance bandwidth. However, it depended on direction of frequency changing. For the better direction of changing frequency, the bandwidth was more than three times wider with half amplitude, so maximum power was lower, but the average power around resonance frequency was higher which was the goal of this research.

10246-34, Session 9

Comparison of methods for static charge energy harvesting on aircraft

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Aircraft monitoring sensors are highly desirable due to profound advantages in safety, security, insurance, predictive maintenance and reliability to the global aviation industry, but also in material and structural innovation. However, the development and testing of

such systems is still limited due to their cabling complications and/or maintenance overhead due to the requirement for battery replacement. Various technologies have been developing rapidly towards energy autonomous aircraft sensors, mainly using thermoelectric[1], non-inertial piezoelectric[2], or solar[3] systems. In addition, the possibility of using the static charge that is accumulated on an aircraft fuselage during flights has been examined[4-6] . However, experimental implementations have been limited, mainly by the difficulty in emulating air-flow induced static charge in laboratory environments. Electrostatic studies of this effect towards the estimation of the corresponding energy availability from within and from the outside of an aircraft structure is also very limited.

On the other hand, triboelectric energy harvesting from relative motion between nanostructured surfaces has been studied extensively[7], and impressive simple prototypes have been developed [8]. The main possible mechanisms of charge transfer for static charge induced by relative motion between two insulating surfaces in contact are illustrated in Fig.1. Experimental results for the case of charge collection in a 25nF capacitor, by scanning over a charged-surface are shown in Fig.2(left). The capacitor discharge into the input resistance of an oscilloscope demonstrates accumulated energy of around 8 μJ. The circuit used for this measurement is shown if Fig.2(right). Similarly, the case of airflow-induced, aircraft fuselage static charge and possible charge transfer methods are shown in Fig.3. The results of this work indicate that static charge accumulation could potentially be utilised to power wireless sensors, by inductive exploitation of corona discharges to the air environment using discharge wicks (Fig.4). Smaller amounts of energy are expected from interior harvesting implementations.

10246-35, Session 9

Improved thermal and electrical design for an all-Si thermoelectric micropower source

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In this work, we are comparing the performance of a re-designed planar thermoelectric microgenerator with the one of a previously reported device in this conference [1]. In both studies, p-type Si nanowires have been grown by a bottom-up VLS method between the hot and cold parts of a suspended microplatform. Since the length of the Si NWs is limited by the growth method, several 10μm wide trenches are introduced to increase the effective length of the nanowires and hence their thermal performance.

Structural differences between both devices led to improvements in thermal and electrical performance of the generator. Narrow bulk Si beams supporting the platform and hosting the metallic interconnection are replaced by a thin dielectric membrane which helps to increase the thermal isolation and hence the generated voltage [2]. Since the membrane was thin, it could be made wide, allowing a wider and shorter metal leg with a much reduced electric resistance. In addition, metal-silicon contact resistance was reduced with proper doping of the SI device layer of the starting SOI wafer and appropriate metal deposition (TiW/W) and annealing. Overall, internal resistance was reduced an order of magnitude.

The original interdigitated platform structure has been replaced by a square platform to ease the eventual integration of a heat exchanger. Despite having less perimeter filled with SiNWs, higher power densities are achieved. Measurements were done under natural convection conditions and hot plate temperatures up to 300ºC. Power increased almost two orders of magnitude in packaged devices (from ~180pW to ~13nW). Higher values (~370nW) were measured for pre-packaged devices. This anomaly is under investigation. Considering simulation results on the effect of a heat exchanger (not yet integrated) and current designs for connecting several devices in series or parallel, the proposed microgenerator may be useful for micropower wireless sensor nodes.

[1] I. Donmez et al., “Interdigitated design of a thermoelectric microgenerator based on silicon nanowire arrays” Proceeding of SPIE 9517, 95172C (2015).

[2] C. Calaza et al., “Thermal test of an improved platform for silicon nanowire-based thermoelectric micro-generators” Journal of Electronic Materials 45 (3), pp 1689–1694 (2016).

10246-36, Session 9

Integrated TiN coated porous silicon supercapacitor with increased capacitance per foot print

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Electrochemical double layer capacitors (EDLC), or so called supercapacitors, are used as secondary energy storage elements in many different areas during the last years, including, for example, transportation, cranes, mobile phones. This is based on the higher specific power and larger number of charge/discharge cycles as compared to the batteries. Recently, growing range of wearable or implantable microdevices and activities related to IoT are directing more attention to the development of micro-supercapacitors. In this field, the standard fabrication of supercapacitors – based on assembly of electrodes with activated carbon type materials – becomes complicated. Main reasons are high temperature needed in the process and complicated integration with other active/passive elements of silicon chip. As an alternative, electrodes with porous silicon have been proposed, which fabrication can be IC compatible. Main obstacle in development of porous silicon supercapacitors is high chemical activity and low conductivity of the material. In this work we have fabricated a supercapacitor with porous silicon electrodes coated with TiN by ALD. The coating is resulted in efficient surface passivation and high conductivity of electrodes, resulting in stable (more than 13 000 cycles) and almost ideal EDLC-type microdevice with characteristics comparable to carbon based micro-supercapacitors: specific capacitance of 15 F/cm3, energy density of 1.3 mWh/cm3 and power density of up to 200 W/cm3. Using silicon microfabrication steps, the integration of both electrodes inside a silicon chip was succeeded and silicon based in-chip supercapacitor was fabricated for the first time. This approach allowed to increase the capacitance per foot print of device area (till 5 mF/cm2) and can support the integration of energy storage element with energy harvester and other elements on the chip.

10246-37, Session 10

Programmable differential capacitance-to-voltage converter for MEMS accelerometers

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MEMS capacitive sensors are one of the most used accelerometers, since they offer excellent noise performance, high sensitivity and low power consumption. However, the changes in the capacitance tend to be extremely small and the parasitic effects can be higher than the sensor capacitance, which reduces the sensitivity. Moreover, as the technology scales down, the lower supply voltage degrades the linearity and the signal-to-noise ratio. In order to measure the small capacitance changes, a highly-linear, low-noise sensor interface is needed, being the capacitance to voltage converter the most critical stage.

In this work, a capacitance to voltage converter based on a fully-differential transimpedance amplifier with programmable gain and bandwidth for MEMS accelerometers is presented. The transimpedance amplifier consists of a high gain differential voltage amplifier implemented with three cascaded differential pairs, with load resistors in the first two pairs, and a resistive feedback loop, in a shunt-shunt topology, which presents low impedance input, high linearity and low

noise. With variable feedback and load resistors, the transimpedance can be modified with constant bandwidth, with a 34 dB gain control range, as well as the bandwidth can be modified from 50 kHz to 1 MHz with constant transimpedance, thus allowing the use of this system in a wide range of MEMS capacitive sensors, with different sensitivities or mechanical responses.

The capacitance to voltage converter presented in this work is aimed for a differential surface-micromachined comb-finger capacitive accelerometer, but can be used in many other capacitive sensor applications. The TIA has been designed in a 180 nm CMOS technology and it achieves a minimum equivalent input noise (EIN) of 45 fA/√Hz.

10246-38, Session 10

Robust design of an inkjet-printed capacitive sensor for position tracking of a MOEMS-mirror in a Michelson interferometer setup

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Mechanical micro-mirrors are, nowadays, employed in a variety of devices ranging from high precision measurement equipment to industrial production lines as well as consumer goods. To guarantee high performance of these devices, precise motion control and position feedback are crucial. Drawbacks of the widely used optical position feedback are complexity and space requirements. We thus propose an inkjet-printed capacitive position sensor for a resonant MOEMS in a Fourier Transform infrared spectrometer as part of a smart packaging solution (e.g. 3D-printed ceramics). Despite the advantages for rapid prototyping, both printing processes suffer from tolerances in excess of those from standard processes such as deposition or printed circuit board fabrication. To us, it is thus mandatory to additionally evaluate design criteria with respect to variations in topology (size, accurate positioning etc.) as well as boundary conditions and material properties (conductivity, linearity, hysteresis, etc.). Essentially aiming at an improvement of the sensor system as a whole. Finite Element Method simulations are structured following a design of computer experiments targeted at determining an optimal design for the considered sensor structure. Statistical models are adopted based on finite element method simulations for the dynamic system. A specifically designed hardware is considered to cope with the challenging requirements of a position accuracy of ~50 nm at 10 MS/s with an overall measurement range of 1000 μm to be reached with a sensor limited to < 5mm diameter at 500 μm minimum distance. A noise analysis is performed and the influence of uncertainties out of the simulations is considered in the position measurement, limitations in resolution and bandwidth capabilities of the system are assessed.

10246-39, Session 10

Universal and inductorless DC/DC converter for multi-output power supplies in sensor and actuator networks

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A key building block for a node of a Sensor and Actuator Network (SAN) is the DC/DC converter [1]. While for low-power sensing applications the power source is typically at few Volts (e.g. 3.6 V for a Li-Ion cell), in case of vehicles, satellites, telecom apparatus, industrial machines, robots, the DC power source can be tens of Volts. For example, the power supply in the automotive world is at least 12 V, and is going towards 48 V for hybrid and electric vehicles [2]. Electric scooters, e-bikes and trucks use 24 V to 36 V batteries. The standard telecom power bus is 48 V, as well as that on-board a satellite. To address the low voltage supply requirements of sensors and control boards (from 5 V down to 1 V), a DC/DC converter able to regulate a large input voltage range is needed.

However, in the market there are thousands of DC/DC converters, with different performances and costs, each addressing a specific application. Moreover, to achieve high-energy efficiency the DC/DC converters usually adopt inductors, which are cumbersome and difficult to integrate.

To address the above issues, this work proposes a universal and low-cost DC/DC converter that can be used for a wide input range, from few V to 60 V to regulate output voltages from 5 V downto to 1V. The proposed converter has been developed within the Athenis3D European project [2]. As shown in Fig. 1, it is composed by a cascade of multiple switching capacitor stages, with a proper skip-mode control to implement both step-down and step-up converting ratios (e.g. x 1, x1/2, x1/3, x2, ...), thus regulating all input sources to a voltage of about 6 V. These switching stages are further cascaded with Low-Drop Out (LDO) regulators, which can provide stable output voltages at 5 V or lower (e.g. 3.3 V, 2.5 V, 1.65 V, 1.2 V, 1 V). The multi-output regulator has been realised as a single-chip in a low-cost 0.35 ?m CMOS technology from AMS ag, and has been fully characterised in terms of electrical, thermal and EMI/EMC performances. Its area is 36 mm2 and it is available as a naked die to be mounted directly on a PCB board, see Fig.1A, or in a ceramic package, see Fig.1B. The only needed external components are surface mount (SMD) capacitors from few tens of nF to μF. The capacitors up to 100 nF can be integrated on top of the naked chip die, creating a 3D structure, using trench capacitors embedded in a passive interposing layer. This way the size of the power management unit is further minimized.

Using a topology without inductors the electromagnetic problems are reduced and this expands the applications range that it can cover. The efficiency of the converter is comparable to those with inductors, and much higher than traditional linear converters. An advantage of the proposed converter is that it isn't optimized for a particular input voltage, therefore can be used with no constant input power, like power harvesting systems (e.g. solar cells, wind and water turbines) and very disturbed power supplies.

The full paper version will detail the design of the converter and will show the main characteristics of the proposed converter when integrated within an hybrid automotive control network to supply, directly from a 48 V bus, a set of sensors and electronic devices requiring 5 V and 1.65 V, with current levels from 20 mA to 300 mA.

A prototype demonstrator will be shown at the conference.

10247-11, Session PTue

Microfluidic system for monitoring of cardiac (H9C2) cell proliferation

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We applied electrical impedance spectroscopy analysis for investigation of cardiac cell (H9C2 – rat cardiomyoblast) proliferation after verapamil hydrochloride exposure. For this purpose, two different PDMS/glass microsystems with circular microchamber and longitudinal microchannel integrated with Pt/Al electrodes were used. The microchambers were fabricated in PDMS using photolithography and replica moulding techniques. Pt/Al electrodes were fabricated on a 4-inch glass substrate using Physical Vapor Deposition. Solution of verapamil hydrochloride was introduced into the microsystems with H9C2 cell culture (a flow rate of 1 μl/min) for 96 h continuously. The impedance spectra were recorded from 100 Hz to 1 MHz.

Based on impedance plots, differences between proliferation of H9C2 cells after incubation with different concentrations of verapamil chloride were analyzed. It was found, that perfusion conditions enhance the proliferation of H9C2 cells in cultures maintained with culture medium in both tested (with circular and longitudinal chambers) microsystems. The increase of H9C2 cell proliferation was observed daily. The impedance plots showed that continuous exposure of verapamil, L-type calcium channel blocker, inhibited cell growth. The decrease of the cell proliferation was observed during the following days of the culture.

In this work, we confirmed that impedance spectroscopy can be used for non-invasive, label-free and real-time analysis of cardiac cells proliferation based on cells dielectric properties and biological structure. We demonstrated that the integrated microsystems could be helpful to monitor the growth of heart cells as well as to test newly developed compounds applied in cardiac diseases.

10247-15, Session PTue

Simulation of the novel compact structure of an interferometric biosensor based on multimode interference waveguides

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We propose the novel structure of an interferometric biosensor based on multimode interference (MMI) waveguides. We present the design of the biosensor using eigenmode expansion (EME) method in accordance with the requirements and standards of today's photonic technology. The MMI structures with a 90 nm Si3N4 core are used as power splitters with 5 outputs. The 5 high-resolution images at the end of the multimode region show high power balance. We analyze the coupling efficiency of the laser source with the structure, the excess loss and power imbalance for different compact MMI waveguides with widths ranging from 45 ?m to 15 ?m. For a laser source with a tolerance of ±1mm in linearization we achieve a coupling efficiency of 52%. MMI waveguides with tapered channels show excess loss values under 0.5 dB and power imbalance values under 0.08 dB. In addition, we show that a for 10 nm deviation of the wavelength of the source from its optimal value and for a 10 ?m deviation of the MMI length from its optimal value, the performance of the MMI waveguides remains acceptable. Finally, we analyze the power budget of the whole biosensor structure and show that it is sufficient for the proper operation of this device.

10247-16, Session PTue

Design of an embedded sensor system for measuring laser scattering on blood cells

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A technology that allows non-invasive continuous monitoring of blood cells would have a profound major impact on diagnosis and treatment of various pathological conditions and diseases. An indicative example is the now ubiquitous pulse oximetry technology, which corresponds to a market over 1 b$. Existing systems monitor medical indicators such as oxygenation[1] , bilirubin[2] and haemoglobin[3] by spectrophotometric methods. Furthermore, a variety of techniques has also been proposed for non-invasive glucose monitoring[4]. Existing non-invasive blood monitoring techniques don't measure cell concentrations. Potential methods for non-invasive measurement of blood cells include spectrophotometry, light scattering, optical microscopy[5], acoustics and photo-acoustics[6].

Here, we propose an embedded system that allows the in-vivo study of directional light scattering on blood cells (Fig.1). It comprises a directional light source with 1 mm2 spot size and power below 1mW. The beam passes through the specimen (e.g. a cuvette or a person's finger) and the intensity of transmitted light at different scattering angles is detected using a photo diode array (PDA). Recordings are captured for a duration and sampling rate adequate for analysis over several heart pulses, allowing detection, measurement and analysis of light scattering effects originating from blood cells, using as targets blood emulation solutions, real samples and the human finger, for in-vivo experiments. In doing so, the system should employ state-of-the-art techniques already in place for other blood monitoring applications (Table 1). For data analysis and correlation to physical blood cell characteristics, the fitting of experimental results to Mie scattering models [7,8], and subsequent statistical correlation with conventionally obtained blood count measurements is proposed.

Experimental results from a specific implementation (Fig.2) demonstrate the capability of pulse recognition and scattering angle measurements (Figs.3-4). They demonstrate the feasibility of the proposed sensing architecture which is expected to enable systematic measurements and data analysis towards non-invasive blood-cell counting systems.

10247-17, Session PTue

Travelling-wave dielectrophoresis allowing flexible microchannel design for suspended cell handling

Sander van den Driesche, Frank Bunge, Sebastian Tepner, Marcus Kotitschke, Michael J. Vellekoop, Univ. Bremen (Germany)

In this contribution we present travelling-wave based dielectrophoretic microfluidic devices for the handling of suspended grown cells.

Dielectrophoresis is an attractive label-free method to position and separate biological cells 1,2. Microfluidic devices that deflect or attract biological cells by means of dielectrophoresis rely on different electrode geometries to realise an effective electric field gradient. The distance between the electrodes and the height of the microfluidic channel are important parameters. If the distance between the electrodes is large or

the channel is high, the required applied voltage over the electrodes could induce electrolysis and even harm the sample.

A special setup that operates at lower voltages is travelling-wave based dielectrophoresis. It relies on a moving electric field gradient, which can be realised by applying phase-shifted AC-voltages between sets of parallel electrodes.

In this contribution we describe how travelling-wave dielectrophoresis can be applied in different microchannel designs for the separation of particles and cells; from channels with a height of only a few micrometer to channel heights of a few hundred micrometer.

The first device, consisting of a structured Parylene-C layer bonded between two glass wafers, has a separation channel of 22μm high with 32 electrodes. The second device has a 380μm high channel realised by etching a 380μm thick silicon wafer, anodically bonded between two glass wafers.

The measurement results show that yeast cells from a bacteria contaminated sample moved across the 12μm and 20μm wide electrodes. The bacteria however, did not cross the electric field gradient barrier between the 12 and 20μm width electrodes, yielding a successful separation. In the second device yeast cells were lifted slightly above the electrodes and moved towards the region where the phase of the electric field is decreasing. This yields successful redistribution of cells within a 380μm high channel.

