PHOTOMASK

BACUS—The international technical group of SPIE dedicated to the advancement of photomask technology.

SPIE Photomask Technology

A New Generation Cost-efficient Laser Mask Writer, addressable up to the 90nm node

Robert Eklund, Mats Rosling, Mikael Wahlsten, Martin Glimtoft, Göran Hansson, and Anders Svensson, Mycronic AB, Nytorpsvägen 9, 183 03 Täby, Box 3141, Sweden

Youngjin Park, Mycronic Co., Ltd., 3rd floor Jungsan-bldg 162 LS-Road, Gunpo-si, Gyeonggi-do, 15808 South Korea

ABSTRACT

The semiconductor industry is enjoying the "Semiconductor super cycle" catalyzed by the pandemic. In addition, the variety of semiconductor chips are increasing driven by electronification of everything results in increased demand for laser based mask writers due to low exposure cost per mask. However, many laser mask writers in operation today are getting old.

As a response to the growing demand Mycronic introduced SLX series, a new generation cost-efficient laser mask writer and the superiority of the system is demonstrated by sharing recent evaluation data with two different laser sources.

1. Introduction

The semiconductor market has seen a 6.8 percent growth in last year and is expected to grow to USD 551 billion in 2021, which represents a growth-rate of 25.1 percent. For year 2022, the global semiconductor market is forecasted to grow by 10.1 percent to USD 606 billion.[1] Part of that growth is catalyzed by the pandemic, and at the same time, the number of semiconductor chips in each electronic device is increasing. One example seen in automotive industry is that automotive electronics are already accounting for around 40% of a car's manufacturing cost. Furthermore, during the last few years, semiconductor technology has taken new directions. Heterogeneous integration is one of new trends fueled by electronification of everything – from IoT, edge computing, consumer goods to automotive devices – and drives the demand for photomasks of

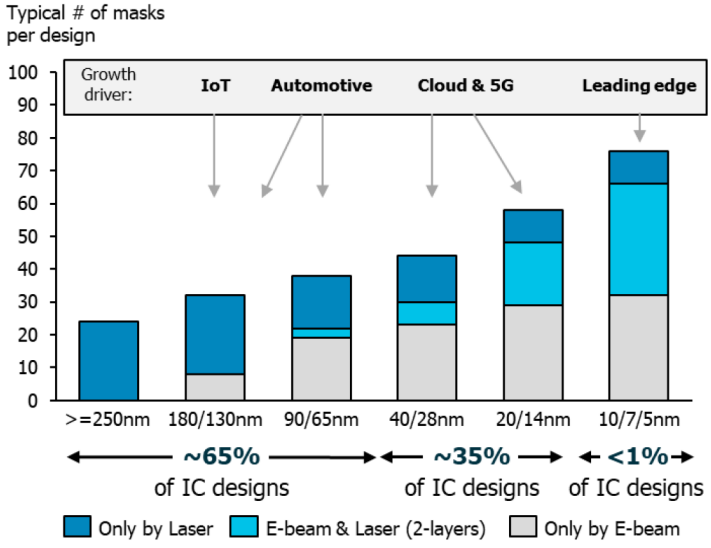

Figure 1. Number of masks by semiconductor nodes and applications/pattern generator technology types[2].

BACUS NEWS

JUNE 2022
VOLUME 38, ISSUE 6

TAKE A LOOK INSIDE:

SPIE.

11855-21

EDITORIAL

Welcome Back!

Eric Panning, Intel Principal Engineer

I am writing this from the San Jose Convention Center at SPIE Advanced Lithography + Patterning 2022. The last face-to-face meeting with this profile was held in February 2020 on the eve of a broad and sustained interruption in worldwide travel in response to Covid-19. It was a tough call for many companies to attend SPIE that year given the uncertainty on how bad it would be. 2021 was virtual during what was then a raging worldwide pandemic with wider access to vaccines just starting. 2022 pushed from February to April in response to Omicron, but the commitment to meet FTF this year was unchanged.

