Optics and Photonics, Essential Technologies for Our Nation

2012

REPORT OVERVIEW

An overview of “Optics & Photonics, Essential Technologies for Our Nation,” authored by the Harnessing Light Committee of the National Research Council

A report sponsored in part by SPIE

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The report on "Optics and Photonics, Essential Technologies for Our Nation" was produced by the National Academies project "Harnessing Light: Capitalizing on Optical Science Trends and Challenges for Future Research."
The project was supported by funding from DARPA, NSF, NIST, ARO, DOE, AFOSR, NRC, OSA, and SPIE.

SPIE, the international society for optics and photonics, has joined other professional societies in the sector in working with the National Research Council to disseminate the report.

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by section

IN 1998, HARNESSING LIGHT,

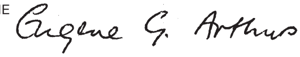
the precursor to the new National Research Council report "Optics and Photonics, Essential Technologies for our Nation," presented a comprehensive view of optical science and engineering and its potential. Since then, optics and photonics have indeed changed the world in the realization of some of that potential.

During the last 14 years, countries like Germany and Japan advanced their already strong optics and photonics industries, while others rapidly developed technical expertise and manufacturing leadership. In many cases the successes were based on formal policy agendas, often borrowing from the "Harnessing Light" study. In 2010, the European Commission designated photonics as one of only five key enabling technologies for future prosperity (advanced manufacturing was recently added as a sixth focus area). The United States, however, did not develop a cohesive strategy, and so failed to seize the opportunities described in the 1998 report.

New technology is essential to job growth and a healthy economy. Calculating the amount of revenue and the number of jobs related to optics and photonics is complex. According to the Report, public companies active in optics and photonics generated an estimated 10% of all public-company revenues within the U.S. in 2010. These 282 unique public companies account for $3 trillion in revenues and 7.4 million high-value U.S. jobs. SPIE alone interacts with 72,000 companies across the globe that are either active in the field or rely on optics and photonics in their daily business. (In reality, almost all companies need or use the Internet, but are oblivious to the underlying photonics technology).

Education is inextricably linked to innovation. The importance to the nation of maintaining a strong educational infrastructure should not be understated. The optics and photonics industry is sizable on its own, but mastery of the technology also contributes to innovation in most other high technology sectors. This is because, as both reports show, photonics is a pervasive enabling technology. Advances in the field have a broad impact from health and energy to defense and manufacturing.

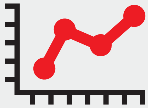
Eugene G. Arthurs,
CEO, Executive Director
SPIE



Communicating that impact – to policy makers, heads of companies large and small, investors, and young people planning careers – must be a priority for each of us.

Sec. **01**

IMPACT OF PHOTONICS ON THE NATIONAL ECONOMY



PUBLIC PHOTONICS COMPANIES IN THE U.S.

	2009	2010
Revenue ($millions)	**2,741,289**	**3,085,292**
No. of Employees (000s)	**7159**	**7415**
R&D: Expenditures ($millions)	**151,104**	**166,603**
R&D: % of Revenue	**5.5%**	**5.4%**

Source: Table 2.2 Optics and Photonics, Essential Technologies for Our Nation. Data from 282 of the 285 unique public companies listed as members, employers, or exhibitors by SPIE & OSA.

Public companies that are focused on optics and photonics create more than 10% (>$3 trillion) of all U.S. public company revenues and 6% (7.4 million) of public company jobs.

Optics and photonics are central to modern life; these technologies are needed to make and inspect the integrated circuits in nearly every electronic device we use. Moreover, optics and photonics technologies are used in the displays on smart phones and computing devices, optical fiber that carries the information on the Internet, advanced precision manufacturing and metrology, enhanced defense capabilities, and a plethora of medical diagnostics tools. New opportunities arising from optics and photonics offer the potential for even greater societal impact in the next few decades, including solar power, high-efficiency lighting, genome mapping, medical devices, and new optical capabilities that will be vital for supporting the continued exponential growth of the Internet.

It is critical for the United States to take advantage of emerging optical technologies for creating new industries and generating high-value job growth. While a majority of optics and photonics companies are small and medium enterprises (SMEs), there are a number of public companies that provide key data. These public photonics companies comprise less than 2% of the 17,000 public companies in the U.S., but they account for approximately 10% of public company revenues and 6% of public company employment.