10247-1, Session 1

Multilayered tissues model for wave propagation loss assessment in cochlear implants

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Cochlear implants have been used for a few decades, in order to restore the hearing in affected patients, with severe nerve deafness by electrically stimulating nerves inside the inner ear. As the human body is a lossy medium, which attenuates the electromagnetic waves sent from the transmitter to the receiver, and in order to optimize the power transfer in the implanted device, a good knowledge of propagation loss is required. In this paper, a study of the power loss attenuation of the plane wave travelling through the tissue layers, from the outside to the inside of the skull within a cochlear implant, is performed. Different implantation depths of the internal antenna, from 10 to 50 mm are considered. To this purpose, the gain and attenuation in dB are studied. A multilayer tissue model is developed, consisting of mainly skin, mastoid bone and brain. An s-parameter analysis is also carried out, using loop antennas and pork head tissue. We will use the same frequency for remote powering and data transmission and this will be 2.45 GHZ, corresponding to ISM band. Among the necessary requirements for the proper functioning we have to compute the maximum allowed dissipated power, in order to have a difference in temperature ΔT no more than 1 °C. SEMCAD software is used for electro-magnetic simulations regarding the different types of human tissues. In this paper, a multilayered tissues model for wave propagation analysis in cochlear implants has been developed. An antenna-independent propagation loss model for inside to outside body communication for multilayered lossy tissues was studied. The model efficiency consists in the fact that it can be immediately simulated and run on the computer with respect to the chosen parameters (dielectric constants) and the cochlear implant can be therefore swiftly designed depending on the type of patient (age, skull dimension, skin type).

10247-2, Session 1

Integration of a capacitive pressure sensing system into the outer catheter wall for coronary artery FFR measurements

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1.9 million deaths in Europe in 2012 were cardiovascular disease related, a figure that is exacerbating by a rapid ageing population. Many of these deaths are related to a narrowing of blood vessels – also called stenosis. A good way to assess the different levels of stenosis in the coronary arteries is by Fractional Flow Reserve (FFR) measurements. This involves determining the ratio between the maximum achievable blood flow in a diseased coronary artery and the theoretical maximum flow in a normal coronary artery. The blood flow is represented by a pressure drop, thus a pressure wire or pressure sensor integrated in the catheter can be used to calculate the ratio between the coronary pressure distal to the stenosis and the normal coronary pressure. For the reported work a, 2 Fr (0.67mm) outer diameter, catheter was used. The catheter has an eccentric guidewire lumen with a diameter of 0.43mm. This implies that the thickest catheter wall section is less than 210 microns, which dictates the thickness of the dies and interconnection height on top of the flexible circuit. Two dies, a capacitive MEMS pressure sensor and an ASIC, were flip chip mounted and faced down into a cavity in the outer catheter wall. In order to achieve the allowable thickness, the chips needed to be thinned back to 75 microns, but prior to that the Aluminium bond pads required Gold stud bumping and coining. The flexible circuit has to be wrapped around the catheter, thereby mechanically stressing the interconnect joints. Also in order to achieve the required bendability and torquability of the catheter, the flexible circuit requires stress relief slots to prevent the chips from getting damaged during the manoeuvring. Further challenges consisted of connecting the flexible circuit to the catheter wiring and integrating the sensing device into the catheter.

10247-3, Session 1

A novel, scalable microfluidic device for switching of microparticles using dielectrophoresis (DEP)

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A novel microfluidic device that utilizes Dielectrophoresis (DEP) in order to perform switching of cells/particles into different sub-channels down the stream is reported. Switching is the path diversion of micro-objects towards a desired downstream branch of a microchannel. The microfluidic device uses two sets of coplanar electrodes micropatterned at the bottom of each side-wall to create non-uniform electric field. Each set of electrodes is controlled independently. By manipulating the actuating voltages, the cells can effectively be focused in a single file and directed (switched) to the desired sub-channel. In this work, several parameters that affect the switching of cells were numerically studied using FEM. A micro device was fabricated and tested with human red blood cells. The microfluidic device consists of a glass substrate and a PDMS layer. The microfluidic device was fabricated using standard microfabrication. Experiments were carried out using red blood cells to demonstrate the effectiveness of the microdevice in switching of cells to three sub-channels.

The behavior of cells as they passed through the channel was analyzed using FEM. Forces due to drag and dielectrophoresis were included in the analysis. All properties of the particles used in the FEM model were assigned to mimic Red Blood Cells. Various parametric studies were performed to optimize and monitor the effect of each parameter, e.g.,

channel width, actuation voltage etc., on the performance of the device. Switching of red blood cells between three sub-channels was achieved by changing the applied voltage on both set of electrodes. The numerical results, fabrication method, experiments details, and results are reported.

10247-4, Session 1

Microfluidic platform for detection and quantification of magnetic markers

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In this paper we present a microfluidic platform with integrated spin valve giant magneto-resistance (GMR) sensors used for the detection and quantification of single magnetic micromarkers. The developed platform lacks common disadvantages of existing microfluidic systems such as complicated structures (e.g., micropumps) often required for on-chip microfluidic flow. In our microfluidic platform no flow is required thus simplifying its fabrication and reducing its cost. The fluid is static and the magnetic markers are directed towards the sensing area by a series of parallel gold microconductors (MCs) which are sequentially and automatically switched on and off by a microcontroller. In addition, most of the newly reported microfluidic techniques do not provide information regarding the pathogen load. Our microfluidic platform however, can be used to monitor pathogen load in addition to pathogen identification; by developing appropriate protocols where a single bacterium or cell can be labeled by a single micromarker we can count the exact number of pathogens in the sample.

Our microfluidic platform consists of a reference channel and a detection channel as shown in Fig. 1; in the reference channel sample fluid containing non-functionalized magnetic markers is injected while in the detection channel the sample fluid containing the functionalized magnetic markers loaded with the pathogens is injected. Ordyl®SY335 dry negative photoresist was utilized as the mold of the microfluidic channels, upon which a polymeric organosilicon compound, Polydimethylsiloxane (PDMS), was poured, degassed, and cured, resulting into the approximately 25 μm deep channels. The fabrication process is described in detail in [1]. Fig. 1b shows a photo of the device.

In this work we focused solely on proving that the fabricated GMR spin valves can be used for the counting of single magnetic markers without loading the markers with any pathogens. Commercially available M-270 Dynabeads® (diameter, ~ 2.8 μm) magnetic markers were used during the experiments; they are uniform, superparamagnetic, porous polysterene spheres with an even dispersion of iron oxide maghemite (gamma-Fe2O3) and magnetite (Fe3O4) encased into the bead matrix by an additional thin polymer shell and with protruding carboxylic acid groups (-COOH). For the detection of single markers, the double frequency modulation technique was used. Specifically, the MC on top of the sensor was supplied with a current of 20 mA at 234 Hz (fm). The resulting magnetic field, circumferential to the conductor, magnetized each single M-270 Dynabead as it was traveling above the GMR element and contributed to the field measured by the GMR sensor together with the stray magnetic field of the Dynabead [2-3]. The sensor was supplied with a current of 1 mA at 1.234 kHz (fs), which provided the carrier signal for the modulation of the signal to be measured. This way the latter was moved higher at the spectrum of the sensor making it distinguishable from the flicker (1/f) noise, which dominated the lower frequencies. The modulated signal must be demodulated in order to acquire the magnitude of the field generated by the conducting microstructure, done by a lock-in amplifier. The duration that each MC remained switched on was decided upon the mean time a single marker needed to travel from one MC to the next; in our case, for the 2.8 μm markers, it was set at 3.81 s, corresponding to a mean velocity of 3.25 μm/s. Fig. 2 shows the measurements taken under the above mentioned conditions. It is observed that when a single marker is attracted by the magnetic field gradient, generated by the MC, and immobilized directly above the sensor, the average value of the sensor's output increases to Vout´ = 312 μV, suggesting a change of 3 μV due to the markers stray field. As the second marker crosses the sensor area an additional increase of 7 μV in the sensor's output is observed. Experiments are planned with pathogens labeled to a single marker so as test the ability of the platform to be used for pathogen quantification.

10247-5, Session 2

Easy-to-use microfluidic chip for long-term 3D-cell cultures

Frank Bunge, Sander van den Driesche, Michael J. Vellekoop, Univ. Bremen (Germany)

We present a microfluidic chip for an easy setup of a 3D-culture of mammalian cells. The chip contains feeding structures and gas supply for long-term cultivation of mammalian cells. We show the good viability of HaCat cells over 24hours which are embedded in agarose hydrogel.

Mammalian cells of 2D-cell cultures in petri dishes differ enormously from those of 3D-in-vivo tissue[1]. This results in the demand of microfluidic chips for 3D, long-term cell cultures with supply of gases and media. Often, these chips are made out of PDMS which is easy to handle and enables gas supply but is not fully biocompatible[2,3]. Therefore we present a chip made out of biocompatible silicon and glass and featuring the required supply channels.

The mammalian cells are embedded in an agarose hydrogel (1%w/w low-melting agarose) which is 1.5mm wide, 380μm high and 4mm long. The gel is flanked by a channel for feeding the cells with nutrition and an air channel on the other side. The nutrition and the air reach the cells by diffusion through the agarose.

For the realization of the channels alongside the agarose, the bottom and top plate of the channels are coated with platinum and hydrophobic octadecanethiol while the culture region is kept hydrophilic (see Fig.1). Once melted agarose is inserted into the chip, it fills only the hydrophilic region and forms a wall-less channel[4]. Finally the chip is cooled to room temperature for gelation of the hydrogel and clamped in a 3D-printed holder (see Fig.2).

We prepared the 3D-cell culture by mixing HaCat cells into the melted agarose gel. After the gelation (see Fig.3a), the entire device is placed in an incubator to provide suitable gases and temperature. After 24hours, we filled the nutrition channel with TrypanBlue to stain dead cells blue. The majority of the cells shows good viability, which proves the functioning of the feeding structures and the biocompatibility of the chip (see Fig.3b).

10247-6, Session 2

Inkjet-printed selective microfluidic biosensor using CNTs functionalized by cytochrome P450 enzyme

Matic Krivec, Raimund Leitner, CTR Carinthian Tech Research AG (Austria); Florian Überall, Johannes Hochleitner, Medizinische Univ. Innsbruck (Austria)

Selective bio-sensors that exploit the key-lock principle of bio-molecules like enzymes have demonstrated a considerable potential for diagnostic and therapeutic applications. Increasingly complex interactions between multiple drugs and co-medication with natural substances motivate the development of selective bio-sensors in particular addressing the patient's individual response additionally. The metabolisation of 30% of the clinically prescribed drugs is carried out by the isoenzyme P450 CYP2D6. Thus, a bio-sensor based on this enzyme would enable measurements targeting individual interferences between medical drugs and natural substances. An ink-jet printed bio-sensor with a CNT layer functionalised using a CYP2D6 enzymes has been developed employing a 3-electrode principle of an electro-chemical sensor. The direct electron transfer (DET) between enzyme and electrode is exploited using a voltammetric measurements. Dedicated read-out electronics and a 3D-printed measurement chamber have been developed for sensor characterisation. As a model substrate various concentrations of dextrometorphan have been used to verify the sensitivity of the bio-sensor. The results confirm the considerable potential of enzymatic bio-sensors for smart health applications and that they are compatible with additive manufacturing techniques.

10247-7, Session 2

A miniaturized bioanalytical system for rapid quantitative label-free detection of multiple analytes in a single run

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The realization of small size bioanalytical systems capable for multi-analyte determinations at the point-of-need is a long sought research goal. The only viable solution to this direction is the employment of sensors based on silicon integrated photonic transducers since they provide for the realization of arrays of miniaturized sensors without cross-talk problems due to the galvanic isolation of the transducer from the excitation and detection electronics. In this work, chips accommodating an array of ten Mach-Zehnder interferometers integrated in a silicon chip along with the respective integrated broad-band light emitting diodes on a less than 40-mm2 footprint are presented. This is done through standard silicon based microelectronic processing. The broad spectrum of the LEDs is modulated by the interferometer so that sinusoidal modulations appear on the output spectra with frequencies characteristic of the two polarizations. Each sensor onto the chip can be individually functionalized by a recognition biomolecule in order to perform multi-analyte determinations in a single run. To accomplish this goal, the chip is combined with a fluidic module designed so as to allow for ultra-fast assays of multiple-analytes simultaneously onto the same sample. The output of the ten Mach-Zehnder interferometers is monitored by an external spectrometer tuned to the emission spectrum of the monolithically integrated light emitting diodes. By multiplexing the LEDs all 10 interferometers are interrogated. The spectra recorded in the course of the experiment are analysed using a specially developed Matlab application that subjects each individual spectrum to Discrete Fourier Transform. Thus, biomolecular reactions taking place on the sensing arms of the ten Mach-Zehnder interferometers could be monitored as shifts of the transition spectra in both the TE and TM mode. The bioanalytical capabilities of the system developed were exploited through simultaneous determination of analytes related to food safety at concentrations well below the maximum allowable concentrations.

10247-8, Session 2

Real-time phase correlation based integrated system for seizure detection

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Epilepsy is at current the world's second most common neurological disorder affecting an estimated 50 million people. While up to 70% of epileptic suffers are treated successfully with epileptic medication some 30% continue to suffer untreated [1]. This gap could be filled by the implementation of implantable neural prostheses which are able to detect when a seizure is coming and eventually actuate in the brain to stop its progression.

The change in brain activity during epileptic fits has been leading scientists to investigate neural features such as neural spiking [2], correlation [3] and the most tantalizing, phase synchronization, in order to predict seizures before they happen. As described in [4], a large decrease in synchronization between two neural signals can be seen during the pre-ictal stage. This decrease in synchronization is believed to be a significant bio-marker which could hold the key to prediction and prevention of epileptic seizures via neural prosthesis.

The majority of current phase extraction algorithms are based on the Hilbert Transform (HT) [4] and require the use of complex FIR filters (which incur many expensive multiply operations) and CORDIC (Coordinate Rotation DIgital Computer) algorithms which need many iterations and or occupy large amounts of space via look up tables [5].

The Discrete Distance Approximation (DDA) algorithm proposed in this work can drastically reduce the number of complex operations (multiplications and divisions), relying only on basic addition, comparison and shifting. In terms of logic, the DDA can reduce the amount of hardware needed to detect pre-ictal events by as much as 96.8% when compared to systems with similar functionality. Due to its highly efficient area and power consumption, the proposed approach could lead to a truly functional medical in-vivo application for real time monitoring and or prevention.

10247-9, Session 2

Bio-optical sensor for brain activity measurement based on whispering gallery modes

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In this paper, a high-resolution bio-optical sensor is developed for brain activity measurement. The aim is to develop an optical sensor with enough sensitivity to detect small electric field perturbations caused by neuronal action potential. The sensing element is a polymeric dielectric micro-resonator fabricated in a spherical shape with a few hundred microns in diameter. They are made of optical quality polymers that are soft which make them mechanically compatible with tissue. The sensors are attached to or embedded in optical fibers which serve as input/output conduits for the sensors. Hundreds or even thousands of spheres can be attached to a single fiber to detect and transmit signals at different locations. The high quality factor for the optical resonator makes it significantly used in such bio-medical applications. The sensing phenomena is based on whispering gallery modes (WGM) shifts of the optical sensor. To mimic the brain signals, the spherical resonator is immersed in a homogeneous electrical field that is created by applying potential difference across two metallic plates. One of the plates has a variable voltage while the volt on the other plate kept fixed. Any small perturbations of the potential difference (voltage) leads to change in the electric field intensity. In turn the sensor morphology will be affected due to the change in the electrostriction force acting on it causing change in its WGM. By tracking these WGM shift on the transmission spectrum, the induced potential difference (voltage change) could be measured. Results of a mathematical model simulation agree well with the preliminary experiments. Also, the results show that the brain activity could be measured using this principle.

10247-10, Session 3

Dark field imaging system for size characterization of magnetic micromarkers

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In this paper we demonstrate a dark field video imaging system for the detection and size characterization of individual magnetic micromarkers suspended in liquid. The system is convenient to follow dynamic processes and interactions of moving micro/nano objects close to or below the optical resolution limit, and is especially suitable for small sample volumes. The principle can be used to obtain clinical information about liquid contents when an additional biological protocol is provided, i.e., binding of microorganisms to specific magnetic markers. Advantages of the method are the increased sizing precision in the micro- and nano-range as well as the setup's simplicity (see Figure 1). Hence the introduced method is applicable for miniaturized devices and measurements can be carried out in a quick, inexpensive, and compact manner. A minor

limitation is that the concentration range of micromarkers in a liquid sample needs to be adjusted such that the number of individual particles in the microscope's field of view is sufficient.

Brownian motion & 2D- tracking

The label-free dark field video microscopy method, aimed to enhance contrast, object edges and refractive index gradients, is producing an image comprised of bright spots (corresponding to moving diffusive particles) over a dark background. After filtering frames and reducing noise, hundreds of bright intensity pixels were assigned to equivalent micromarkers on subsequent frames and tracked over time in order to generate trajectories. Random collisions of micromarkers with surrounding molecules due to thermal energy defined as Brownian motion (i.e., small diffusion movement) is described by the Stoke-Einstein equation: d= (k_b T)⁄3ϖ?D, where T is the absolute temperature, D the diffusion constant determined from trajectory analysis, k_b the Boltzmann constant, ? the solvent viscosity, and d is the marker diameter. For this approach only resistance to flow due to liquid viscosity was taken into account (there were no strong interaction forces between particle and sample container observed).