I am happy to report that SPIE Advanced Litho was an engaging conference with excellent talks, dialogue, and opportunities to re-engage in person. For some, this was re-connecting with suppliers and customers, but for quite a few people this has meant finally seeing colleagues at their own company. Some have met their manager in person for the first time!

Overall SPIE AL'22 attendance was ~1300, smaller than the years past, but the energy and engagement of the audience was inspiring. The enthusiasm during talks and in the halls was obvious with much to be proud of as a community. The patterning community has delivered with continued growth in advanced patterning technology innovation as well as deployment of new tools, materials, and techniques.

We know the importance of semiconductors and the patterning of semiconductors to the world around us. The world is also waking up to this with significant efforts now underway worldwide to increase capacity, capability, and enable the next generation of experts. Collectively, we can all do a better job to attract and retain the best and brightest in their fields.

Keeping progress on track was not luck – or just good project plans. This was the result of a community that knows how to work together to achieve big goals despite the unexpected. Global supply chain challenges have tested timelines, relationships, and contingency plans - we are still collectively seeing broad impacts and responding with new solutions.

The mask industry has delivered certainty and yield enabling pattern fidelity for a broad range of wavelengths. The mask industry is supporting critical gaps in all technology nodes as well as evolving capabilities and processes to enable the future. At this conference, we learned of the progress made in developing mask infrastructure to support high-NA lithography as well as the increasing capacity in multibeam mask writing to support EUV critical layers – on track for 50 tools in the field by the end of the year.

I am proud to be part of this community and looking forward to seeing everyone face-to-face during the SPIE Photomask Technology + EUV Lithography conference, Sept 25th to 28th in Monterey, CA.

BACUS

N • E • W • S

BACUS News is published monthly by SPIE for *BACUS*, the international technical group of SPIE dedicated to the advancement of photomask technology.

Managing Editor/Graphics Linda DeLano
SPIE Sales Representative, Exhibitions, and Sponsorships Melissa Valum
BACUS Technical Group Manager Tim Lamkins

SPIE.

P.O. Box 10, Bellingham, WA 98227-0010 USA
Tel: +1 360 676 3290
Fax: +1 360 647 1445
SPIE.org
help@spie.org

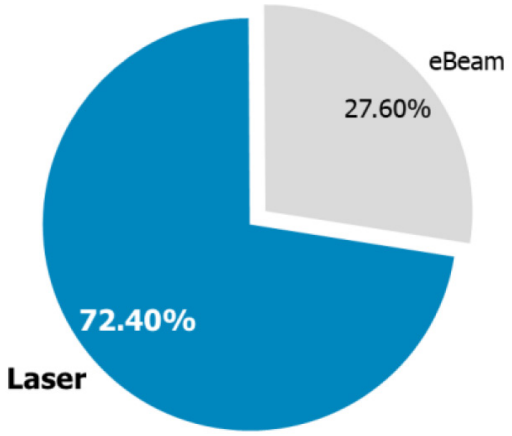

Figure 2. Photomask distribution by pattern generator technology type[2].