The report calls for a National Photonics Initiative to improve the efficacy of U.S. public and private R&D resources, emphasizing the need for public policy that encourages adoption of a portfolio approach to investing in the opportunities available within photonics.

"graph" symbol – Scott Lewis, from thenounproject.com collection

Sec. 02

COMMUNICATIONS, INFORMATION PROCESSING & DATA STORAGE

Optics and photonics have increased the capacity of the Internet by nearly 10,000-fold over the past two decades, and bandwidth demand is expected to grow another 100-fold, possibly more, over the next 10 years. A technology wall is currently blocking the next factor-of-100 growth. Without optics, the Internet as we know it would not exist, and it may not be able to keep up with growing demands without a breakthrough.

Grand Challenge: invent technologies for the next factor-of-100 cost-effective capacity increases in optical networks.

Traditionally, optical technologies have been used for long-distance communications and more recently in local communication like the optical mouse. In the future they will also be used for micro distances, including chip-to-chip and on-chip interconnects, reducing chip size, increasing speed, and reducing the energy consumption for data processing and transmission. Optical components for communications involve several processes and/or materials–including complementary metal-oxide-semiconductor (CMOS) technology, indium phosphide, lithium niobate, and silica—meaning that the manufacturing volume of any one of them is reduced. The company/nation that finds a cost-effective consolidation technology—photonic integration—will achieve higher production volumes and gain substantial advantage over competitors.

Data centers, such as those used by Amazon and Google, are located overwhelmingly in the United States. These data centers will grow dramatically over the next decade, and they will be major consumers of new communications technologies; it is critical that they do not migrate overseas.

Grand Challenge: develop a seamless integration of photonics and electronics components, as a main-stream platform for low-cost fabrication and packaging of systems on a chip.

Many past optical communications successes originated from large commercial laboratories that no longer exist. A strong partnership between industry, universities, and government will be necessary to ensuring that the U.S. leverages its innovation abilities to regain market leadership.

Sec. **03**

DEFENSE AND NATIONAL SECURITY

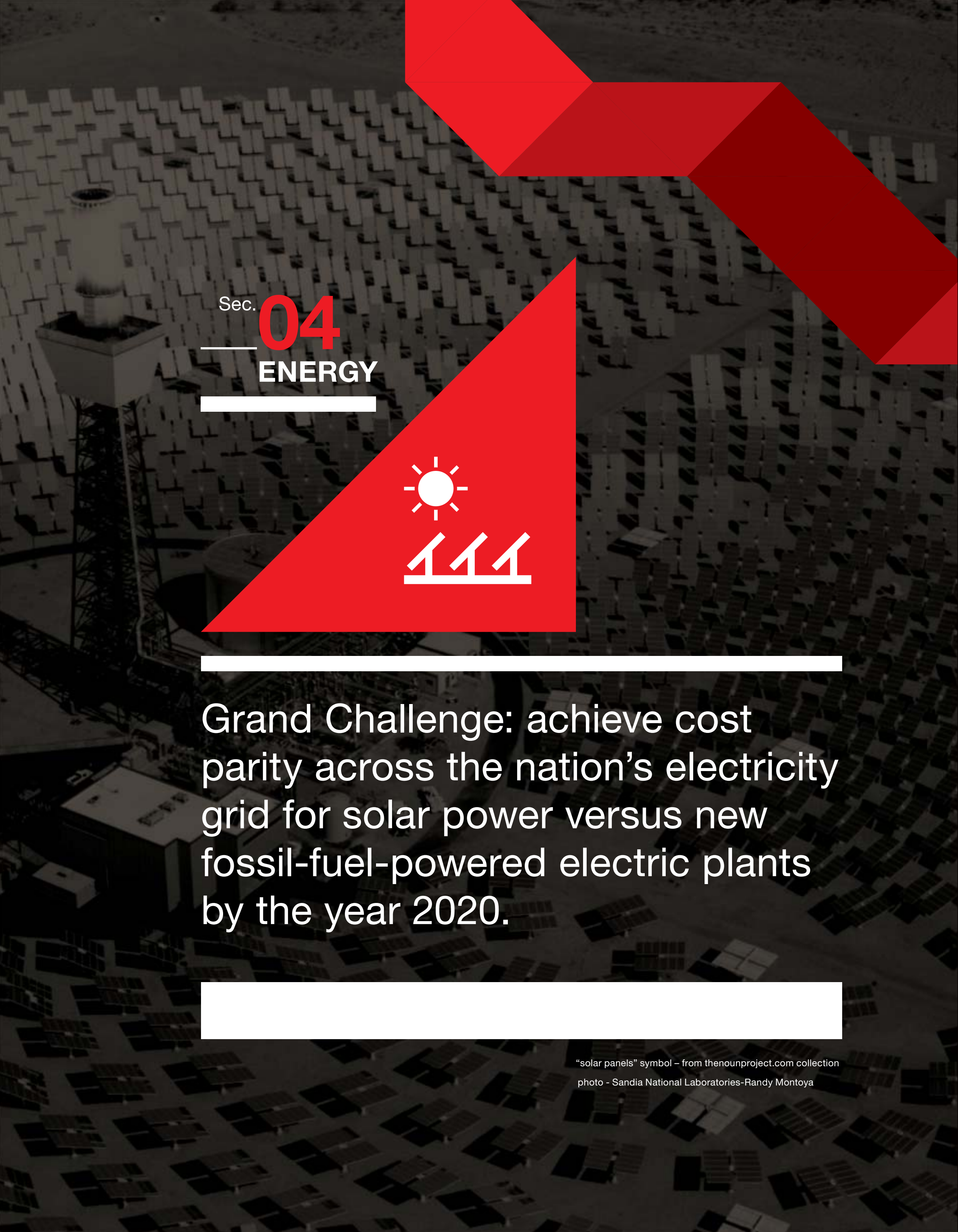
Grand Challenge: develop military platforms capable of wide area surveillance, exquisite object identification, high-bandwidth free-space communication, laser strike, and defense against missiles.