Experiments

Commercially available, uniform, monosized, superparamagnetic Dynabeads® M-270 Carboxylic Acid (coated with a hydrophilic layer of glycidyl ether followed by a further coating with carboxylic acid groups) with a single bead diameter of approximately 2.8 μm were diluted in filtered DI water to obtain around 700 particles per objective field of view as shown in Figure 2. Sandwich arrangement of cover slips (0.17mm thickness) with the liquid of interest between them (approximately 20 μm liquid film thickness) was sealed to avoid evaporation and drift motion. Constriction of the liquid film in the direction of the optical axis allowed keeping the moving particles in focus for the entire time. Measurements were carried out with vertically oriented sample to impose sedimentation movement. The stage was illuminated with a conventional halogen light source with flexible light guides at an angle in a manner to avoid saturation of camera pixels and prevent reflected light entering the optical path. Changes in scattering of light coming from particles undergoing Brownian diffusive motion were observed with a camera (MIKROTRON EoSens MC 1362) using a simple dark field microscopy setup with long working distance objective (Nikon 10x/0.3) giving constant spatial resolution of recorded images of 0.88 pixel/μm. In order to obtain the hydrodynamic radius from the diffusive particle motion in liquid, the diffusion coefficient D is determined from particle coordinates for every frame i=1...N, with a time step ?t to obtain the averaged mean square displacement of a single particle. Then D is substituted in the Stoke-Einstein equation. Mean square displacement calculations as well as a treatment of sedimentation motion superimposed on Brownian motion are described in detail in [ ]. With the employed automatic detection and tracking method, using a MATLAB implementation, displacements of individual particles were analyzed by linking their positions for N=1000 video frames recorded with 25 fps. The particle diffusion in x- and y-direction in conjugation with sedimentation movement in negative y-direction was observed. The resulting diameter calculations for 25°C as shown in Figure 3 correspond to the expected 2.8 μm value range. Outliers above 5000 nm could correspond to attracted magnetic particles which created doubles. Calculated sizes are distributed over a 0 to 5000 nm range due to the underlying physical size distribution of the particles (statistics of the manufacturing process) but also because of localization uncertainty inherent in particle tracking methods.

The presented approach has shown to be an effective method for optical size characterization of micromarkers and is planned to be used for automatic detection, quantification, and size calculation of pathogens labelled with magnetic markers based on the concept of reduced Brownian motion due to the increased dimension of the tracked particle when a microorganism binds to its surface.

10247-12, Session 3

Infrared spectroscopy as a screening technique for colitis

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Two major forms of IBDs, Ulcerative Colitis and Crohn's disease are debilitating gastrointestinal tract disorders that can lead to life threatening complications such as colorectal cancer. Assessment of intestinal inflammation in IBD remains a difficult challenge. Currently, the clinical diagnosis is achieved by colonoscopy that assesses the endoscopic appearance of the colon. However, this technique is not ideal for monitoring disease activity regularly or as an annual checkup since it is expensive and invasive, requiring sedation. Here we describe a rapid, simple and cost-effective minimally invasive technique that could lead to a screening method for colitis which includes the testing of serum using Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy for the colitis-induced increased presence of mannose. Chronic (Interleukin 10 knockout) and acute (Dextran Sodium Sulphate-induced) models for colitis are tested using the ATR-FTIR technique. Arthritis (Collagen Antibody Induced Arthritis) and metabolic syndrome (Toll like receptor 5 knockout) models are also tested as extra-intestinal inflammatory controls. The spectral signature identified as mannose uniquely screens and distinguishes the colitic from the non-colitic samples and the controls. Another signature, namely the alpha helix to beta sheet ratio of the protein secondary structure further discriminates colitic from non-colitic and other controls. The same signature was also used to monitor remission resulting from targeted treatment. By performing second derivative spectral deconvolution of the absorbance spectra, various other spectral markers were identified based on the statistical significance analysis. The reference or the baseline spectrum could be the pooled and averaged spectra of non-colitic samples.

10247-14, Session 3

Micro-resonator-based electric field sensors with long duration of sensitivity

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In this paper, we present a new fabrication method for the whispering gallery mode (WGM) micro-sphere based electric field sensor based which allows for longer time periods of sensitivity. Recently, a WGM-based photonic electric field sensor was proposed using a coupled dielectric microsphere-beam. The external electric field imposes an electrtrostriction force on the dielectric beam, deflecting it. The beam, in turn compresses the sphere causing a shift in its WGM. As part of the fabrication process, the PDMS micro-beams and the spheres are curied at high-temperature (100oC) and subsequently poled by exposing to strong external electric field (~8 MV/m) for two hours. The poling process allows for the deposition of surface charges thereby increasing the electrostriction effect. This methodology is called curing-then-poling (CTP). Although the sensors do become sufficiently sensitive to electric field, they start de-poling after a short period (within ~ 10 minutes) after poling, hence losing sensitivity. In an attempt to mitigate this problem and to lock the polarization for a longer period, we use an alternate methodology whereby the beam is poled and cured simultaneously (curing-while-poling or CWP). The new fabrication method allows for the retention of polarization (and hence, sensitivity to electric field) longer (~ 1500 minutes). An analysis is carried out along with preliminary experiments. Results show that electric fields as small as ~ 100 V/m can be detected with a 300 ?m diameter sphere sensor a day after poling.

10248-501, Session Plen

Smart integrated microsystems: the energy efficiency challenge

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The "internet of everything" envisions trillions of connected objects loaded with high-bandwidth sensors requiring massive amounts of local signal processing, fusion, pattern extraction and classification. From the computational viewpoint, the challenge is formidable and can be addressed only by pushing computing fabrics toward massive parallelism and brain-like energy efficiency levels. CMOS technology can still take us a long way toward this goal, but technology scaling is losing steam. Energy efficiency improvement will increasingly hinge on architecture, circuits, design techniques such as heterogeneous 3D integration, mixed-signal preprocessing, event-based approximate computing and non-Von-Neumann architectures for scalable acceleration.

10248-1, Session 1

Metal halide perovskite nano-platelets *(Invited Paper)*

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Synthesis routes and optical investigations of highly fluorescent metal halide perovskite nano-platelets with controllable thickness down to one monolayer are reported [1-3]. Quantum size effects lead to drastic blue-shifts of the photoluminescence (PL) and of the excitonic onset for absorption. Exciton binding energies up to 300 meV are found which depend on the number of monolayers present in the respective nano-platelets. The radiative emission rates of these two-dimensional colloidal semiconductors are found to depend on thickness and temperature in a similar way as known for III-V quantum wells. Transient pump-probe and four-wave mixing experiments provide additional insight into the excitonic properties of this novel 2D semiconductor system.

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10248-2, Session 1

Tailoring the shape of oxide complex nanostructures

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The ability to synthesize complex nanostructures that combine materials and dimensionality, promises the ability to identify novel designs and architectures with enhanced properties that could be used in new devices. One of the building blocks in nanomaterials are nanowires, which offer several possibilities to get complex nanostructures [1]. In this talk, we present two kind of morphologies based on oxide nanowires obtained by a thermal evaporation method. The common feature of both morphologies is a central oxide nanowire and, depending on the growth parameters, either nanowires with modulated diameter or nanowires with nanocrystallites attached to the central wire are obtained. We have previously reported the fabrication of several oxide nanowires and in particular, gallium oxide (?-Ga2O3) and zinc germanate oxide (Zn2GeO4) nanowires [2]. Here we report the shape evolution of these nanowires by the suitable modification of the growth parameters. The addition of tin oxide (SnO2) to the precursors and variation of the thermal treatments duration result in the formation of the above-mentioned complex nanostructures. Structural and chemical characterization were performed by electron microscopy techniques and Raman spectroscopy. The results shed light on the understanding of the driving mechanisms that lead to the formation of complex oxide nanostructures.

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10248-3, Session 1

Fabrication and optical properties of InGaN/GaN nanotube for cavity based laser

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III-Nitride vertical-cavity surface-emitting lasers are challenging to achieve due to the difficulties involving incorporation of mirrors [1,2]. Whispering gallery mode laser has been suggested to overcome this challenge. Low-threshold laser in InGaN/GaN nanoring has been demonstrated on single nanoring with a diameter of 950 nm and a width of 80 nm, fabricated via a rather complex nanosphere lithography process (NSL) [3]. While these cavities dimensions could be obtained via NSL or EBL process, the high roughness, low density of structure, high cost, low throughput and poor etch selectivity is hindering high-throughput fabrication of WGMs based laser.

In our work, we demonstrate the use of Displacement Talbot Lithography (DTL) [4] and inductively coupled plasma dry-etching to fabricate highly uniform arrays of InGaN/GaN nanotube over a full 2" LED structures on sapphire. The high-aspect ratio nanoring resist (inner diameter ~ 850 nm, nanoring wall width ~ 100-150nm) obtained using the DTL was transferred into 600 nm SiNx (Figure 1.a), subsequently used as an etch mask for the fabrication of InGaN/GaN nanotube array (Figure 1.b).

Individual InGaN/GaN nanotube LED structures were characterized optically via continuous and pulsed micro photoluminescence, confocal photoluminescence and hyperspectral cathodoluminescence. The energy position and spacing of the resonances observed in the nanotube (Figure 2) were compared with Finite different time domain (FDTD) simulation and ascribed to WGMs and FPMs (Figure 3). The impact of the non-circular nanotube shape on the quality factor, resonance position and spacing were modelled (Figure 3 and 4). The position of the active region (gain medium), relative to the strength and quality factor of the supported modes, was studied by FDTD and compared with experimental data. This simple and scalable nanotube fabrication process along with the obtained results opens new perspectives for the fabrication of WGMs-FPMs based lasers using III-Nitride materials.

10248-4, Session 1

Eu-implanted AlxGa1-xN nanowires for solid state light emission

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Group III-nitride semiconductors based on AlxGa1-xN alloys span a wide range of bandgap energies that could enable the realization of laser diodes in the deep UV spectral range with interesting applications such as absorption and luminescence spectroscopy, bioagent detection, medical diagnostics, gas sensing, 3D printing and photolithography. For laser diode applications in particular, Favennec et al. [1] demonstrated that materials with wider bandgaps present lower thermal quenching of rare earth (RE) luminescence, enabling to explore the AlN-rich hosts such as AlGaN. Indeed, from the structural point of view, AlxGa1-xN nanowires (NWs) show high crystalline quality; it was recently reported that micro-optical properties of compositional fluctuations are slightly dependent on the alloy growth temperature and AlN molar fraction [2].

AlxGa1-xN NWs grown by molecular beam epitaxy on Si (111) substrate, were implanted with europium (Eu) ions at the same fluence (1?1014 Eu/cm2) at room temperature with a tilt of 45°. The as-implanted samples containing Al, were further submitted to rapid thermal annealing (RTA) treatments in nitrogen for 30 seconds, at two temperatures 1000°C and 1200 °C, while the GaN samples were only annealed at 1000 °C. Eu3+ luminescence was observed in all samples with the most intense emission assigned to the 5D0 - 7F2 transition, indicating that such implantation and annealing conditions successfully activated the Eu ions. This transition is more intense for the binaries compared to the ternary alloys. In addition, similarly to previous results observed in AlxGa1-xN layers, the linewidths of the component lines of the the 5D0 - 7F2 emission multiplet present variations with Al composition associated to alloy disorder [3]. After annealing the NWs containing Al at 1200 °C, the Eu emission intensity at 622 nm was enhanced by a factor of two. Raman spectroscopy revealed that the RTA treatments efficiently recovered the crystal after Eu implantation.

10248-5, Session 1

Large-area fabrication of silicon nanostructures by templated nanoparticle arrays

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Direct approach of an improved nanoscale processing technique by using polystyrene (PS) nanoparticles as mask is successfully implemented to produce vertically aligned silicon nanowires (SiNWs) arrays. Lithographic microstructures with different shape and opening were applied to determine the fabrication area, followed by deposition of PSS/PDDA/PSS layer. Therefore, most of the substrate area was covered and long-range order deposition of PS nanoparticles can be acquired. Furthermore, the impact of different spin coating parameters (i.e., waiting time after particle drop, spin speed and rotating time) in relation to the hexagonal close-packed (hcp) percentage of nanoparticles were investigated. Prior to the last step, i.e., cryogenic etching by inductively coupled plasma (ICP), particle diameter and roughness depending on O2 plasma parameters (e.g., plasma density) were investigated. Afterwards, particle diameter ranging from 459 ± 9 nm down to 248 ± 11 nm can be precisely determined. Using this as a mask for nanofabrication, a feature-size variation of high-density SiNWs from 225 ± 18 nm to 146 ± 7 nm can be achieved. Finally, a method with simple patterning steps has been developed and tested on more than 100 samples emerging as an alternative method for reliable high-density (up to ~107/cm?) nanostructures realization.

10248-6, Session 2

Dynamics and emission characteristics of semiconductor nanowire lasers *(Invited Paper)*

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The growing demand for faster communications technologies and the inherent limitations of electronic integrated circuits stimulated the research of nanophotonic components accompanied by the urgent need for nanoscale light sources. The demonstration of laser emission from single semiconductor nanowires makes them interesting to accomplish these demands in generating highly localized intense monochromatic light as they mark the lower size limit of photonic laser systems. High quality II-VI semiconductor nanowires consisting of zinc oxide (ZnO) emit in the ultraviolet spectral range acting as Fabry-Pérot laser resonators with the capability of achieving modulation speeds in the single ps regime due to ultrafast carrier thermalization and gain recovery [Nat. Phys. 10, 870 (2014)]. However, the fundamentally coupled angular emission and light-matter interaction of the nanowire device depend on the operating transverse laser mode, thus several optical measurement techniques and a combined FDTD and semiconductor Bloch equation approach [Phys. Rev. B 91, 159903 (2015)] are required for the investigation. The laser output originating out of the end facet of a single nanowire is detected “head-on”, while a double pump technique is applied to measure the laser dynamics. This measurements combined with the optical simulations prove mode switching from single transverse mode operation of the HE11 in thin ZnO NWs to an admixture of several transverse modes in thicker NWs at approximately 180 nm diameter. We furthermore predict that tapered nanowires starting with a diameter well in the multimode regime and ending in the single-mode regime show mode filtering with superior emission properties.

10248-7, Session 2

Cathodoluminescence study of InGaN/GaN core-shell nanorod structures for optimising next generation LED devices

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LEDs based on a core-shell nanorod architecture provide multiple advantages over the planar devices found in most modern LED bulbs. Firstly, the greater surface area allows for improved extraction of the light created in the material. Secondly, the periodic nature of an array of nanorods provides the opportunity for enhancement from photonic crystal effects. And finally, as this geometry allows for access to facets of the crystal whose production usually requires specialised growth techniques, and each rod is surrounded with an InGaN quantum well (QW) layer, light production is enhanced. It is therefore critical for device performance that the QW layer is embedded homogenously around the nanorods.

This paper presents a study of the light emitted from structures where reactor conditions during growth of the InGaN quantum well layer were varied: the temperature between 675°C to 750°C, and the pressure between 150mbar to 450mbar.

Cathodoluminescence (CL) spectra reveal emission peaks centred in the 1.8eV to 2.2eV, 2.0eV to 2.5eV, and 3.0eV to 3.3eV ranges, which are associated with defect (yellow-) band, quantum well, and near band-edge emission. Spatially and spectrally resolved CL data maps these emissions to the various facets on the nanorod and provides information on the

uniformity and changes with growth pressure and temperature.

We report the ability to control relative InN incorporation in InGaN/GaN QWs grown on the semi-polar and non-polar facets of a core-shell nanorod LED structure by varying the growth pressure or temperature respectively. A study of the CL emitted from structures where the temperature and pressure was varied during growth of the InGaN QW layer revealed that increasing the growth pressure had the effect of increasing InN incorporation on the semi-polar facets, while increasing the growth temperature improves the uniformity of light emission from the QWs on the non-polar facets.

10248-8, Session 2

New nanosized hybrid phosphors for lighting applications

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Organic luminescence converters are investigated as attractive alternatives common inorganic phosphors, because of their broad absorption and emission, moderate cost, ease of fabrication and total absence of critical raw materials identified and classified by the European Commission. There have been a number of attempts to use organic luminescence converters for LED and CFL applications, but there is a big concern mainly for their stability against thermal and optical stress, which regularly leads to reduced lifetimes and avoids the integration in the actual devices. In LED application there are experimental evidences showing that the working temperature of the GaN/Ga1-xInxN junction is about 400-500 K.

S-Triazine derivated compounds show interesting structural properties, high temperature stability (up to 500 °C) and, depending on the terminal groups, give rise to different optical properties and emission spectra in the visible range. In particular three class of samples will be studied: Methyl termination (-CH3 termination), Melamine (-NH2) and/or Ciano termination (-CN).

The proposal is focalized on the study of hybrid organic/inorganic nanocomposites achieved by a nanostructured inorganic template (SIO2) surrounded by selected organic dye molecules.

Optical characterization such as absorption, photoluminescence and time resolved luminescence will be carry out. In particular, time resolved luminescence in pristine and hybrid samples will permit to identify and to study energy transfer mechanism among the shell and the core.

Finally, the phosphors with the optimal optical characteristic with will be inserted in commercial LED (emission at 405 nm and/or 450 nm) in a conventional epoxy resin and their suitability for a direct implementation (such as temperature degradation and time stability) will be considered.