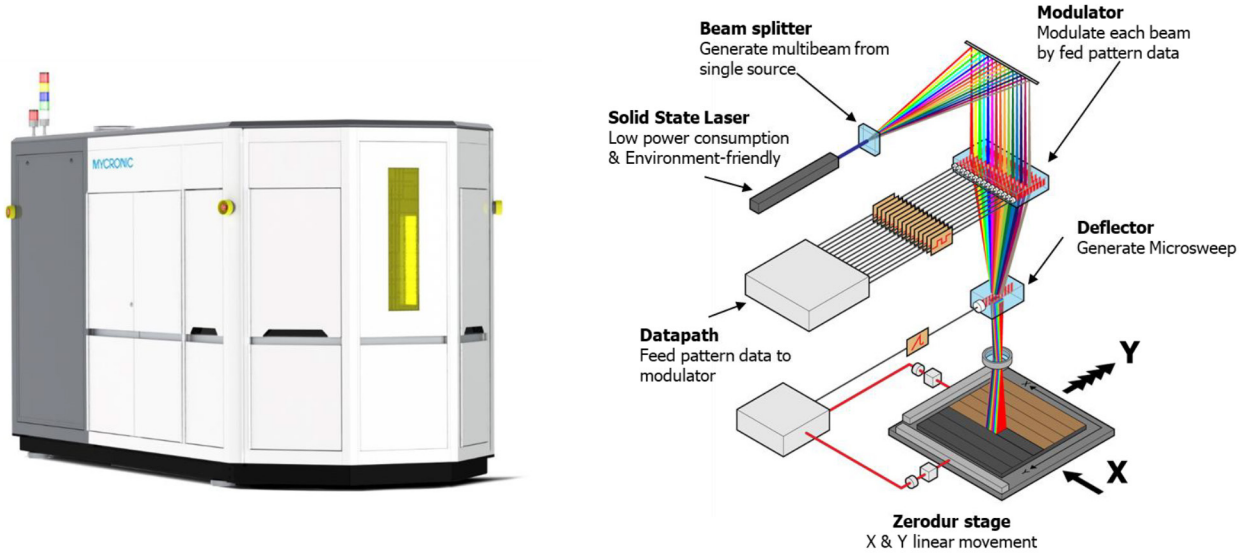

Figure 3. The physical SLX system and schematic of the writing strategy.

mature design nodes due to larger variety of designs required combined with price-sensitive volume manufacturing.

1.1 Photomask pattern generator technologies and semiconductor nodes

eBeam and laser are well established technologies to produce photomasks for semiconductor. Each technology is used for different purposes. For example, eBeam has advantages to expose with high resolution with great pattern fidelity. However, the throughput is slow thus exposure cost per mask is high. In order to improve the throughput of eBeam mask writers, a new multibeam writer was introduced, which enabled write times of around 10 hours regardless of pattern complexity, in contrast to VSB (Variable Shaped Beam) eBeam writers, where write time is pattern dependent. However, still the exposure cost per mask is too high to cover low to mid end nodes masks. Laser based technology, on the other hand, has advantages in throughput while the resolution is low compared to eBeam technology. Consequently, it has limited use for high-end mask production but as long as it fulfills the requirements, laser-based technology is the preferred choice due to the throughput advantage. Laser mask write time is only a few hours.

Semiconductor chip is produced in different technology nodes depending on application. The number of masks required depends on technology node and it increases with technology node. Looking at a typical distribution of masks in various design nodes, masks produced with laser-based technology are widely used in all nodes even in the leading edge. See Figure 1.

1.2 Laser mask writer, the backbone of semiconductor industry

In year 2019, around 600,000 masks were produced in the world and over 70% of those were written by laser-based mask writers[2], Figure 2. Laser mask writers are the preferred choice over eBeam, as long as they meet the required specification, due to cost.

There are other trends in the industry, so called “More-than-Moore”, that increases the demand for laser masks since other parameters than miniaturization of transistors are important in these applications. Examples are RF, power electronics and MEMS.

New mask writers are normally developed for the leading-edge nodes, and older equipment takes care of the lower nodes. However, the existing fleet of laser writers are typically more than 15 years old, and it is challenging to keep these systems running.

2.The SLX Series

Mycronic has been providing mask writers for photomask manufacturing in several fields of application. These include display manufacturing, production of semiconductors and applications in the multi-purpose market,

Table 1. Key specifications of SLX series. Based on 1 pass writing.

	SLX 1	SLX 2	SLX 3
Writing speed*	~20 minutes	~30 minutes	~56 minutes
Minimum Line Width	700 nm	550 nm	400 nm
CD Uniformity (3α)	35 nm	20 nm	20 nm
CD Linearity (range)	40 nm	25 nm	20 nm
Registration (3α)	40 nm	30 nm	30 nm