It is becoming increasingly clear that sensor systems will be the next “battleground” for dominance in intelligence, surveillance, and reconnaissance (ISR), with optics-based sensors representing a considerable fraction of ISR systems. Ubiquitous knowledge across an area provides a major defensive advantage, along with the ability to communicate information at high bandwidths from mobile platforms. Optical sensing technology can also identify chemical, biological, and nuclear threats, an ability fundamental for homeland security.

Defense against missile attacks is a significant security need with laser weapons systems poised to cause a revolution in military affairs. Laser weapons can provide a substantial advantage to U.S. forces. There are also potential synergies from fully merging optical surveillance technology, laser weapons technology, and free-space laser technology.

Downward trends in the U.S. citizen STEM workforce mean fewer technically qualified individuals are capable of obtaining security clearances, creating a defense workforce supply problem. Meanwhile, there has been a steady migration of photonics manufacturing overseas, a substantial part of which is driven by outdated ITAR regulations. Leadership in the manufacture of optical communications components and the production of some crystals fundamental to laser function has already been lost. Hence, the U.S. may be losing both first access and assured access to key optics and photonics technologies at the same time as these technologies are becoming a technological advantage.

A flexible display keeps troops informed during operations with night vision, GPS, and physiological feedback.



Sec. 04

ENERGY

Grand Challenge: achieve cost parity across the nation’s electricity grid for solar power versus new fossil-fuel-powered electric plants by the year 2020.

“solar panels” symbol – from thenounproject.com collection

photo - Sandia National Laboratories-Randy Montoya

Solar energy can potentially produce the current and projected future U.S. energy consumption many times over. We need to bring the cost of solar energy down to the price of other alternatives without subsidies – this will require advances in materials, technology, transmission and manufacturing. Not only is there a need for affordable renewable energy, but there is also a need to create jobs in the United States. A focus in this area can contribute to both.

Solid-state (SS) lighting is clearly the next step in lighting. It is more energy efficient, generates less heat than current options and is becoming increasingly cost-competitive for general lighting applications. The record efficiency for SS light today is 231 lumens per watt, compared to 4-15 lumens per watt for a conventional incandescent bulb. Cost is presently the main issue preventing widespread adoption of SS lighting: while lower electricity use and longer life result in a net savings, bulb cost is higher. Major progress is being made, however, and the U.S. needs to exploit its current expertise in SS lighting to bring this technology to maturity and to market.

See-through solar modules can generate electricity from either side, are transparent, and can come in various shapes, greatly expanding locations where solar energy can be economically collected.

Sphelar Power Corporation

The oil and gas industry is increasingly using optical systems to monitor wells, thereby increasing production and mitigating risks. Distributed temperature sensors (DTS) are common tools for monitoring well performance, and optical fiber systems are being used for distributed acoustic sensing (DAS) to monitor activity during well drilling.