10248-9, Session 2

Characterisation of the structural and luminescence properties of microstructured and nanostructured nitride materials in the scanning electron microscope

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The novel scanning electron microscopy techniques of electron backscatter diffraction (EBSD); electron channelling contrast imaging (ECCI) and hyperspectral cathodoluminescence imaging (CL) can provide complementary information on the structural and luminescence properties of materials rapidly and non-destructively with a spatial resolution of tens of nanometres and are therefore useful tools for the characterisation of nanostructures [1-4]. EBSD provides orientation, phase and strain analysis, whilst ECCI is used to determine the planar distribution of extended structural defects such as threading dislocations and stacking faults over a large area of a given sample. CL provides information on the influence of crystallographic defects on light emission, either specific defect-related luminescence or dark spot/line features where carrier recombination due to the presence of defects is non-radiative. CL can also provide information on the composition of alloy thin films used in the manufacture of light emitting devices, e.g., the AlN content in AlGaN based structures for UV emitting devices.

In our presentation I will describe the EBSD, ECCI and CL techniques and give examples of their application to the understanding of the structural and luminescence properties of a number of micropatterned and nanopatterned nitride structures. I will show examples of the use of ECCI and EBSD to investigate the type, density and distribution of defects and the distribution of strain in patterned polar and semipolar GaN and in polar AlGaN and show the influence of defects and strain on their luminescence properties. Our results illustrate that optimisation of patterning can be used to significantly reduce defect densities.

10248-10, Session 3

Flame based growth of ZnO nano- and microstructures for advanced optical, multifunctional devices, and biomedical applications

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The recent flame based growth strategy offers a simple and versatile fabrication of various (one, two, and three-dimensional) nano- and microstructures from different metal oxides (ZnO, SnO2, Fe2O3, etc.) in a desired manner.[1] ZnO structures ranging from nanoscales wires to macroscopic and highly porous 3D interconnected tetrapod networks have been successfully synthesized, characterized and utilized for various applications. The ZnO micro- and nanoneedles grown at walls in silicon trenches showed excellent whispering gallery mode resonances and photocatalytic properties.[2] Using the same strategy, large polycrystalline micro- and nanostructured ZnO platelets can be grown with grains interconnected together via grain boundaries and these grain boundaries exhibit a higher conductivity as compared to individual grains. [3] This flame transport synthesis (FTS) approach offers the growth of a large amount of ZnO tetrapods which have shown interesting applications because of their 3D spatial shape and micro-and nanoscale size, for

example, interconnected tetrapods based devices for UV-detection and gas sensing.[4-5] Because of their complex 3D shape, ZnO tetrapods can be used as efficient filler particles for designing self-reporting,[6] and other interesting composites. The nanostructured materials exhibit an important role with respect to advanced biomedical applications as grown ZnO structures have shown strong potentials for antiviral applications.[7] Being mechanically strong and micro-and nanoscale in dimensions, these ZnO tetrapods can be easily doped with other elements or hybridized with various nanoparticles in form of hybrid ZnO tetrapods which are suitable for various multifunctional applications, for example, these hybrid tetrapods showed improved gas sensing properties.[8] The sacrificial nature of ZnO allows the for growth of new tetrapods and 3D network materials for various advanced applications, for example, highly porous and ultra light carbon based Aerographite materials[9] and hollow silicon tetrapods.[10] These carbon based highly porous network can be further utilized for growth of new hybrid 3D nanomaterials, for example, Aerographite- GaN[11] and Aerographite-ZnO[12] for advanced optical and other applications.

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10248-11, Session 3

Methanol sensor for integration with GaP nanowire photocathode

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We proposed a new type of the methanol concentration sensor that may be integrated directly to the GaP nanostructured photocathode. Necessary attribute for this design is the possibility to make it compatible with p-type of semiconductor. This condition follows from the fact that photocathodes for the CO2 splitting are exclusively prepared from p-type of semiconductors. Design of methanol sensor emanates from this principle. On the GaP substrate is deposited thin Pt supporting layer (100-200 nm thick).This layer is covered by 300 nm thick Nafion membrane that serves as proton filter. On the top of Nafion layer is deposited top Pt contact layer covered by thin nanostructured Pt layer layer with various thickness (0.5 -5 nm). This nanostructured Pt is formed into small islands. It serves as an absorption layer for methanol. Sensor detection properties were estimated from monitoring of I-V characteristics. They were measured in dark and under various methanol concentrations. Dark current values are in order 10-9 A, and this current increases up to order of microamps for methanol of concentration more than 95%.These measurements proved high sensitivity of the GaP compatible sensor structure. Methanol sensors were realized in form of narrow stripe on the side of the photocathode.

10248-12, Session 3

Nanosensor array systems based on single functional wires selectively integrated and their sensing properties to C2H6O and NO2

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Whilst previous studies have demonstrated that chemical nanosensors based on a single (or few) nanowire (NW) structures connected in parallel are the ideal architecture to achieve well defined conduction channel easy to modulate by external stimuli (e.g, gaseous molecules), the integration of single NW structures in functional devices still represents a technological challenge that needs to be solved to fully exploit these concepts. In this context, the design and fabrication of nanosystems that allow for a facile integration of single NW structures via cost effective methods, such as dielectrophoresis (DEP), is worthy of study. Thus, this work presents the fabrication and characterization of gas nanosensors comprised of electrode arrays with finger widths closely related to the diameter (<100 nm) of the sensitive material based on Pt nanoparticle-functionalised tungsten oxide NWs synthesised in a single-step process via aerosol-assisted (AA) CVD.

The sensor chip consists of arrays of gold electrodes with finger widths of ~100 nm and a separation gap over 3 μm (consistent with the range of NW diameters and lengths obtained via AACVD). The electrode array was isolated by an interlevel dielectric layer, and surrounded by a hydrophobic layer to confine the suspended NWs in the area of the electrodes during the DEP process. The chips were produced employing various fabrication steps, including electron-beam and direct writing laser lithography, metallization, dry etching, and DEP process to integrate the NWs. Further analyses of the sensitive material using XRD, TEM and XPS were also performed, and proved the incorporation of the Pt nanoparticles at the surface of the tungsten oxide NWs. The functionality of the nanosensors was evaluated towards various concentrations of ethanol using a constant current. These systems registered up to 28% higher responses to ethanol compared to similar systems based on only tungsten oxide NWs (without Pt nanoparticles at the surface).

10248-13, Session 3

Microfield emitters: characteristics and applications

Hidenori Mimura, Tomoaki Masuzawa, Yoichiro Neo, Shizuoka Univ. (Japan)

Recently, our group has developed volcano-structured double-gated field emitter arrays (FEAs), which can electrostatically focus electron beam. The volcano-structured double-gated FEA has two gates; an electron extraction gate for extracting electrons from the tip and a focus gate for focusing electron beam from the tip. The height of the focus gate is lower than that of the extraction gate. Due to this structure, the focus gate potential, which is lower than that of the extraction gate, does not affect the electric field of the tip. Therefore, both high focusing electron beam and high emission current are realized. One of the good applications is a radiation tolerant compact image sensor which can be used in the Fukushima Daiich nuclear power plant. Conventional semiconductor based image sensors such as CMOS and CCD degrade at the exposure of about 1kGy. However, the image sensor using FEAs and a CdTe-based photoconductor has radiation tolerance beyond 1MGy. In the presentation, I will talk about the emission and focusing characteristics of the volcano-structured double-gated FEAs, and a radiation tolerant compact image sensor using FEAs and a CdTe-based photoconductor.

10248-14, Session 3

Field emission properties of ring-shaped Si ridges with DLC coating

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Si field emission (FE) cathodes are promising candidates for novel electron sources. To obtain a higher field enhancement factor ?, we previously fabricated p-type Si structures on top of elongated pillars with a high aspect ratio. Furthermore, this led to a pronounced current stabilization. Since an open end of a ridge leads to an inhomogeneous ?, we fabricated ring-shaped ridges. Moreover, the emission area is increased with ring-shaped Si ridges compared to Si tips. In addition, a thin layer of diamond-like carbon (DLC) was deposited to lower the work function of the emitter to improve the FE characteristics.

The fabrication process is similar to the Si structures on top of elongated pillars with a high aspect ratio. The reactive ion etching and the subsequent inductively coupled plasma step were adjusted to realize samples with ring-shaped ridges with a height of 15 μm and a radius of about 20 nm. The samples were coated with a DLC layer (thickness ≈ 3 - 10 nm) by a filtered cathodic vacuum arc deposition system.

In diode configuration with cathode and anode separated by a 50 μm thick mica spacer, we observed an emission current of 0.6 μA at 1 kV. We achieved a significantly higher emission current with a single coated ring-shaped ridge compared to an array with 271 Si tips. The stability of the emission current was investigated in the plateau regime at 1 kV for 10 min and current fluctuations of ±12 % were measured. A long term measurement over 6 h was performed and we observed a stable FE behavior. In the next step the FE characteristics of samples with several concentrically ring-shaped ridges with or without DLC coating will be investigated.

10248-15, Session 3

Li-ion battery performance of silicon microwire array anodes under extreme conditions

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Silicon microwire arrays are fabricated by electrochemical macropore etching. The macropores are usually etched in n-doped silicon by backside illumination very easily, as shown by Lehmann et al. In contrast, the here discussed arrays are formed in p-doped silicon. Specially, modulated macropores with a length of 70 μm are converted into an array of wires by chemically etching out the interstices between the pores. Those wire arrays are used as high-energy battery anodes, as demonstrated in [1, 2]. With a deliberate capacity limitation of 75 % SOC (3150 mAh/g), they show stable capacity of exactly these 3150 mAh/g for over 400 cycles. The limitation ensures the anode stability and reduces the compressive stress during volume expansion.

Based on that superior performance with exceptionally high areal capacity, the anodes are taken deliberately to their limits to make them attractive for all fields of applications. Test conditions contain SOC, temperature and C-rate variation. The essential consequences of these conditions are the change in the charge transfer kinetics and the deterioration of the solid electrolyte interface (SEI) layer. Upon temperature increase up to 60 °C, the capacity fails drastically of more than 50 %. This is due to the enhanced decomposition of the electrolyte, which leads to loss in ionic conductivity in the electrolyte. By covering the wires with a material with higher thermal capacity, the degradation of the wires is limited and the capacity is re-established.

With an increase in C-rate up to 5C (~12 minutes charging), the cycling performance is still exceptionally high at as well 3150 mAh/g. This could exclusively be achieved by modifying the electrolytes and achieving an elastic SEI layer.

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[2] E. Quiroga-Gonzalez, J. Carstensen, and H. Föll, Materials 6, 626 (2013).

10248-16, Session 3

Plasmonic enhanced SnO2 gas sensor with segregated silver nanodots

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SnO2/Ag nano-composite layers were produced by magnetron sputtering of Sn1-xAgx alloy on a fused silica (FS) followed by oxidation at high temperature. Silver nano-islands and particles were then segregated inside the SnO2 layer by means of the Kirkendall process followed by segregation. A plasmonic-based optical sensing effect is demonstrated for selective detection of acetone and alcohol in the temperature range of 200-400 °C. Red- and blue-shifts in the position of the plasmon-resonance peak in optical transmission spectra due to the silver nanoparticles are monitored for different conditions of SnO2+Ag layer formation and gas exposure. A dynamical response of the SnO2/Ag sensor to methane (CH4)/air cycles is measured, and the sensitivity of the sensor as a function of the operation temperature and illumination is determined. The concept of plasmonic-based SnO2 sensors is discussed having in mind two main phenomena: First, the ability of metallic nanoparticles to hold plasmonic resonances which depends on the dielectric properties of surrounding SnO2 layer and second, the possibility of space-limited heating of nanoparticles and the neighbouring region with light, and in this way to control the chemisorption of oxygen on the sensor's surface.

10248-17, Session 3

Nano and microcrystallites of KSbOSiO4 in glass matrix as a source of internal strain and fatal corrosion of historic turquoise glass

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Presently, deterioration of glass beads is a significant problem in conservation of beaded exhibits in museums. Corrosion affects nearly all kinds of glass beads but cloudy turquoise (or blue-green) ones are subjected to disastrous destruction more than others are. The problem is very urgent since most of exhibits made of glass beads may lose authenticity in the near future. Therefore, the study of causes of corrosion of the historic blue-green lead-potassium glass of beads is required for keeping authentic historic beadworks in museum collections. However, physical and chemical mechanisms of this phenomenon have not been understood thus far. The paper presents results of a study of elemental and phase composition of glass of the blue-green beads of the 19th century obtained from exhibits kept in museums aimed to ascertainment of physical mechanisms of glass corrosion at microscale and nanoscale. Using Raman, FTIR and light transmission microspectroscopies, EDS, SEM, EBSD, X-ray fluorescence microspectrometry and X-ray powder analysis

we have detected and investigated Sb-rich precipitates in the glass matrix of these beads and found them to be micro and nano crystallites of orthorhombic KSbOSiO4 (KSS). These crystallites were not detected in other kinds of glass less subjected to corrosion and decaying differently. We conclude that KSS precipitates and their clusters play a major role in the bead glass destruction giving rise to internal glass corrosion: potassium as a dopant and antimony as an opacifier cause the strain-induced corrosion forming KSS crystallites in the glass matrix; strain gives rise to glass cracking and formation of heterogeneous grains. The strain-induced diffusion of metal impurities, resembling the internal gettering process used in the Si technology, explains changes in the glass color. This study may also be important for predicting long-term stability of technical glasses as well as for synthesis of nano-KSS/glass composites.

10248-40, Session 3

NFFA-Europe: enhancing European competitiveness in nanoscience research and innovation

Flavio Carsughi, Forschungszentrum Juelich GmbH (Germany); Luis Fonseca, Ctr. Nacional de Microelectrónica (Spain)

NFFA•EUROPE is an European open access resource for experimental & theoretical nanoscience and sets out a platform to carry out comprehensive projects for multidisciplinary research at the nanoscale extending from synthesis to nanocharacterization to theory and numerical simulation. Advanced infrastructures specialized on growth, nano-lithography, nano-characterization, theory and simulation and fine-analysis with Synchrotron, FEL and Neutron radiation sources are integrated in a multi-site combination to develop frontier research on methods for reproducible nanoscience research and to enable European and international researchers from diverse disciplines to carry out advanced proposals impacting science and innovation. NFFA•EUROPE will enable coordinated access to infrastructures on different aspects of nanoscience research that is not currently available at single specialized ones and without duplicating their specific scopes. Approved user projects will have access to the best suited instruments and support competences for performing the research, including access to analytical large scale facilities, theory and simulation and high-performance computing facilities. Access is offered free of charge to European users and users will receive a financial contribution for their travel, accommodation and subsistence costs. The users access will include several “installations” and will be coordinated through a single entry point portal that will activate an advanced user-infrastructure dialogue to build up a personalized access programme with an increasing return on science and innovation production. The own research activity of NFFA•EUROPE will address key bottlenecks of nanoscience research: nanostructure traceability, protocol reproducibility, in-operando nano-manipulation and analysis, open data.

10248-18, Session 4

Carbon nanotube transparent charge collectors for hybrid perovskite photovoltaics *(Invited Paper)*

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The hybrid (organo-inorganic) lead-halide perovskites revolutionized the field of solar cell research due to the impressive power conversion efficiencies of up to 21% recently reported in perovskite based solar cells. This talk will present first the general concepts of excitonic photovoltaics, as compared to conventional Si-type solar cells, asking a question: is hybrid perovskite PV an excitonic solar cell or not? Do we need excitons dissociation at D-A interfaces or CNT charge collectors? Then I will show our recent experimental results on the fast spectroscopy of excitons, magnetic field effect on generation of correlated (e-h) pairs. Also will discuss our Hall effect results, that allows to evaluate intrinsic charge carrier transport and direct measurements of mobility in these materials performed for the first time in steady-state dc transport regime. From these measurements, we have obtained the electron-hole recombination coefficient, the carrier diffusion length and lifetime. Our main results include the intrinsic Hall carrier mobility reaching up to 60 cm2V-1s-1 in perovskite single crystals, carrier lifetimes of up to 3 ms (surprisingly too long!), and carrier diffusion lengths as long as 650 ?m (huge if compared to organic and even best inorganic materials). Our results also demonstrate that photocarrier recombination in these disordered solution-processed perovskites is as weak as in the best (high-purity single crystals) of conventional direct-band inorganic semiconductors. Moreover, as we show in our experiment, carrier trapping in perovskites is also strongly suppressed, which accounts for such long carrier lifetimes and diffusion lengths, significantly longer than similar parameters in the best inorganic semiconductors, such e.g. as GaAs. All these remarkable transport properties of hybrid perovskites need to be understood from fundamental physics point of view. Looks like we need some new concepts to explain the mysterious properties of “protected” hybrid perovskites. We suggest that some of this unusual properties can be attributed to a special type of “dipole rotational polaron” formed in their lattice due to interactions of charge with methyl-ammonium organic dipoles, each of 2.3 Debye. Examples of perovskite solar cell with transparent CNT charge collectors will demonstrated the 3 D charge collection in the monolithic tandems of perovskite PV with other dissimilar materials PVs, such as OPV and inorganic PV. We describe the pioneering methods to create highly transparent CNT sheets by dry lamination from vertically alligned CVD forests of MWCNTs. Transparency can be further increased by converting CNT aerogels into locally collapsed meshs with micron scale oppenings by spraying Ag nanowires, which lowers sheet resistance to values of Rsh< 40 ohm/sq. such AgNW@ CNT transparent sheets are ideal interlayers in three terminal tandems of perovskite PV with polymeric OPV and/or inorganic solar cells. We show that nanoimprinting can further improve the performance of perovskite photodetectors and optoelectronic devices

10248-19, Session 4

Preparation and characterizations of ZnS thin films by the chemical bath deposition method with the self-catalyst growth process

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Nowadays, the conversion efficiency of Cu(In?Ga)Se2 (CIGS)-based solar cell already reached over 20%. CdS thin films prepared by chemical bath deposition (CBD) method are used for CIGS-based thin film solar cells as the buffer layer. Over the past several years, a considerable number of studies have been conducted on ZnS buffer layer prepared by CBD in order to improve in conversion efficiency of CIGS-based solar cells. In addition, application to CIGS-based solar cell of ZnS buffer layer is expected as an eco-friendly solar cell by cadmium-free. However, it was found that ZnS thin films prepared by CBD included ZnO or Zn(OH)2 as different phase [1]. Nakata et. al reported that the conversion efficiency of CIGS-based solar cell using ZnS buffer layer (CBD-ZnS/CIGS) reached over 18% [2]. The problem which we have to consider next is improvement in crystallinity of ZnS thin films prepared by CBD.