* Estimate exposure time for 6" mask with area 150mm x 150mm

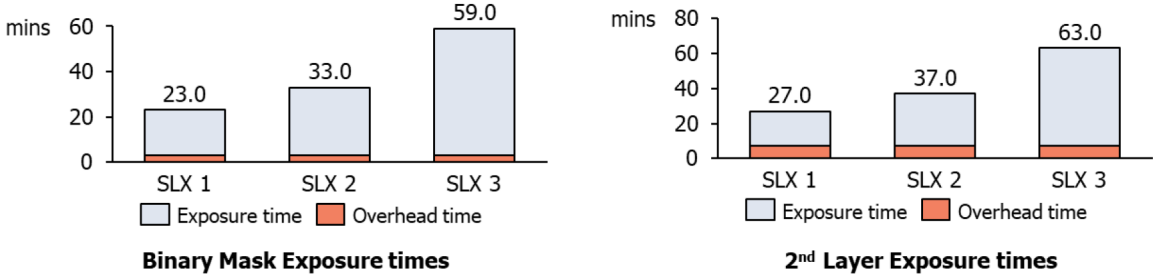

Figure 4. Total turnaround time between SLX models (Full 6" mask writing with 1 pass).

a broad segment that comprises several different areas of application, like micro-optics and packaging. With this experience and built-up knowhow Mycronic decided to develop a new line of laser-based mask writers, the SLX series, to meet the growing demand and to replace the aging fleet of legacy writers. The SLX series are built on field proven modern platform that shares the same technology from all other mask writer from Mycronic. Therefore, SLX system's modern design, performance, productivity and reliability provides an attractive solution for mask shops.

2.1 SLX design and writing principle

Figure 3 shows the physical appearance of SLX system. To the right is a schematic showing the architecture of the SLX system. The SLX system uses SSL (Solid State laser) to cut down power consumption. The laser beam is split into several by the beam splitter and the datapath provides pre-processed rasterized pattern data for modulation of each beam. The optical head is fixed with a deflector that generates micro sweeps in the Y-direction as described in the figure. The final lens is equipped with a high accuracy focus system with a long working range, based on voice coils, glass encoders and air bearings. The mask itself is placed on a zerodur stage, controlled by glass scales and interferometers. The writing principle consist of the well proven cycle of scanstrips in X-direction and micro sweeps in Y-direction. The beams are separated in X-direction and swept simultaneously, although individually modulated. The exposure stroke is created by moving at constant speed in X-direction, while repeatedly scanning the multibeam in Y-direction.

2.2 Wide range of configuration

Different users have different technical requirements depending on applications and production mix. The SLX series today has three models, where the main difference is resolution.

[1] SLX 1: The fastest model delivers utmost productivity based on i-line laser source. The model is addressable down to 180nm semiconductor node.

[2] SLX 2: A well-balanced model for users who aim for both productivity and higher semiconductor nodes addressable down to 130nm node. It is also based on i-line laser source.

[3] SLX 3: The most advanced model with a deep UV laser source. SLX 3 is addressable down to 90nm semiconductor nodes.

Key specifications of each model is shown in table 1.

3. The Utmost Productivity

3.1 Enhancing writing speed

SLX series use multibeam modulation and deflection to achieve high writing speed. But there is another feature that enhances writing speed even further, but without introducing any mechanical trade-off. Adding more beams will require increasing in stage movement and related heat and vibration. Instead, a new deflector design with multiple transducers extends the micro sweep substantially up to 70% compared to old deflector design. This has provided around 50% productivity enhancement regardless of pattern complexity.

3.2 Overhead time optimization

The overall turnaround time is an important factor in productivity too. Figure 4 shows total turn around time, including for loading and unloading from/to stage by each SLX model. The overhead time is around 3 minutes regardless of SLX model and for 2nd alignment it adds 3 ~ 4 minutes overhead time. Resulting around 23 minutes turnaround time and around 27 minutes turnaround time for 2nd layer exposure on 6 inch mask in case of SLX 1 model.

A camera based pre-alignment design provides not also speed but also clean and accurate centrality performance.

4. Assured Image Quality

4.1 Eliminating multibeam error

The multibeam exposure strategy used by SLX to achieve high writing speed has a trade off in accuracy since each beam has a position error due to imperfections in optical components. One way to create a cost-effective optical design is to use high quality optics which have minor systematic error that can be compensated by software. This is to large extent possible due to the advanced custom-made electronics that controls the modulator and the deflector. One example of this type of optical compensation is shown in figure 5, where multibeam variations is compensated for by adjusting the edge dose for each feature according to its beam position error.