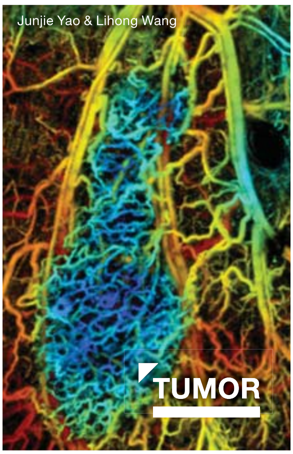
New energy sources based on nuclear fusion like the National Ignition Facility (NIF) offer the potential for clean, safe, abundant energy for the future.

Sec. 05

HEALTH AND MEDICINE

The U.S. boasts the most technologically advanced, and the most costly, healthcare system in the world, with almost 20 cents of every dollar spent going to healthcare.

Photonics technologies are already essential for delivery of effective and low-cost diagnosis, treatment and prevention of disease. Applications in medicine span from elective sight correction and minimally invasive surgeries to characterization of the human genome and bedside clinical analyses in the future. Light-based technologies will also help optimize individual responses to medications while minimizing side effects: health care costs will be reduced as costly late intervention procedures are curtailed and hospital stays shortened.



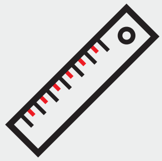
Cancer can be detected earlier by measuring the increased oxygen around a tumor, using optics and photonics enabled technology.

Medical imaging, which is widely used and is still a rapidly developing area, is key to many health-related needs, both for understanding the status of a patient and for guiding and implementing corrective procedures. Real-time images using fluorescent biomarkers that selectively bind to tumor cells provide a clear demarcation between healthy and diseased tissue during surgery.

Biophotonics research is driving advances that, together with improved medical instrumentation, will save lives and provide business opportunities. Optics and photonics (sources, materials, imaging, and microfluidics) provide unprecedented speed, sensitivity, selectivity and resolution for biomedical instrumentation to aid the physician. Opportunity lies in the development of new instrumentation for simultaneous measurement of all immune system cell types in a blood sample and instruments for detecting antibodies, enzymes, and important cell phenotypes. Remaining a world leader in medical innovation while simultaneously bringing down costs requires continued investment in R&D.

Sec. **06**

ADVANCED PHOTONIC MEASUREMENTS & APPLICATIONS



Precise measurements (metrology) impact our daily lives. The ability to make precise and reliable photonics measurements is what underlies areas as diverse as global positioning systems (GPS), communications, and satellite and aircraft positioning and manufacturing.

Today's integrated circuits—found everywhere from cellphones and tablets to automobiles—could not be manufactured without optical sensing and metrology. The entire consumer electronics industry relies on optical sensing and metrology. Advanced metrology and precision laser printing have enabled continuing improvements in the level of detail (number of transistors) that can be built into new integrated circuits. Processor power and memory capacity have increased dramatically while cost has remained flat.

Continued leadership in the field of nano/microelectronics—among others—will depend on further advances in metrology and sensing. The U.S. will need to support fundamental research in this area to remain at the forefront of applications in sensing, imaging, and metrology, which are all intertwined.

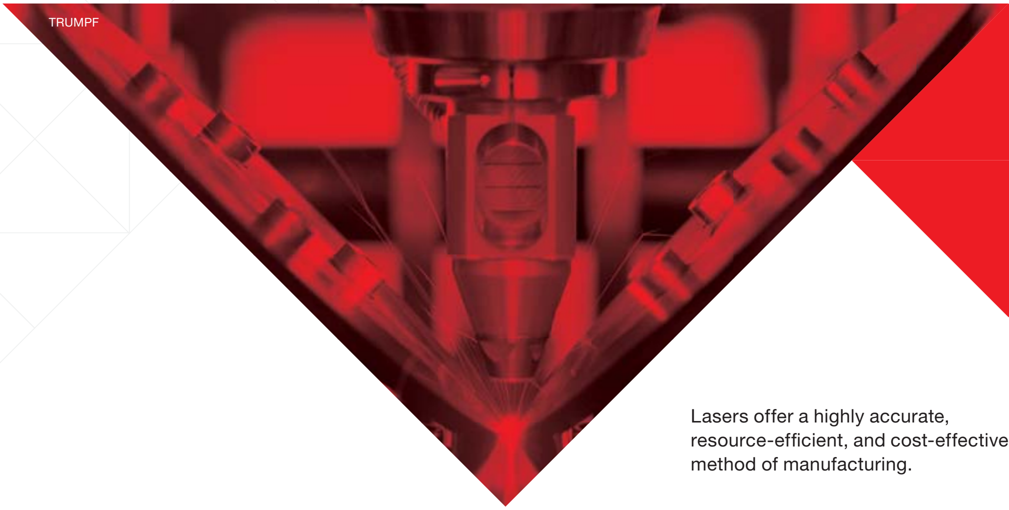
The proliferation of mobile low-cost sensors connected to high-bandwidth data-transfer capability (e.g., cell phone cameras) will allow rapid growth of applications otherwise not economically viable like remote point-of-care diagnostics and environmental monitoring across large areas (distributed sensing).