In this work, we prepared ZnS thin films on quarts (Si02) and SnO2/glass substrates by CBD with the self-catalysis growth process in order to improve crystallinity and quality of CBD-ZnS thin films.

The solution to use for CBD were prepared by mixture of 0.2M ZnI2 or ZnSO4, 0.6M (NH2)2CS and 8.0M NH3 aq. In the first, we prepared the particles of ZnS on Si02 or SnO2/glass substrates by CBD at 80? for 20 min as initial nucleus (1st step). After that, the particles of ZnS on Si02 or SnO2/glass substrates grew up to be ZnS thin films by CBD method at 80? for 40 min again (2nd step).

We found that the surface of ZnS thin films by CBD with the self-catalyst

growth process was flat and smooth. Consequently, we concluded that the CBD technique with self-catalyst growth process in order to prepare the particles of ZnS as initial nucleus layer was useful for improvement of crystallinity of ZnS thin films on SnO2/glass.

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10248-20, Session 4

Silicon-germanium and platinum silicide nanostructures for silicon based photonics

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This paper presents a study of Ge/Si(001) thin granular films. We deposited Ge films at 300K on the Si(001) surface using MBE and explored their structure and their crystallization during annealing at 600°C. Ge granular films form on Si(001) at 300K with grain sizes of a few nanometers. We demonstrate that the Ge/Si(001) heterostructure forming during a short-term annealing under the closed system conditions consists of a wetting layer (WL) and Ge oval clusters; pyramids and domes do not appear; a mixed c(4?2) + p(2?2) reconstruction typical to the low-temperature MBE (Tgr < 600°C) forms on WL. We show that the Ge drops disappear during long-term annealing; the sizes of the large clusters increase at the expense of the smaller ones, the Ge cluster number density decreases by several orders of magnitude. WL reconstruction changes to c(4?2) typical to high-temperature MBE (Tgr > 600°C).

Platinum silicides have attracted attention of researchers for decades due to their prospects in microelectronics and microphotonics. This class of materials is one of the friendliest to silicon technology. However, as silicide films become thinner and reach tens or units of nanometers their resistivity becomes of primary importance. In this connection Pt3Si, which has the lowest sheet resistance among the Pt silicides (18.9 ?/ square in comparison with 2.6 ?/ square of Pt, 31.8 ?/ square of Pt2Si and 57.6 ?/ square of PtSi), starts to play the main role. So, the development of simple processes of formation of thin Pt3Si films becomes more and more important. This paper describes a phenomenon of formation of a thin bilayer Pt3Si/Pt2Si film at room temperature on a poly-Si substrate as a result of Pt magnetron sputtering and wet etching and introduces a formation process of such films.

10248-21, Session 4

Homogeneous fluorescent thin films as long-term stable microscopy reference layers

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Calibration and validation of fluorescence microscopy devices and components require a high level of stability and repeatability. In order to establish a dependable reference point, from which all variations within the microscope and peripheral devices can be tested, an exceedingly homogeneous fluorescence response must be provided through a calibration tool. We present material combinations and microfabrication considerations, as well as metrology methods for such a calibration tool. The formulations are based on polymer matrices, into which fluorescent nanoparticles were embedded. The solutions are spin-coated on silicon and glass wafers for structural and optical characterization, respectively. Stringent specifications for film thickness (< 1μm ± 0.1% over 1.5x1.5 mm) and for fluorescence response distribution (within 1%) apply, and should hold for up to 100 hours under continuous white light. The film thickness is significant, because fluorescent microscopy applications require a well-defined focus range for optimized response from the observed film.

The reported films were fabricated using poly(methyl methacrylate) (PMMA), since it is the most promising film with the most homogeneous thickness [1]. PMMA was mixed with core-shell quantum dots as the fluorophore species, again for stability reasons, as well as the ability to distribute these particles in the PMMA solution with minimal local variation in the concentration [2]. Fluorescent Surface modified core-shell quantum dots (SMQDs) were embedded in diluted PMMA at low concentrations, 0.5 – 10 μM. The formulations were spin coated on silicon wafers to obtain films with thicknesses under 1μm and variations under 5% on a 100 mm wafer. Fluorescence properties of the SMQD were preserved in the matrix material, and agglomerations, insofar as they exist, were not detectable in the fluorescence response nor in SEM images. The optimized results, as well as effects of processing outside of tolerances are presented through optical and structural analysis of the resulting thin films.

10248-22, Session 5

Displacement Talbot lithography: an alternative technique to fabricate nanostructured metamaterials

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The fabrication of periodically repeated complex nanostructures is essential for metamaterial and plasmonic applications. The fabrication of fine, submicron patterns can be achieved with several existing techniques. However, these techniques can be expensive (optical lithography), very accurate and flexible but slow (electron-beam lithography) or sensitive to particulates (nanoimprint lithography). Recently, multiple beam interference lithography has been used for the fabrication of plasmonic arrays of arbitrary shaped nanomotifs [1]. However, the quality and reproducibility of the pattern strongly depends on the beam alignment, which is hard to control.

Displacement Talbot Lithography (DTL), a recent lithography technique developed by Eulitha AG, offers away to produce periodic patterns reliably across a large area with high-throughput, combined with the unique ability to control the feature size of the pattern by controlling the exposure dose.

In this work, we demonstrate that sub 100 nm features can be obtained using DTL, such as 90 nm lines on a 500 nm linear gratings period and 75 nm diameter pillars on a 1 micron pitch hexagonal array. We further demonstrate that multiple exposures combined with x-y lateral displacement steps allows the fabrication of a variety of nano-features such as bowties and dashes in resist; a process that can be simply extrapolated to more complex structures. Combined with a lift-off process using a wet-developable bottom anti-reflection coating, DTL offers a unique capability for the fabrication of nanostructures for metamaterial and plasmonic applications with sub-100-nm detail.

10248-23, Session 5

Multilayer porous structures on MOCVD-grown GaN for the fabrication of Bragg reflectors

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of Moldova (Moldova); Vladimir V. Sergentu, Institute of Applied Physics (Moldova); Nicolas Grandjean, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Ion M. Tiginyanu, Academy of Sciences of Moldova (Moldova)

Brag reflectors are based on multilayer structures, in which layers with alternating index of refraction are incorporated. One way of controlling the index of refraction of a material is to introduce porosity. The main advantage of this approach is the fact that the porous GaN layers are perfectly lattice-matched to bulk GaN, therefore ensuring wide possibility for structural integration in various devices.

The goal of this report is to demonstrate possibilities for the fabrication of multilayer porous structures based on MOCVD grown GaN by means of electrochemical etching.

Since the electrochemical etching of a material is strongly impacted by its electrical conductivity, multilayer structures with alternating conductivity have been initially prepared by MOCVD on sapphire substrates with a high resistivity buffer layer. Technological conditions of electrochemical etching have been optimized for producing multilayer porous structures. Several electrolytes have been tested for these purposes such as oxalic acid, HNO3, and KOH aqueous electrolytes. It was found that oxalic acid electrolyte is the most suitable for these purposes.

The morphology of electrochemically etched GaN samples was studied using scanning electron microscopy. The multilayer porous structures produced by optimized technologies have been investigated by micro-reflectivity measurements in order to assess their suitability for distributed Bragg reflector applications. The experimentally measured reflectance spectra were calculated by using a Transfer Matrix technique with three fitting parameters, such as the volume fraction of GaN in the porous layer, the porous GaN layer thickness, and the GaN buffer layer thickness. The parameters deduced from the Transfer Matrix analysis were compared to those found from scanning electron microscopy and capacitance-voltage carrier concentration profiling.

The results of this analysis demonstrate the feasibility of the produced structures for the design and fabrication of Bragg reflectors and other photonic elements.

10248-24, Session 5

Self-nanostructuring in SiGeSn alloy layers induced by laser melting and fast recrystallization

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Self-organized nanostructures of Si-based alloy layers are valuable for nano- and opto-electronics and next generation of solar cells. One of the major advantages of Si-Ge-Sn alloying is the enhanced optical absorption and tunable energy band gap of the alloy. In this talk, a short review of phase transitions, structural changes and segregation in Si-based alloy layers during laser melting and fast crystallization will be given. Samples of continuous layers of epitaxial, polycrystalline or amorphous SiGe+Sn alloy as well as nano-dotted layers of Ge or GeSn are used as initial structures. The structures are deposited by MBE or CVD and subsequently treated by a pulsed laser beam (25-100 ns, 0.2-3.5 J/cm2). Structural changes and optical properties of the heterostuctures are studied by using electron microscopy, time-resolved reflectivity, RBS/Channelling, atomic force microscopy and Raman spectroscopy.

The following subjects will be reviewed and discussed:

- Fast crystallization of Si-based alloy layers and formation of cellular structures. We will concentrate on crystallization and segregation of solutes to a nanometer-scale cellular network, time-resolved reflectivity measurements of melting, pulsed laser modification of Ge and GeSn nanodots, and optical properties of nanostructured SiGeSn/Si layers.

- Pulsed laser modification of Ge and GeSn nanodots. Fast segregation is used for production of non-equilibrium compounds, e.g. metastable Ge1-xSnx dots with a tunable energy band gap.

- Laser-induced melting and fast recrystallization of CVD grown polycrystalline GeSn layers is used for modification of structural and optical properties of GeSn layers for IR-photodetectors and solar cells thanks to suitable band-gap and strong light absorption. The results are discussed within the frame of fast solid-liquid-solid phase transitions.

10248-25, Session 5

Nano scale doping in CdTe for radiation detector

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Irradiation of high resistivity p-like CdTe crystals pre-coated with an In dopant film from the CdTe side by nanosecond laser pulses with wavelength that is not absorbed by the semiconductor made it possible to directly affect the CdTe-In interface because radiation was strongly absorbed by a thin layer of the In film adjoining to the CdTe crystal. The doping mechanism was associated with the action of laser-induced stress wave which was generated under extreme conditions in the confined area at the CdTe-In interface under laser irradiation. The developed technique allowed avoiding evaporation of In dopant and resulted in the formation of the In-doped CdTe region and thus, creation of a built-in p-n junction. The temperature distribution inside the three layer CdTe-In-Water structure was calculated and correlations between the characteristics of the fabricated In/CdTe/Au diodes and laser processing conditions were obtained.

10248-26, Session 5

Interlocked by nanoscale sculpturing: pure aluminum copper contacts

Melike Gerngross-Baytekin, Mark Daniel Gerngross, Jürgen Carstensen, Rainer Adelung, Christian-Albrechts-Univ. zu Kiel (Germany)

Connecting metals reliable with different corrosion potential is a well-known challenge. An extreme example are copper aluminum contacts. Galvanic corrosion occurs if the two different metals are in contact with each other and an electrolyte, the aluminum becomes susceptible to corrosion under current flow. Usually, antioxidant pastes containing metals are employed but create difficulties e.g. for fatigue resistant power electronic connections.

The recently described process of nanoscale sculpturing [1] offers an alternative. Usually, if the surface of metals like aluminium are prepared they are just arbitrary cuts through the bulk. There is no optimization of the surface grain structure towards stability at all. Neither the crystalline facets in the grains are in their most stable orientation nor is the protective oxide shell the most stable one. The nanoscale sculpturing approach is carving out the most stable grains and planes by chemical or electrochemical treatment. The decisive trick is that the chemistry is targeting towards the instable oxide and not the metal. Aluminium sample surfaces including alloys like AA575 exhibit afterwards single crystalline surface facets covered with nanoscale stable oxide films. Galvanically deposited copper forms extremely reliable interlocked connections on top, even allowing for soldering on top of their surface.

[1] M. Baytekin-Gerngross, M.D. Gerngross, J.Carstensen, and R. Adelung, Nanoscale Horiz., 2016,1, 467-472

10248-31, Session PTue

Two-electron states and time exchange control in quantum dash systems

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The electronic structure and optical properties of the semiconductor quantum dots (QD) have been in the spotlight of researchers in recent years thanks to the rapid development of fabrication technology. QDs are thought to have vast potential for future technological applications in fields of quantum computing and information as a possible application as qubits, quantum cryptography, application in memory chips also as mid-infrared quantum dot detectors and room-temperature QD lasers, etc.

Modern precise technologies allow growing spherical, cylindrical, conical, lens-shaped, ellipsoidal and ring-shaped QDs, etc. QDs with highly elongated truncated prism geometry (so-called quantum dashes have been obtained recently. Besides, modern technologies made it possible to put any number of charge carriers in QDs. Therefore, in this paper, we will concentrate on the investigation of electronic and optical properties of two-electron prism-shaped quantum dash.

The characteristic particularity of the two-electron systems is the exchange interaction between the electrons, which is responsible for the exchange between the states in a quantum system. The state exchange time cane be controlled by changing geometrical parameters of the quantum dash.

The dependence of ground-state energy and Coulomb electron-electron interaction energy correction on the QD size is studied. Besides, the ground-state energy value estimations using the Heisenberg uncertainty relationship have been done by the minimization of the energy expression for two electrons. The correlation function approach is used to obtain ground state two-electron wave function. The two-electron optical absorption has been studied. The state exchange time control in quantum dash taking into account the spins of the electrons in the Russell-Saunders approximation is studied.

10248-32, Session PTue

An electrochemical ceruloplasmin nanoaptasensor using a glassy carbon electrode modified by diazonium-functionalised multiwalled carbon nanotubes

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Aptamers are oligonucleotides of either single-stranded DNA or RNA to bind specific target molecules, which are in vitro selected by systematic evolution of ligands by exponential enrichment (SELEX) technology. Theoretically, all kinds of aptamers can be obtained to recognize any molecules with excellent specificity and high affinity. Since its first report in 1990, aptamers have received extensive interests as arrival of antibody due to several advantages over antibodies. One of the most important adequate of using aptamers is that there are not limited to their targets. Ceruloplasmin (Cp) is a ?2-glycoprotein containing more than 95% copper present in blood. It belongs to the group of inflammation-sensitive proteins (ISPs). It is considered as an important cardiovascular diseases risk factor. Fast and accurate determination of biological compounds in human fluids is of key importance in clinical analysis. Low levels and high levels of Cp in serum cause several diseases such as Wilson's disease, so its accurate determination in human fluids is much essential. A selective and sensitive electrochemical biosensor was developed for Cp detection using a Cp-specific recognition aptamer. The proposed nanoaptasensor was based on a glassy carbon electrode modified with diazonium-functional multiwall carbon nanotubes. The aptamer was linked onto the electrode surface, via electrochemical approach, followed by chemical immobilization of aminated-aptamer. Each fabrication steps was accompanied by changes to the electrochemical parameters. The binding of Cp to aptamer was monitored using cyclic voltammetry (CV), differential pulse voltammetry (DPV), and electrochemical impedance spectroscopy (EIS). The effective parameters was optimized. The calibration curve for Cp concentration was linear at 2.0?10-2 to 80.0 ng mL-1 with detection limit (signal-to-noise ratio of 3) of 1.7 pg mL-1. The fabricated aptasensor can serve as a powerful sensor for rapid diagnosis of Cp in human serum sample and shows great potential for practical bioapplication.

10248-34, Session PTue

Resonant tunneling transport in ZnxBe1-xSe/ZnSe/ZnyBe1-ySe asymmetric quantum structures

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The resonant tunneling transport in ZnBeSe/ZnSe/ZnBeSe symmetric and asymmetric double-barriers resonant tunneling diodes (RTD) is investigated numerically by solving the self-consistent coupled Schrödinger-Poisson equations using non-equilibrium Green's function method. The transfer matrix approach was used to model the tunneling current density. The simulated symmetric RTD structure consist of 10 nm thick 10^18 cm-3 n-doped ZnSe emitter/5nm thick undoped ZnSe spacer/5 nm thick undoped Zn0.7Be0.3Se quantum barrier/9 nm thick undoped ZnSe quantum well/5 nm thick undoped Zn0.7Be0.3Se quantum barrier/5 nm thick undoped ZnSe spacer/10 nm thick 10^18 cm-3 n-doped ZnSe collector. The sensitivity of electrical transport characteristics of this RTD to the potential barrier due to the interplay between potential symmetry and its height and width is analyzed. We found that the tunneling transport and respective peak-to-valley ratio (PVR) of this symmetric RTD structure is 4.16 @ 0.21-0.22 V at 150 K, and it could be optimized to achieve a value of 5.24 @ 0.18-0.19 V by increasing the Zn ratio in the both ZnBeSe quantum barriers from 0.7 to 0.85. The further improvement of ZnSe-based RTD structures could be made by employing asymmetric ZnBeSe quantum barriers with different potential heights. Our simulations show that the asymmetric RTD with quantum barrier composition of ZnSe/Zn0.85Be0.15Se/ZnSe/Zn0.8Be0.2Se/ZnSe has an extraordinarily high PVR ratio of 7.82 @ 0.17-0.175 V at 150 K, which is of significant advantage for highest-frequencies, including terahertz ranges. This ZnBeSe/ZnSe-based asymmetric RTD diode is a potential candidate for designing a high power RTD terahertz source.