By doing this, the systematic CD uniformity variations can be greatly reduce up to around 60% with software correction.

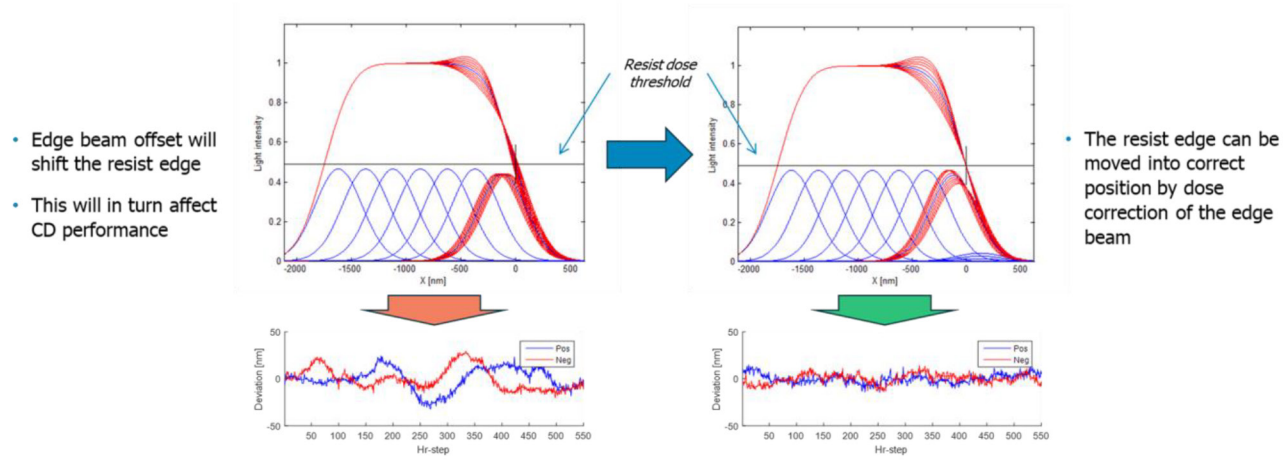

Figure 5. Experiment showing the CD variation is compensated for all deterministic beam errors.

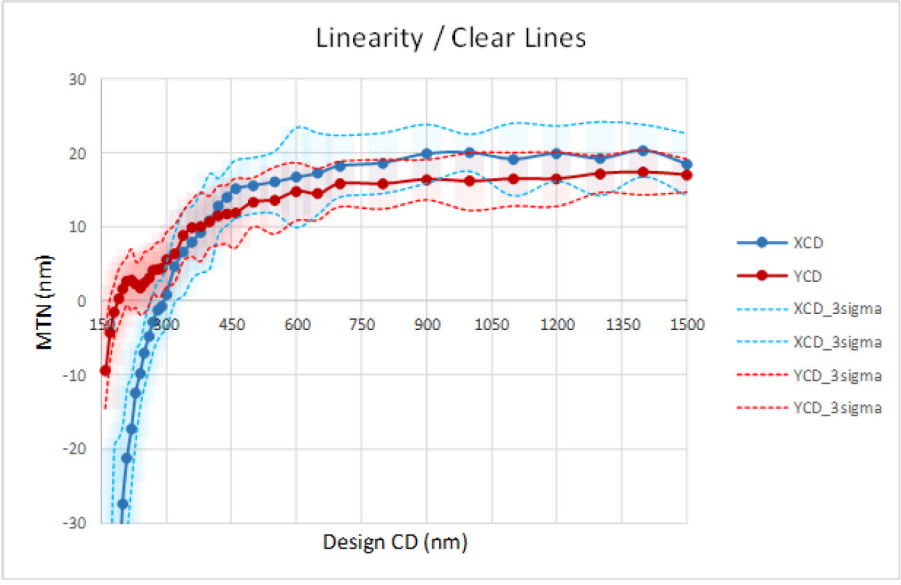

Figure 6. SLX 3 DUV model, CD Linearity performance. Evaluated in standard DUV process.