10248-36, Session PTue

Ultrafast laser patterning of graphene

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In this report we describe our recent results in ultrafast (femtoseconds and picoseconds) pulsed laser patterning of carbon nanomaterials (single layer graphene, graphene oxide (GO) film, carbon nanotubes). We investigated such effects of nonlinear optical interaction like selective laser ablation of graphene, laser reduction of graphene and local functionalization (oxidation) of graphene based on multiphoton absorption.

Laser ablation is tested as a direct structuring process creating an isolating path. The peak pulse power strongly affects the ablated line widths. The processing window to produce a sound, stable ablated line is narrow, in terms of laser energy deposition required for supported graphene ablation. The upper bound is limited by substrate damage (namely amorphization), while the lower bound is limited by the stability of the ablation effect, causing a discontinuity in the ablated path, hence

shortcuts in the desired isolation path. Just below the threshold energy of laser ablation we demonstrate the optical and chemical change in graphene we claim is rise from two-photon oxidation of graphene by water trapped and oxygen absorbed.

The same effects were implemented for laser induced reduction of GO (LrGO). The laser reduction for thick (about 1000 nm) and thin (about 20 nm) GO film dominates by interplaying of photothermal and photochemical effects in different layers of GO film causing reduction, recrystallization and exfoliation of the GO film. This leads to slight difference in laser processing parameters for achieving the high conductivity and best crystalline quality of hexagonal lattice of LrGO. The tight connection between GO layers provides also the possibility of 3D structuring of GO film using laser embossing from transparent support side.

In conclusion, we discuss the role of different mechanisms of ultrafast pulses and graphene lattice interaction in chemical and physical modification of graphene.

10248-37, Session PTue

A low Curie temperature Fe-Cr-Nb-B ferrofluid for biomedical applications

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Ferrofluids are colloidal suspensions of magnetic particles (MPs) that have been lately investigated for different biomedical applications such as contrast agents for MRI, magnetic cell separation and magnetic hyperthermia.

Recently, we have developed a new type of ferromagnetic nanoparticles with Curie temperature ranging from 16 to 50°C based on glassy Fe79.7-xCrxNb0.3B20 alloys (x = 11.5-13 at.%). A content of 12.5% Cr leads to a Curie temperature around 47 OC. These particles appear to be suitable for self-regulated hyperthermia and are also biocompatible, as shown in our previous studies.

The purpose of this work was to prepare a ferrofluid based on low Curie Fe67.2Cr12.5Nb0.3B20 particles, in order to obtain a stable suspension and to avoid particles agglomeration, aspects important in biomedical applications. To this aim, MPs which have sizes under 100 nm, were dispersed by sonication for 30 min at 80°C in an aqueous solution containing calcium gluconate, then the mixture was allowed to settle for 12h.

The obtained saturation magnetization for the ferrofluid was 1.5 emu/cm3. The heating power of the ferrofluid was investigated by using a magnetic induction hyperthermia unit. The SAR value of calcium gluconate-Fe67.2Cr12.5Nb0.3B20-ferrofluid is 8.72 W/g for a frequency of 185 kHz and a value of 41 mT of the alternating magnetic field applied. When the ferrofluid is introduced in the AC magnetic field, its heating curve starts to saturate after 12 minutes of continuous heating when temperature reaches 47°C, and increases afterwards with only 0.6°C during the next 20 minutes.

Cytotoxicity tests performed on osteosarcoma cells showed that the cellular viability was not significantly reduced, the calcium gluconate-ferrofluid presenting a good biocompatibility and also a good distribution of the particles in the cell culture, which represents an advantage for hyperthermia as well as for drug delivery applications.

10248-38, Session PTue

Design and fabrication of a novel impedimetric sensor for sensitive determination of Tecfidera

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The injuries to the central nervous system (CNS; brain and spinal cord), are one of the most challenging fields of medical development [1]. Multiple sclerosis (MS) is the most common autoimmune disease involving the nervous system. The first clinical signs of MS typically begin in young adulthood, and women with the disease outnumber men 2:1 [2]. Tecfidera or Dimethyl fumarate, previously known as BG-12 or DMF, is a newer oral agent for the management of relapsing-remitting forms of multiple sclerosis (RRMS) that was approved by the FDA in March 2013 [3]. Tecfidera also has been used for treatment of psoriasis due to its suppressive actions on pro-inflammatory T-cell activation. In this work has presented a novel strategy to carry out direct and sensitive determination of Tecfidera in complex matrices based on the L-cysteine/Nano chitosan modified glassy carbon electrode. This novel structure was characterized by different techniques including atomic force microscopy (AFM), Transmission electron microscopy (TEM) and Fourier-transform infrared (FT-IR) spectrometry. Electrochemical impedance spectroscopy of ferri/Ferro cyanide was used as a marker to probe the interface and as a redox probe to determine Tecfidera. The fabricated electrochemical sensor showed good electrochemical response towards Tecfidera. Under the optimized conditions, the calibration curve for Tecfidera concentration was linear in the range from 0.002 to 7.00 nM with the detection limit of 0.841 pM. In addition, the practical analytical performance of the sensor was examined by evaluating the selective detection of Tecfidera in biological fluids and pharmaceutical samples with satisfied recovery. Therefore, the prepared sensor may hold great promise for fast, simple and sensitive detection and biomedical analysis of Tecfidera in various real samples.

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10248-39, Session PTue

Endothelial cell proliferation under exposure to GaN nanoparticles

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In this paper we report on the interaction of living endothelial cells (EC) and semiconductor material based nanoparticles. Gallium nitride (GaN) nanoparticles with the dimensions ranging from 50 to 100 nm have been obtained in a single hydride vapour phase epitaxy (HVPE) growth process, where GaN layer was deposited on ZnO sacrificial nanoparticles. Cellular viability, proliferation and uptake of nanoparticles by endothelial cells were investigated. The effect of free GaN nanoparticles versus the effect of growing endothelial cells on GaN functionalized surfaces was examined. The uptake of GaN nanoparticles by porcine endothelial cells was strongly dependent upon whether they were fixed to the substrate

surface or free floating in the medium. We found that ECs attract free NPs and, depending on the NP concentration, the cellular activity is slowed down resulting in lower cellular mobility. Nevertheless, cellular proliferation is not affected as cells continue to divide even when relatively high amount of NPs are internalized. Guiding cells targeted with nanoparticles was demonstrated, which represent a step forward to the cellular therapy applications.

10248-27, Session 6

Silver nanoparticles fabricated via green synthesis using plant leaf extracts

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Silver nanoparticles have attracted a lot of attention due to their optical, antibacterial and antimicrobial properties which makes them useful in electronics as sensors, in medicine as drug carriers, as coating agents for dressing wounds, for food preservation and for treating contaminated water etc. Though these nanoparticles can be synthesized chemically, the more environmentally friendly biosynthesis is a possible alternative (1). The use of leaf extracts is of special interest because there is no need of external stabilizers or capping agents as these are already inherent in the leaf extracts. This method also produces biocompatible nanoparticles which are said to be useful in the field of medicine (2)

The direct synthesis of the silver nanoparticles using the precursor silver (aqueous silver nitrate) with the leaf extracts(Ocimum gratissimum (Og) and Vernonia amygdalina (Va)) during the spontaneous reaction proceeds and results in the formation of Nanoparticles after several hours (Fig 1 a) While the direct synthesis has shown the effect of leaf extract on the size of nanoparticle distribution, here we present our work, exploring a faster method of the silver nanoparticle synthesis using electrochemical deposition method . The study has shown that electrodeposition produces silver particles with shapes and sizes as well as surface roughness dependent on the leaf extract used. The structure of the silver nanoparticles from both methods were compared. While the sizes and shapes of the nanoparticles from the conventional method were dependent on the concentration of the precursor materials used, the much faster electrodeposition method produced nanostructures whose sizes and shapes were more uniform and dependent on the leaf extract used and the deposition conditions controlling the rate of silver growth.

The electrodeposition was done in a three electrode electrochemical cell. The working electrode used was gold thin films evaporated on glass thermally treated to have the (111) dominant surface orientation (3)

Silver nanoparticles were deposited at constant potentials using Chronoampereometry and the dependence of the rate of deposition has been established. The morphology of the Ag deposits with and without the leaf extracts as well as the morphology of the started gold surface is shown in Figure 1(b-d).

Furthermore, the properties of the silver nanoparticles and the electrochemical behaviour of the nanoparticles was studied using Cyclic Voltammetry to establish the effect of the leaf extract adsorption (Figure 1 e) on deposition as well as the surface reactive behaviour. In addition to that, the obtained silver nanoparticles were characterised using UV-Vis, DLS, XRD, TEM and AFM. We demonstrate an alternative way to create new nano-templates and coatings of silver nanoparticles using simple and controllable electrochemical deposition process which due to its low cost and scalability can be used in a variety of applications.

10248-28, Session 6

Production of silver nanoparticles by the diatom Phaeodactylum tricornutum

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Diatoms (Bacillariophyceae) are the most species-rich group of algae, they are single-celled (2-200 micrometers) characterized by a silicified cell wall called a frustule that consists of two parts called thecae. Diatoms are diverse in shapes and have a wide variety of morphological features like striae and areolae. The diatom cell wall morphology and its ideal hierarchy structure make it a unique unicellular organism for nanotechnology research and applications.

Diatom cells are a promising system for green synthesis of nanomaterials like metallic nanoparticles (NPs), nanostructured polymers and other nanomaterials. The production of NPs is achieved today by using methods like solvothermal process, attrition, or pyrolysis. The cost and the toxic substances often used in these common methods of NPs synthesis limit their usage and applications. Therefore, NPs biosynthesis by diatom cultures, which can be done at ambient CO2 concentration, temperature and pressure, offers a sustainable alternative solution.

In this work, we examined the formation of silver NPs (AgNPs) by the diatom P. tricornutum cultivated at 25°C for a period of 8 days. Using this approach, diatom cultures were either grown throughout the duration of the experiment in an artificial seawater (ASW)-f/2 medium enriched with 1 ppm Ag+ or grown in an ASW-f/2 medium where similar silver ion concentrations were added on experimental day 4. We found that 1 ppm Ag+ reduces the P. tricornutum growth by up to 50% as compared with the control. Moreover, Scanning Electron Microscopy (SEM) in combination with Energy Dispersive Spectrometry (EDS) revealed the presence of AgNPs nanoparticles with different sizes and chemical composition associated with the diatom frustules and extracellular polysaccharides.

10248-29, Session 6

Growth scheme for entanglement ready quantum dots at telecom wavelength

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Next challenge in quantum technology field are efficient light sources at telecom wavelengths suitable to deliver entangled photons. Quantum dots based on InAs/InP are promising candidates to be used in future quantum networks applications based on existing fibre optics infrastructure as they emit with wavelength suitable for the standard telecom window around 1550 nm. A prerequisite for the generation of such entangled photons is a small fine structure splitting (FSS) in the quantum dot excitonic eigenstates, as well as the ability to integrate the dot into photonic structures to enhance and direct its emission. Using optical spectroscopy, we show that a growth strategy based on droplet epitaxy can simultaneously address both issues.

Contrary to the standard Stranski-Krastanow technique, droplet epitaxy dots do not rely on material strain during growth, which results in a drastic improvement in dot symmetry. As a consequence, the average exciton FSS is reduced by more than a factor 4, which in turn increases the probability of finding a dot with FSS below 15 micro eV from less than 1 in 1000 to 1 in 10. Furthermore, we demonstrate that droplet epitaxy dots can be grown on the necessary surface (001) for high quality optical microcavities, which increases dot emission count rates by more than

an order of magnitude. Together, these properties make droplet epitaxy quantum dots readily suitable for the generation of entangled photons at telecom wavelengths.

10248-30, Session 6

3D flexible ZnO networks: synthesis and their multifunctional applications

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Superfast, flame transport synthesis method was recently introduced by Mishra et al.,[1] at Kiel University which offers very simple growth of ultra-large crystals of hexagonally shaped facets of ZnO micro- and nanostructures. Not only the efficiency of this method was quite high, but also the macroscopic interconnected semiconductor networks consisting of 3D shaped tetrapods could be produced in desired manner. By varying the synthesis parameters and precursor materials more modifications of the established method showed the growth results that allow the mixture, hybrid structure formation and functionalization of the existing networks. In the present work, the growth strategy for Ga, Al, doped and others hybrid structures of ZnO-SnO2 will be demonstrated and the effect of dopants on structure-property relations will be discussed in detail. Based on that the pronounce improvement in conductivity enhances the possible applications of the semiconductor networks. These tetrapods can also used as sacrificial template for the growth of new materials and the synthesis of extremely light weight and highly porous Aerographite tetrapods will be presented. Being hollow in nature, the Aerographite tetrapods can be used as better filler elements in contrast to conventional carbon nanotubes for fabricating various carbon-polymer composites[2-3] with enhanced mechanical and electrical properties.

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10248-500, Session Plen

Graphene technologies for bioelectronics and neuroprosthetics

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Establishing a reliable bidirectional communication interface between the nervous system and electronic devices is crucial for exploiting the full potential of neural prostheses. Despite recent advancements, current microelectrode technologies evidence important shortcomings, e.g. challenging high density integration, low signal-to-noise ratio, poor long-term stability, etc. Thus, efforts to explore novel materials are essential for the development of next-generation neural prostheses. Graphene and graphene-based materials possess a rather exclusive set of physicochemical properties holding great potential for biomedical applications, in particular neural prostheses. In this presentation, I will provide an overview on fundamentals and applications of several graphene-based technologies and devices aiming at developing an efficient bidirectional communication with electrogenic cells and nerve tissue. The main goal of this talk is to discuss pros and cons of graphene technologies for bioelectronics and neuroprosthetics, and at the same time to identify the main challenges ahead.

10249-1, Session 1

Co-integrating plasmonics with Si3N4 photonics towards a generic CMOS-compatible PIC platform for high-sensitivity multi-channel biosensors: the H2020 PlasmoFab project approach *(Invited Paper)*

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Silicon photonics meet most fabrication requirements of standard CMOS process lines encompassing the photonics-electronics consolidation vision. Despite this remarkable progress, further miniaturization of PICs for common integration with electronics and for increasing PIC functional density is bounded by the inherent diffraction limit of light imposed by optical waveguides. Instead, Surface Plasmon Polariton (SPP) waveguides can guide light at sub-wavelength scales at the metal surface providing unique light-matter interaction properties, exploiting at the same time their metallic nature to naturally integrate with electronics in high-performance ASPICs.

In this article, we demonstrate the main goals of the recently introduced H2020 project PlasmoFab towards addressing the ever increasing needs for low energy, small size and high performance mass manufactured PICs by developing a revolutionary yet CMOS-compatible fabrication platform for seamless co-integration of plasmonics with photonic and supporting electronic. We demonstrate recent advances on the hosting SiN photonic hosting platform reporting on low-loss passive SiN waveguide and Grating Coupler circuits for both the TM and TE polarization states. We also present experimental results of plasmonic gold thin-film and hybrid slot waveguide configurations that can allow for high-sensitivity sensing, providing also the ongoing activities towards replacing gold with Cu, Al or TiN metal in order to yield the same functionality over a CMOS metallic structure. Finally, the first experimental results on the co-integrated SiN+plasmonic platform are demonstrated, concluding to an initial theoretical performance analysis of the CMOS plasmo-photonic biosensor that has the potential to allow for sensitivities beyond 150000nm/RIU.

10249-2, Session 1

Polymer ring resonator based devices prepared by DLW

Daniel Jandura, Dušan Pudiš, Peter Gašo, Matej Goraus, Univ. of Žilina (Slovakia)

Over the past several years the polymer material has become very useful especially in field of microfluidics, soft lithography and sensing area. Its unique mechanical, chemical and optical properties are interesting for new devices in visible and near-infrared applications, especially different waveguide structures and tunable devices. In silicon photonics, Y-branch waveguide splitters, ring resonators and Mach-Zehnder interferometers play an important role especially in modern optical communication systems. Preparation of this devices with flexible properties was a challenge for polymer photonics. Polymer photonics is a field where polymer materials are used instead of semiconductor. One of the best advantages on polymer materials is flexibility. It means that structure shows unique elastic properties often allowing elongation more than 100%, what creates tunable devices with unique optical properties. The main idea of this paper is to show the fabrication method of waveguide structures and devices as ring resonators for different waveguide applications based on polymer material. We designed structures in CAD software and we used two-photon polymerization lithography system for preparation of desired devices. Morphological properties of prepared devices were investigated using SEM and confocal microscope. Finally, we performed the measurement of optical spectrum characteristics in telecommunication wavelengths range. The results corresponds to calculated parameters. Final polymer devices are promising for lab on a chip and sensing applications due to unique elastic and chemical properties.

10249-3, Session 1

Silicon photonics sub-wavelength structures for communications and sensing

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Silicon sub-wavelength structures have found widespread applications in devices ranging from fiber-to-chip couplers to spectrometers. So far, these structures have been mainly used to engineer the local refractive index. Here we focus on two further applications. We describe how to engineer the waveguide electromagnetic field distribution for enhanced evanescent field sensing, predicting a 6-fold enhancement of the sensitivity compared to conventional waveguides. We furthermore report experimental results on broadband multimode interference couplers, which, by leveraging the inherent anisotropy of the sub-wavelength structures, achieve virtually perfect operation over a bandwidth of more than 300nm at telecom wavelengths.

10249-4, Session 1

Silicon photonic sensor arrays with complex microfluidics for compact automated biosensing

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In order to enable point-of-care diagnostic systems, there is a need for highly sensitive and selective biosensors with integrated fluid handling to achieve quantitative measurements in a automated and reproducible manner.

The use of integrated photonics for label free bio-sensing applications allows highly sensitive detection, eliminating the requirement for bulky microscopes for analysis. It even allows dense integration of multiple sensors into the same device enabling more diverse and precise measurements.

In this paper we present integrated photonic devices which are interfaced with complex microfluidic systems. They allow precise control of the sample fluids, utilising on chip valves and pumps. The automated measurement system allows a high reproducibility of the acquired results, reduced working volume of reagents and increases assay sensitivity.

Our platform makes use of traditional photonic structures like Mach-Zehnder-Interferometers, harnessing integrated photonics to create long, spiralled sensing arms to enhance analyte photon interaction length; as well as novel resonant plasmonic structures with arrays of sub-wavelength nano-antennas to achieve field enhancement and an easily detectable

spectral band-gap.

We show two different approaches to build integrated biosensors with complex integrated fluid handling. Test measurement are done with Thiol modified Aptamers, which are designed to bind specifically to Kanamycin, as well as measurements of C-reactive protein (CRP) and Interleukin 6 (IL-6). The bonding event at the surface of the sensors will disturb the evanescent field, which can quantitatively interpreted via the transmission.

10249-5, Session 2

Phase array antennas with silicon photonics *(Invited Paper)*

Jérôme Bourderionnet, Thales Research & Technology (France)

No Abstract Available

10249-6, Session 2

Robust integration schemes for junction-based modulators in a 200mm CMOS compatible silicon photonic platform

Bertrand Szelag, Alexis Abraham, Stéphane Brision, Paul Gindre, Benjamin Blampey, André Myko, Segolene Olivier, Christophe Kopp, CEA-LETI (France)

Silicon photonic is becoming a reality for next generation communication system addressing the increasing needs of HPC (High Performance Computing) systems and datacenters. CMOS compatible photonic platforms are developed in many foundries integrating passive and active devices. The use of existing and qualified microelectronics process guarantees cost efficient and mature photonic technologies. Meanwhile, photonic devices have their own fabrication constraints, not similar to those of cmos devices, which can affect their performances.

In this paper, we are addressing the integration of PN junction Mach Zehnder modulator in a 200mm CMOS compatible photonic platform. Implantation based device characteristics are impacted by many process variations among which screening layer thickness, dopant diffusion, implantation mask overlay. CMOS devices are generally quite robust with respect to these processes thanks to dedicated design rules. For photonic devices, the situation is different since, most of the time, doped areas must be carefully located within waveguides and CMOS solutions like self-alignment to the gate cannot be applied. In this work, we present different robust integration solutions for junction-based modulators. A simulation setup has been built in order to optimize of the process conditions. It consist in a Mathlab interface coupling process and device electro-optic simulators in order to run many iterations. Illustrations of modulator characteristic variations with process parameters are done using this simulation setup. Parameters under study are, for instance, X & Y direction lithography shifts, screening oxide and slab thicknesses. A robust process and design approach leading to a pn junction Mach Zehnder modulator insensitive to lithography misalignment is then proposed. Simulation results are compared with experimental datas. Indeed, various modulators have been fabricated with different process conditions and integration schemes. Extensive electro-optic characterization of these components will be presented.

10249-7, Session 2

Strain-induced Pockels effect in silicon waveguides

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With the increasing demand of data, current chip-scale communication systems based on metallic interconnects suffer rate limitations and power consumptions. In this context, Silicon photonics has emerged as an alternative by replacing the classical copper interconnects with silicon waveguides while taking advantage of the well-established CMOS foundries techniques to reduce fabrication costs. Silicon is now considered as an excellent candidate for the development of integrated optical functionalities including waveguiding structures, modulators, switches... One of the main challenges of silicon photonics is to reduce the power consumption and the swing voltage of optical silicon modulators while increasing the data rate speed. However, silicon is a centrosymmetric crystal, vanishing the second order nonlinear effect i.e. Pockels effect which is intrinsically a high speed effect. To overcome this limitation, mechanical stresses on silicon to break the crystal symmetry can be used depositing a strained overlayer.

In this work, we have studied the effect of the stress layer in the modulation characteristics based on Mach-Zehnder interferometers. The deposition of silicon nitride as the stress layer and its optimization to induce the maximum effect will be presented.

10249-8, Session 2

Enhanced optical properties of GeSn photonic components by strain relaxation

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Interest is rising for GeSn alloys as a potential laser material for Mid-Infra-Red Silicon Photonics, due to their direct band-gap predicted emission1. Recently, a laser effect for Sn content between 10% and 12% at cryogenic temperatures was demonstrated2, thanks to the progress in GeSn growth by Chemical Vapor Deposition. The next step towards a fully CMOS compatible laser working at room temperature relies now in the strain control of GeSn layers.

Here, we studied the strain impact on optical properties for GeSn layers and micro-devices with Sn content ranging from 6% to 15%. First, by measuring the elastic stiffness coefficient for different Sn concentrations, we accurately determine the strain induced by epitaxial growth of GeSn with high Sn content, onto Ge substrates. We then use X-ray diffraction, Raman spectroscopy, photocurrent experiment and photoluminescence (PL) to measure the deformation and optical properties of 2D GeSn layers and patterned optical components. Using different layer thicknesses, we studied the influence of the compressive strain relaxation up to a full relaxation at the top surface for very thick layers (>400nm). This full relaxation modified PL properties of GeSn and this effect will be discussed. GeSn micro-devices with high Sn content were then fabricated to locally control the strain and by using a selective etching, we can get fully relaxed GeSn. Finally, we will compare the impact of strain on the PL properties to our theoretical predictions. Our results give a better understanding on the strain properties in GeSn devices with high Sn content for laser applications.

1 C.H.L. Goodman, Solid-State Electron Devices, 129 (5), pp. 189-192 (1982)

2 S. Wirths, Nat. Photonics 9, 88 (2015).

3 A. Gassenq, Appl. Phys. Lett. 107, 191904 (2015).

10249-23, Session PTue

Equalizing Si photodetectors fabricated in standard CMOS processes

Erick Guerrero Rodriguez, Javier Aguirre, Carlos Sánchez-Azqueta, Guillermo Royo, Univ. de Zaragoza (Spain); Cecilia Gimeno, Univ. Catholique de Louvain (Belgium); Santiago Celma Pueyo, Univ. de Zaragoza (Spain)

Fully integrated optoelectronic interfaces in CMOS technology are a very interesting option for optical smart sensors because they are a cost-effective and compact solution. However, CMOS standard n-well/p-bulk differential photodiodes (DPDs) are the bottleneck in this field due to their inherent limited bandwidth which falls below 10 MHz in 65 nm CMOS. This work presents a new equalization approach to enhance the bandwidth of CMOS integrated DPDs used in optical sensors. It is designed based on a split-path topology in which the gain and the boost are completely decoupled and can be externally adjusted by means of independent control voltages. This feature, particularly helpful for calibration, is not present in conventional equalizers based on the degenerated differential pair. The proposed equalization technique has been simulated in a 65 nm process, where it has been able to increase the bandwidth of the DPD up to 3 GHz with a single supply voltage of only 1.2 V.

Optical sensors have found extensive use in applications such as pressure or acceleration sensing, among others. For a correct measurement of most physical variables, bandwidth is not a limiting factor due to their slow variation rates. However, for high-resolution image sensing and optical sensor for receivers in communication systems, this is not the case. Typically, high-frequency optical sensors are external devices fabricated in expensive technologies such as GaAs and InGaAs. An attractive alternative in terms of cost-effectiveness, size and power consumption is the use of fully integrated optoelectronic circuits in CMOS technology, where joint integration of an array of DPDs in the same chip reduces mismatch between them. However, integrated DPDs in modern nanometer CMOS technologies is a challenging task due to the inherent limited bandwidth of around 10 MHz. A technique to overcome this severe limitation is to use continuous-time linear equalizers, most of which are based on the traditional degenerated differential pair, presenting a serious drawback for their tuning due to the strong dependency between the boosting and gain controls.

This work presents a new continuous-time linear equalization approach. It is based on gm-C high-pass filter architecture to orthogonally control the gain and boost, which simplifies the sensor calibration. The block diagram of the proposed equalizer is formed by four high-pass branches in parallel. Each high-pass filter has different boosting and gain, in such a way that their combination offers a 5 dB/decade roll-up that compensates the intrinsic roll-off of the DPD. The proposed equalizer enhance the bandwidth of the system in order to achieve multi-gigabit data rates. Finally, the the boost and the gain of the proposed equalizer can be adjusted separately, unlike the degenerated differential pair, obtaining a boosting range of 5 dB and a gain range of 5 dB.

10249-24, Session PTue

The increase in the starting torque of PMSM motor by applying of FOC method

Kamil Plachta, Wroclaw Univ. of Science and Technology (Poland)

The article presents a vector control method FOC (Field Oriented Control) of PMSM motor (Permanent Magnet Synchronous Motor). This method makes it possible to obtain similar characteristics for induction motor and DC motor while maintaining a broad range of torque adjustment and rotational speed. The article presents advanced method of increasing the starting torque of PMSM motor through the use of optical sensors. The inductive sensors was replaced by optical sensors because they have shorter time response to change the rotor position and greater resistance to temperature rise of stator windings. The simulation of starting torque for PMSM motor depending on the control method has been performed. In the motor controlled by the presented vector-controlled method the dead zone of starting torque was eliminated. The angle of the slope of characteristic was changed, which allows for a faster achievement of maximum torque. The value of the starting torque increased by 11% as compared to the standard control FOC method. An important parameter is the maximum value of inrush current. The value of which increases with the angle of slope of characteristics. One of the assumptions of the new control method was to limit the maximum inrush current. In case of the standard vector control method a greater value of the inrush peak current equal to 3.1A was obtained, as compared to the presented method. It causes the reduction of inrush current by approximately 5.6%. After reaching the nominal speed motor, the power consumption of the motor controlled by the new method is lower by 2.5% as compared to the standard control method. The use of optical sensors reduced the time response to change the rotor position. A wide range of torque and speed control reduces the maximum inrush current which ensures energy-efficient operation of the motor.

10249-25, Session PTue

Infrared wire-grid polarizer with sol-gel zirconia grating

Itsunari Yamada, Yoshiro Ishihara, Univ. of Shiga Prefecture (Japan)

Inexpensive infrared polarizers are desired in various applications. In this study, the infrared wire-grid polarizer consisting of an Al grating, Si, and sol-gel derived zirconia grating film was fabricated by soft imprint process and Al shadow coating processes. A silicone mold was used because of its low surface energy, flexibility, and capability of transferring submicrosized patterns.

After the sol was dropped on the silicone mold, a Si plate was placed on this mold. The Si plate was placed on the mold filled with zirconia sol. After placing this substrate on the mold, it was heated from room temperature to 150°C. The silicone mold was peeled off from the molded grating. After demolding, the diffraction light from the silicone mold was observed.

The Al grating with a pitch of 400 nm and a depth of ~100 nm was obtained on the zirconia grating film. The fabricated polarizer exhibited a polarization function with the TM transmittance greater than that of the Si substrate in the 4.2–5.3 μm wavelength range, because the zirconia film acted as an antireflection film. The maximum value was 63% at a wavelength of 4.7 μm. Also, the extinction ratio exceeded 20 dB in the 2.5–7.8 μm wavelength range.

This experiment verified that imprinting onto a sol is very effective for the low-cost fabrication of infrared polarizers. This wire-grid polarizer has significant potential in various application areas such as ellipsometry, spectroscopy, and security imaging.

10249-26, Session PTue

Diffusion doped p-i-n/p-n diodes for scalable silicon photonics devices

Riddhi Nandi, Sreevatsa R. Kurudi, Bijoy K. Das, Indian Institute of Technology Madras (India)

Rib waveguides integrated with p-i-n/p-n diodes play an important role in silicon photonic devices such as on-chip Raman laser, two-photon absorption based photodetector, variable optical attenuator, phase-shifter and modulator. All these integrated optical devices can be designed with their own optimized waveguide cross-sectional geometry and dimensions. Therefore, it would be beneficial to have pre-defined p-i-n/p-n diodes in a given silicon-on-insulator (SOI) substrate suitable for large-scale monolithic integration of various passive and active waveguide devices. The implantation used for doping p and n regions for higher junction depths would require higher acceleration voltage and can damage the

crystal quality and increase leakage current. On the other hand by using deeper diffusion doping of a micron device layer SOI and later etching of silicon for the optimum device geometry enable monolithic integration of different photonic components. In this paper, we analyze the fabrication of a p-n diode by doping first approach and later etch silicon to make waveguide structure. We present step-by-step simulation studies of fabrication processes along with the electrical and optical simulations for design optimization.

Simulations have been done in Synopsys Taurus TSUPREM4 process simulator to optimize the temperature and duration for diffusion by varying the gap between the diffusion windows. Once the diffusion profile is obtained, the exact location of the metallurgical junction is found and electrical and optical simulations were done in Lumerical DEVICE and MODE solutions to position the rib which gives the maximum change in effective index with applied bias. For a final device layer of 250 nm after performing a blanket etching,we obtained a VϖL of ~ 1 V.cm and junction capacitance of ~ 1 fF/μm at 0 V, which is comparable to that reported using ion-implantation. Preliminary fabrication results are also reported.

10249-27, Session PTue

Development of a fast steering mirror of large diameter

Byoung-Uk Nam, Hakin Gimm, Jung-gon Kim, Gwang tae Kim, Byung-un Kim, Agency for Defense Development (Korea, Republic of)

A Fast Steering Mirror of 160mm diameter has been designed, built and tested. In order to make continuous tracking ability without loss of target image, a FSM should be equipped with a large scale mirror for a wide field of view and require a high control bandwidth to reduce the tracking error. Therefore, one of the challenging issues is to guide the mirror in the intended directions with the required fast response and the high degree of accuracy, and this is true even for a heavy and large mirror. Special care was taken to purely rotate about the tip and tilt directions in 3D space, handling a large and heavy payload, and can flexibly adjust the rotation of moving body to a desired location in the system. A flux-biased normal stress electromagnetic actuators have been successfully employed in the FSM which have higher force densities than shear-stress electromagnetic actuator(Lorentz-force type actuators) and offer larger actuating strokes than piezoelectric actuators. Finally, this device steers a large aperture mirror about two axes, though an operating range of 1mrad and a small-signal closed-loop bandwidth up to 500Hz which is greater than the structural resonance.

10249-28, Session PTue

Polymer based 3D photonic crystals applied on the surface of LEDs and photodiodes

Dušan Pudiš, Matej Goraus, Univ. of Žilina (Slovakia); Marek Tlaczala, Wroclaw Univ. of Science and Technology (Poland); Peter Gašo, Univ. of Žilina (Slovakia); Jaroslav Kováš Jr., Slovenska Technicka Univ. (Slovakia); Wojciech A. Dawidowski, Wroclaw Univ. of Science and Technology (Poland); Daniel Jandura, Univ. of Zilina (Slovakia); Lubos Šušlik, Jana Durisova, Ivana Lettrichova, Univ. of Žilina (Slovakia); Beata Sciana, Wroclaw Univ. of Technology (Poland)

Unique optical properties of photonic crystals (PhCs) cause the effects, which are interesting in applications in optoelectronic devices. Especially, effects on the emission properties of light emitting diodes (LEDs) were recently intensively studied from the point of view of an improvement of extraction efficiency and modification of radiation pattern. Wavelength and directional selective optical properties may be interesting also in solar cells and photodetectors.

In this paper, we propose concept and method for fabrication and application of 2D and 3D PhC prepared in polydimethylsiloxane (PDMS) membranes for application in LEDs and photodiodes. By photoresist patterning and PDMS embossing and its application on the LED and photodiode surface one can achieve unique optical properties. PhC PDMS structures applied in the LED and photodiode surface can modify its directional and spectral optical properties.

We used interference lithography and direct laser writing lithography for thin photoresist layer patterning in combination with PDMS embossing technique. 2D and 3D PhC structures of different period and symmetry were patterned in photoresist and thin PDMS membranes. The LED and photodiode optical characteristics were investigated in spatial angular measurement using goniophotometer.

Results presented in this paper document the interesting effect of 2D and 3D PhC structures based on PDMS membranes, what may be highly attractive for improvement optical properties of photodetectors and LEDs.

10249-29, Session PTue

Modification of LED radiation pattern by implementation of 1D Fresnel structure in the surface

Ivana Lettrichova, Dušan Pudiš, Univ. of Žilina (Slovakia); Agáta Laurencíková, Institute of Electrical Engineering SAS (Slovakia); Peter Gašo, Lubos Šušlik, Daniel Jandura, Univ. of Žilina (Slovakia); Jozef Novak, Slovak Academy of Sciences (Slovakia)

This contribution presents modification of far field of LED by implementing one dimensional (1D) and two dimensional (2D) Fresnel structure in surface emitting part of the LED. The structure consists of drilled lines distributed with square root of distance in order to obtain structures with different foci – f1 = 12,5 μm, f2 = 1 cm and f3 = 3 cm. The structures were prepared in the surface of thin PDMS membrane that can be stack directly on the emitting surface. The membrane is fabricated using dip in laser lithography combined with PDMS embossing. The mold was patterned via dip in laser lithography (DiLL) using the Nanoscribe Photonic Professional 3D lithography system, where glass slide with a drop of liquid IP-Dip photoresist is used as a substrate. Examples of prepared 1D and 2D Fresnel structures with focus f1 = 12,5 μm are shown in Fig. 1a and Fig. 1b, respectively. After embossing the mold into PDMS membrane, this was directly applied on the emitting part of the LED. Similar structures were prepared by electron beam lithography directly in the LED emitting surface. Implementation of such Fresnel structures leads in modification of LED far field what was proved by goniophotometer measurements.