4.2 Resolution

As explained in Introduction part, photomask manufactures prefer to use laser based technology as long as it meets the technical requirements. The SLX series is equipped with custom made final lens of high specification and an NA chosen to balance resolution, depth of focus and writing speed. A representative sample of the CD linearity from inhouse SLX 3 DUV system is shown in Figure 6.

5. Data Handling

5.1 Proven datapath architecture

Reliable pattern data handling is very important as random errors in the pattern can be very costly in wafer fab. The SLX series use the same field proven datapath architecture that are used in display photomask writer. In case of display photomask data handling, the size of the rasterized pattern data can be 25 Terabytes and with a write time of 24 – 48 hours for a single photomask, a reliable and stable datapath architecture is required. The SLX series data processing is done offline, only data transfer step is done online to avoid risk for data starve due to heavy patterns and minimize risk for errors during exposure. The offline processing also provides possibility to inspect prepared data before the exposure. In addition, this proven datapath architecture provides other benefits such as exposure time independent on pattern data complexity and several functions to enhance image quality on photomask with various compensation algorithms to compensate for process errors, pattern density error and also improve pattern fidelity.

5.2 System diagnostics

Low power consumption with SSL, outstanding writing speed and optimized overhead time provide a cost-effective solution for the users. In addition, another area related to a cost-effective operation is advanced built-in performance related diagnostics. The SLX series use a modern servo electronics which controls all movements in the system. This servo electronics produce extensive log data which can be presented as 2-dimensional heatmap graph, Figure 7.

Figure 7 shows the focus height logged during exposure and maps the Z-position as a function of X and Y-direction of the mask. This kind of diagnostics will enable fast trouble shooting and can potentially simplify root cause analysis. Furthermore, using this log data for deep learning applications, mask shop operation and quality control can be enhanced.

6. Summary

The semiconductor market is expected to expand dramatically this year and is forecasted to continue with double-digit growth in year 2022.

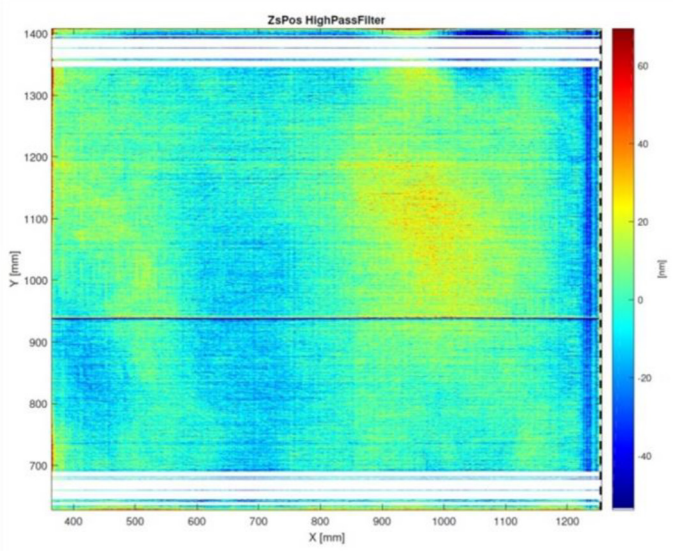

Figure 7. 2-dimensional diagnostic example showing an abnormal Z-value for a strip.

Driven by electronification of everything but also new trends, such as, heterogenous integrated chips, the demand for photomasks of mature design nodes is increasing due to larger variety of designs required combined with price-sensitive volume manufacturing. Still around 70% of all photomasks are produced using laser based mask writers declaring laser mask writers as the backbone of the semiconductor industry. However, the systems in field are old and have difficulties to support these trends.

Mycronic, with built-up knowledge from both FPD and Semicon photomask industry introduces a new generation cost efficient laser mask writer, the SLX series, addressable up to the 90nm node. The SLX series will support the growing demand required by the photomask industry. The SLX series use SSL for low power consumption, multibeam with overhead time optimization offers utmost productivity regardless of pattern complexity, custom made final lens with electronics enable great image quality and with a modern hardware and software platform the SLX allows flexibility in a rapidly changing world and the possibility to develop new functionalities to meet future requirements. In addition, it offers wide range of configuration choices to provide optimized cost-effective solutions depending on applications and product mix.