10249-30, Session PTue

Photonic integrated circuit based on 1x2 multimode-interferometer-Fabry-Perot laser diode

Hua Yang, Mingqi Yang, Alison Perrott, Zhengkai Jia, Tyndall National Institute (Ireland); Frank Hudson Peters, Tyndall National Institute (Ireland) and Univ. College Cork (Ireland)

No Abstract Available

10249-9, Session 3

Mid- and near-IR silicon waveguides for sensing applications *(Invited Paper)*

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Vakarin, Elena Durán-Valdeiglesias, Diego Pérez-Galacho, Eric Cassan, Delphine Marris-Morini, Universite Paris Sud, Paris Saclay C2N (France); Pavel Cheben, National Research Council (Canada); Laurent Vivien, Universite Paris Sud, Paris Saclay C2N (France)

The large transparency window of silicon (1.1 - 8 μm wavelength range) makes it a promising material for the implementation of on-chip sensors operating over an ultra-wide wavelength range. However, the implementation of the silicon-on-insulator platform is restricted by the absorption of buried oxide layer for wavelengths above 4 μm. Here, we report our advances in development of silicon waveguides for broadband operation extending from near- to mid-infrared wavelengths. We present suspended silicon waveguides that exploit a novel periodic corrugation approach to circumvent the buried oxide absorption problem and provide effective single mode operation simultaneously for near- and mid-infrared wavelengths.

10249-10, Session 3

High sensitivity liquid sensing by optimized slot photonic crystal ring resonator

Reyhaneh Jannesary, Johannes Kepler Univ. Linz (Austria); Thomas Grille, Ursula Hedenig, Infineon Technologies Austria AG (Austria); Bernhard Jakoby, Johannes Kepler Univ. Linz (Austria)

In this work, we present a design to enhance absorption of light by a fluid analyte being in contact with photonic crystal ring resonator (PCRR). For this purpose, we propose a new PCRR with higher interaction between guided mode and analyte. A PCRR can be formed by introducing a cavity in the crystal grid in an equilatral hexagonal shape. The cavity is created by removing elements from the regular PhC grid. These types of PCRRs are based on 2D photonic crystals, which consist of an array of holes in silicon slab in a hexagonal lattice. The holes will be filled with liquid analyte. The lattice constant and radius of the holes are tuned to obtain a resonance peak in desired frequency range. The ring size can be adjusted to the desired resonance frequency. A slot is embedded in this hexagonal ring cavity to create a slot-PCRR. The strong confinement of light in the low index region is the key advantage of the slott- PCRR.

We also calculate the relative intensity change in the transmission spectrum due to the absorption in the analyte. The maximum change obtained is given by a mode which has most of the electromagnetic field energy in the region of low-index, i.e. the region filled with the analyte. Furthermore, this mode is well separated from neighboring bands, which has the advantage that impinging light with specified frequency has less possibility to couple to other modes with the same frequency, which would spuriously decrease the amount of energy coupled to desired mode. The slot-PCRR yields a higher relative change due to absorption compared to the PCRR without a slot. In this work, the radius of 6 rods at the outer PhC, were tuned to enhance the quality factor of slot-PCRR; using these optimum values of radii, the Q-factor rises up to 80000.

10249-11, Session 3

3D ring resonator prepared by laser lithography embedded in PDMS

Peter Gašo, Daniel Jandura, Dušan Pudiš, Ivana Lettrichová, Univ. of Žilina (Slovakia)

Three-dimensional (3D) printing technology based on two photon polymerization (TPP) satisfy requirements on complexity, precision and possibility to prepare complex 3D structures. It provides a number of advantages for additive manufacturing of polymer parts with dimensions ranging from a few microns up to the millimeter scale.

Principle of DLW system is based on deflection of focused laser beam. Laser beam is scanned in plane by high resolution galvanometer mirror system. One layer is prepared by this way. The movement in z-axis using motorized micro stage allows preparation of complex micro 3D structures layer by layer directly inside the photosensitive medium.

The desired structure is designed using CAD tool,then export to STL format. Process of design is finalized using Describe software. It is used to define thickness of layers, number of contours, laser power and scan speed.

As a substrate is used special fused silica glass slide. The liquid unexposed IP-Dip photoresist was dropped on substrate and the sample was turned vice versa. In this position remained during whole printing process. The DLW by itself is carried out by focusing the writing laser into the photoresist. After printing, the sample is removed from the sample holder and developed in propylene glycol methyl acetate ether (PGMAE) for 15 minutes.. The sample was finally rinsed in isopropanol.

Prepared structure is embedded in polydimethylsiloxane (PDMS). PDMS is widely used silicon-based organic polymer, and is particularly known for its unusual rheological (or flow) properties. It is optically clear, and is generally considered to be inert, non-toxic and non-flammable. Its applications range from contact lenses and medical devices to optoelectronics. PDMS forms cladding of prepared waveguide and is used like mechanical support for prepared structure too.

10249-13, Session 4

Towards an integrated squeezed light source *(Invited Paper)*

Tobias Gehring, U. Busk-Hoff, Technical Univ. of Denmark (Denmark); Timur Iskhakov, Technische Univ. Delft (Denmark); Ulrik Lund Andersen, Technical Univ. of Denmark (Denmark)

Accurate parameter estimation plays a pivotal role in basic as well as applied sciences. The ultimate precision limits in the estimation procedure are dictated by the quantum fluctuations of the probing state. E.g. by using coherent states, the precision scaling is 1/Sqrt(N) while for NOON states the scaling is 1/N where N is the number of probing photons. The latter is the ultimate scaling known as the Heisenberg scaling. In this presentation, we show experimentally that the Heisenberg scaling can be attained also by the use of squeezed states of light. This is an important result as the squeezed state is much easier to produce and much more robust against losses than the NOON state. We also discuss our recent work on miniaturizing squeezed states sources, towards quantum sensing on-chip.

10249-14, Session 4

Optical signal processing and tracking of whispering gallery modes in real time for sensing applications

Amir R. Ali, The German Univ. in Cairo (Egypt) and Southern Methodist Univ. (United States); Amr N. Afifi, The German Univ. in Cairo (Egypt) and Sapienza Univ. di Roma (Italy); Hazem Taha, The German Univ. in Cairo (Egypt)

A novel approach for tracking of whispering gallery modes (WGM) in real-time for dielectric cavities used in sensing application is presented in this paper. Real-time tracking for the shifts of the WGM can be used to measure the physical quantity of interest precisely, under high repetition rates. The tracking algorithm is based on cross-correlation signal processing technique which has been proved to be accurate in WGM shifts detection. In order to achieve portability, the aforementioned real-time algorithm is implemented using a single-board re-configurable input-output hardware. The hardware platform used combines a real-time processor and a field programmable gate array (FPGA), it also allows for data exchange between them. The tracking algorithms accuracy and real-time behavior is verified by preforming simulations based on experiments conducted on the dielectric cavity, where the cavity is used as a force sensor measuring mechanical compression. The light from a laser diode

is tuned with rates up to 10 kHz and then tangentially coupled into the cavity to excite the WGM. Results show that shifts of the WGM are tracked by the algorithm providing real-time force readings.

10249-15, Session 4

Noninvasive monitoring and control in silicon photonics *(Invited Paper)*

Andrea Annoni, Douglas Oliveira De Aguiar, Andrea Melloni, Emanuele Guglielmi, Marco Carminati, Giorgio Ferrari, Politecnico di Milano (Italy); Annika Buchheit, Hans-Dieter Wiemhöfer, Marina Muñoz-Castro, University of Münster (Germany); Charalambos Klitis, Marc Sorel, University of Glasgow (United Kingdom); Francesco Morichetti, Politecnico di Milano (Italy)

No Abstract Available

10249-16, Session 5

Integrated photonics for infrared spectroscopic sensing *(Invited Paper)*

Hongtao Lin, Derek Kita, Zhaohong Han, Peter Su, Anu Agarwal, Massachusetts Institute of Technology (United States); Anupama Yadav, Kathleen Richardson, University of Central Florida (United States); Tian Gu, Juejun Hu, Massachusetts Institute of Technology (United States)

Infrared (IR) spectroscopy is widely recognized as a gold standard technique for chemical analysis. Traditional IR spectroscopy relies on fragile bench-top instruments located in dedicated laboratory settings, and is thus not suitable for emerging field-deployed applications such as in-line industrial process control, environmental monitoring, and point-of-care diagnosis. Recent strides in photonic integration technologies provide a promising route towards enabling miniaturized, rugged platforms for IR spectroscopic analysis. Chalcogenide glasses, the amorphous compounds containing S, Se or Te, have stand out as a promising material for infrared photonic integration given their broadband infrared transparency and compatibility with silicon photonic integration. In this talk, I will review our work exploring integrated chalcogenide glass based photonic devices for IR spectroscopic chemical analysis. Some recent highlights include the first demonstration of on-chip cavity-enhanced mid-IR sensing and a mid-IR waveguide integrated photodetector monolithically processed on a silicon platform.

10249-17, Session 5

Characterizing the geometrical tolerances of optimized vertical-cavity thermal emitter stack configurations for the mid-infrared via Monte Carlo testing

Gerald Pühringer, Bernhard Jakoby, Johannes Kepler Univ. Linz (Austria)

We test the recently devised design of vertical-cavity enhanced resonant thermal emitter regarding stability to fabrication tolerances of PVD layer deposition techniques. Such an emitter is composed of an aperiodic multilayer stack of dielectric layers (silicon and silica) on top of a reflective metal (silver) structure. The silica layer above the metal acts as a vertical cavity enhancing the electromagnetic field between the reflective metal and the dielectric stack forming a Bragg mirror (1-D photonic crystal). The individual dielectric layer depths were optimized by a genetic-algorithm (GA) in order to achieve coherent and narrowband thermal emission. Various stack configurations featuring different constraints on maximum layer thickness were designed, exhibiting different behavior under random layer depth deviations. In order to examine this behavior, a Monte-Carlo algorithm was used to apply a Gauss-distributed error in depth for every individual layer. Shifts of the resonance frequencies and a decrease of the emissivity at resonance reflecting instability against fabrication errors were evaluated. It is revealed, for example, that an increase of the layer number or the layer thicknesses does not significantly change the variations in resonance frequency. In contrast, configurations with higher average layer thickness have a higher risk of a significant decline of emission performance at resonance. On the other hand, the possibility of thicker layers favors the goal of narrowband and directional emission. As a result, two designs with five and seven thin dielectric layers, respectively, are found, which provide a good compromise between narrowband, coherent emission (at a target wavelength of 4.26 μm) and robustness against fabrication constraints.

10249-18, Session 5

N-type induced junction black silicon photodiode for UV detection

Mikko A. Juntunen, Juha Heinonen, Hannu S Laine, Ville Vähänissi, Päivikki Repo, Anna Vaskuri, Hele I. Savin, Aalto Univ. (Finland)

Silicon photodiodes are used in vast field of applications with a specific subgroup of applications where ultraviolet light is used. When illuminated, a photodiode generates an output which is proportional to light level with excellent linearity over several decades of light intensity.

The performance of photodiodes is limited by both reflectance of incoming light and recombination of generated charges before they get collected to external circuit. The most important recombination modes are surface recombination and auger recombination in doped region forming the diode pn-junction. These phenomena are particularly harmful for ultraviolet detection since ultraviolet is absorbed and charge carriers generated at the very top of the structure, within the doping region. Therefore many of the present day photodiodes exhibit relatively poor UV response.

To overcome these limitations, N-type induced junction photodiodes were developed with atomic layer deposited aluminum oxide surface layer. The oxide layer carries negative oxide charge high enough to generate an induced junction on n-type silicon, thus removing the need of using doping for charge collecting junction formation. Simultaneously, excellent surface passivation was achieved. Additionally, very low reflectance and even higher effective charge was achieved by using surface microstructuring, i.e. black silicon.

Sample photodiodes were manufactured in the facilities of Micronova Nanofabrication Center in Espoo, Finland. External quantum efficiency exceeds 96% over the whole measured wavelength range of 250 to 950 nm and over 100% in wavelengths below 300 nm. Particularly the ultraviolet response is extremely high, clearly exceeding that of commercially available photodiodes.

Such high quantum efficiency photodiodes can potentially be utilized in applications where losses are significant, like for example various calibration purposes. One example of potential applications is Predictable Quantum Efficient Detector. The authors are now proceeding towards measuring the response of these diodes deeper into UV to assess their usefulness in various UV applications.

10249-19, Session 5

Millimeter wave photonic emitter using antenna-integrated UTC photodiode on Si lens

Muhsin Ali, Univ. Carlos III de Madrid (Spain); Longfei Shen, Technische Univ. Eindhoven (Netherlands); Robinson C. Guzmán Martínez, Mu-Chieh Lo, Alejandro Rivera, Univ. Carlos III de Madrid (Spain); Jos J. G. M. van der Tol, Technische Univ. Eindhoven (Netherlands); Luis

Enrique García Muñoz, Guillermo Carpintero, Univ. Carlos III de Madrid (Spain)

Millimeter waves (mmWave, 30-300GHz) have long been used for specific applications such as military radar, security scanners, imaging and radio astronomy [1], [2]. However in recent years there is increasing attention towards using mmWaves for wireless communication purposes. The radio-over-fiber technology has ability to provide speeds of multi-gigabits to user-end level, and can replace fiber links for mobile fronthaul/backhaul [3]. Microwave photonics is the promising technology for photonic generation carrier frequencies in mmWave range, overcoming the problems encountered in electronic signal generation. It has opened up new dimensions of research for a number of fields like photodiode, antenna designing and photonic integration techniques.

One of the main issues in utilizing photonics for generating mmWaves and THz waves is output power and bandwidth provided by photodiode. The InP-based uni-traveling carrier photodiode (UTC-PD) is one of the promising structures that provides high speed and power operations that make it suitable for continuous wave generation [4]. Photonic integration method is also the important factor in order to minimize the signal loss that result from interconnections between PD and antenna. For that purpose, self-complementary antennas are preferred due to their ease of integration as well as wide-band operation [5].

In this paper we demonstrate a robust mmWave photonic emitter consisting of InP PD monolithically integrated with planar antenna. We have fabricated a novel type of InP-based UTC-PD bonded on silicon (Si) using heterogeneous integration method. All photonics components are formed in InP membrane and Si wafer is used as carrier wafer to carry the integrated components. The 3x10 μm2 PD exhibits a 3dB bandwidth of beyond 67GHz which is highest value reported in heterogeneously integrated PDs on silicon. The responsivity of PD is 0.7 A/W at 1.55 μm. Furthermore, using silicon wafer as substrate helps achieve antenna miniaturization. For sack of performance comparison three self-complementary antennas are grown on PD structure including bowtie, logarithmically periodic and spiral antenna. A hyper-hemispherical Si lens is used for focusing and radiating the electromagnetic radiation. The directivity achieved for all three antennas is around 27dBi. The characterization is done in frequency range of DC-110 GHz.

10249-20, Session 5

Design and fabrication of broadband long wavelength resonator-quantum well infrared photodetectors

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ABSTRACT

Resonator-Quantum Well Infrared Photo detectors (R-QWIPs) are the next generation of QWIP detectors that use resonances to increase the quantum efficiency (QE). Recently, we are exploring R-QWIPs for broadband long wavelength applications. To achieve the expected performance, two optimized inductively coupled plasma (ICP) etching processes (selective and non-selective) are developed. Our selective ICP etching process has a nearly infinite selectivity of etching GaAs over Ga1-xAlxAs. By using the etching processes, two format (1Kx1K and 40x40) detectors with 25 μm pixel pitch were fabricated successfully. In despite of a moderate doping of 0.5 ? 1018 cm-3 and a thin active layer thickness of 0.6 or 1.3 μm, we achieved a quantum efficiency 35% and 37% for 8 quantum wells and 19 quantum wells respectively. The temperature at which photocurrent equals dark current is about 66 K under F/2 optics for a cutoff wavelength up to 11 μm. The NE?T of the FPAs is estimated to be 22 mK at 2 ms integration time and 60 K operating temperature. This good result thus exemplifies the advantages of R-QWIP.

10249-21, Session 5

Tunable multiple peak modulation in multi-cavity-coupled graphene-based waveguide system

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Plasmonically induced transparency (PIT) in a multi-cavity-coupled graphene-based waveguide system is investigated theoretically and numerically. By using the finite element method (FEM), not only multi-mode can be achieved, but also a blue shift is exhibited by altering the chemical potential of the monolayer graphene dynamically. By investigating carefully such a structure, we find that the increasing number of the graphene rectangle cavity (GRC) placed above the guided graphene waveguide (GGW) gives rises to the PIT peaks. Importantly, we find that the PIT peaks reduce to one when the distance between the center of the third cavity and the center of the second one is 100 nm. Easily to be fabricated, this graphene-based waveguide system has many potential applications for the advancement of 3D ultra-compact, high-performance and dynamical-modulation PIT devices.

10249-22, Session 5

A graphene-based electrically controllable directional coupler

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We proposed a near lossless, compact, electrically modulated vertical directional coupler, which is based on the controllable evanescent coupling in the previously proposed graphene-assisted total internal reflection (GAFTIR) scheme. In the proposed device, two single-mode waveguides are separate by graphene-SiO2-graphene layers. By changing the chemical potential of the graphene layers with a gate voltage, the coupling strength between the waveguides and hence, the coupling length of the directional coupler is controlled. Therefore, for a fixed properly chosen device length, when input wave is launched into one of the waveguides, the ratio between two output powers of the devices can be controlled electrically. The designed compact 3?m by 1?m device achieved less than 0.11dB insertion loss and 24dB extinction ratio between bar- and cross-states. The proposed low loss device could enable integrated modulation of strong optical signal without thermal buildup.

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