7. References

[1] World Semiconductor Trade Statistics, 16 August 2021, https://www.wsts.org/esraCMS/extension/media/f/WST/5145/WSTS_nr-2021_08.pdf

[2] Mask maker survey 2020, www.ebeam.org & Mycronic estimates

Industry Briefs

Photomask Shortages Grow At Mature Nodes

Mark Lapedus, Semiconductor Engineering, April 21, 2022

A surge in demand for chips at mature nodes, coupled with aging photomask-making equipment at those geometries, are causing significant concern across the supply chain.

Photomask Shortages Grow At Mature Nodes (semiengineering.com)

Intel Launches New AI Chips, Challenging Nvidia's Market

The Business times, May 10, 2022

INTEL on Tuesday (May 10) launched a new chip called Gaudi2 focused on artificial intelligence computing, as the chip manufacturer makes a bigger push into the AI chip market dominated by Nvidia.

Gaudi2 is the second generation processor by Habana Labs, an Israeli AI chip startup Intel bought in 2019 for about US$2 billion. AI chip startups have been getting huge investments as AI computing is one of the fastest growing areas for data centres.

Intel launches new AI chips, challenging Nvidia's market, Technology - THE BUSINESS TIMES

Global Majors Bet on India Becoming a Chip Manufacturing Hub

Suhita Roy, Economic Times, May 12, 2022

India's plan to become a semiconductor hub is one of the most ambitious and challenging tasks the government has ever undertaken, said the Director of Institute of South Asian Studies, National University of Singapore, C Raja Mohan.

https://economictimes.indiatimes.com/small-biz/sme-sector/global-majors-bet-on-india-becoming-a-chip-manufacturing-hub/articleshow/91484005.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

India Prepares to Build Nation's First Chip Fab

Alan Patterson, EETimes, May 10, 2022

India is edging toward the construction of its first IC fab in the southwestern state of Karnataka following ISMC's recent announcement.

The project would invest about $3 billion in a 65–nm analog chip fab, according to a statement by India's Next Orbit Ventures, a fund management firm that aims to kickstart the effort. Israel's Tower Semiconductor said it will be a technology provider for the project.

EETimes - India Prepares to Build Nation's First Chip Fab

Join the premier professional organization for mask makers and mask users!

About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

Individual Membership Benefits include:

- Subscription to BACUS News (monthly)
- Eligibility to hold office on BACUS Steering Committee

spie.org/bacushome

Corporate Membership Benefits include:

- 3-10 Voting Members in the SPIE General Membership, depending on tier level
- Subscription to BACUS News (monthly)
- One online SPIE Journal Subscription
- Listed as a Corporate Member in the BACUS Monthly Newsletter

spie.org/bacushome

CALENDAR

2022

EMLC 2022
20-23 June
Leuven, Belgium
https://www.emlc-conference.com/

SPIE Photomask Technology + Extreme Ultraviolet Lithography
25-28 September 2022
Monterey, California, USA
www.spie.org/puv

You are invited to submit events of interest for this calendar. Please send to lindad@spie.org.

SPIE, the international society for optics and photonics, brings engineers, scientists, students, and business professionals together to advance light-based science and technology. The Society, founded in 1955, connects and engages with our global constituency through industry-leading conferences and exhibitions; publications of conference proceedings, books, and journals in the SPIE Digital Library; and career-building opportunities. Over the past five years, SPIE has contributed more than $22 million to the international optics community through our advocacy and support, including scholarships, educational resources, travel grants, endowed gifts, and public-policy development. www.spie.org.

SPIE.
International Headquarters
P.O. Box 10, Bellingham, WA 98227-0010 USA
Tel: +1 360 676 3290
Fax: +1 360 647 1445
help@spie.org • spie.org

Shipping Address
1000 20th St., Bellingham, WA 98225-6705 USA

SPIE.EUROPE
2 Alexandra Gate, Ffordd Pengam, Cardiff,
CF24 2SA, UK
Tel: +44 29 2089 4747
Fax: +44 29 2089 4750
info@spieeurope.org • spieeurope.org