There are opportunities in niche applications based on combining consumer (high-volume low-cost) components with cutting-edge research that could produce low volume but important products such as portable and/or remote health monitoring and diagnosis. Highly chemical-specific and low-cost biochemical sensing will be a particularly important application.

The research leadership gap between the United States and other countries has significantly narrowed in many disciplines.

"measurement" symbol – Zbigniew Flakus, from thenounproject.com collection

07 ADVANCED MANUFACTURING



TRUMPF

Lasers offer a highly accurate, resource-efficient, and cost-effective method of manufacturing.

The majority of display and photonic component manufacturing has moved overseas, and the U.S. is not a significant player in solar energy system manufacturing. Nevertheless, a great deal of cutting-edge innovation in these areas has remained in the U.S. Dominance in patenting and production of thin-film technologies by U.S.- based firms suggests that the U.S. could be a leader in manufacturing and licensing next-generation solar technology. New market opportunities exist in displays as well, particularly in flexible displays. Assuring that associated jobs remain in the U.S. will be a challenge, but it is one that we need to take on.

Additive manufacturing, including laser sintering and 3D printing, describes technologies that create parts by building them layer by layer. These processes are particularly suited to automation and are inherently low waste, compared to traditional subtractive processes where material is removed from a block to create a part.

Sustained growth in additive manufacturing will require higher resolution technology to build increasingly complex parts and to repair high-cost parts like turbine blades. Optical sources such as soft x-ray lasers and imaging tools will also be needed for manufacturing next-generation chips.

Laser systems are used extensively in shop floor operations such as cutting, drilling, piercing, welding and micromachining, and are essential for the factory of the future. Smart-phone manufacturing typically requires 12 or more different precision laser manufacturing steps.

Advanced manufacturing is vital for the economic well-being of the U.S. While the U.S. may struggle to compete successfully in high-volume, labor intensive low-cost manufacturing, it is likely that we can be a strong competitor in custom, precision, and high added-value manufacturing.

Sec. 07

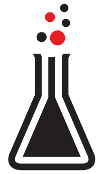
ADVANCED MANUFACTURING

Grand Challenge: develop optical sources and imaging tools to support an order-of-magnitude increased resolution in manufacturing.

photo - TRUMPF

Sec. **08**

STRATEGIC MATERIALS FOR OPTICS



Material science is central to addressing the technical challenges in energy, defense, medicine, and displays that are outlined in the report.

From the standard glass used in lenses to novel “photonic” crystals with customized optical properties, materials underpin every single development in optics and photonics.

Critical energy related materials required to support both next-generation (thin-film) photovoltaics and LED lighting include gallium, germanium, indium, selenium, silver, tellurium, europium, and terbium. White-light solid-state lighting currently depends on expensive rare earth elements that are not routinely produced in the U.S. Limited availability of these elements may drive a need for a U.S. source as opposed to relying on uncertain imports. Availability and cost may drive/accelerate engineering of alternative solutions – such as metamaterials and nanotechnology.

The ability to engineer optical properties (such as reflection, refraction, and absorption of light) promises to open up entirely new applications, as well as benefit existing ones. Engineered materials will lead to solar cells that trap and absorb sunlight more effectively than is currently possible and make energy conversion more efficient. Engineered structures also can raise the efficiency of biosensors by making them more sensitive.

Novel biological systems, such as protein molecules that emit light in response to stimuli and highly-efficient inorganic “dyes,” are being used to detect genetic response to drugs and environmental conditions, moving us toward an era of personalized medicine.

“lab vial” symbol – from thenounproject.com collection

Sec. **09**

DISPLAYS

12 of the 50 best inventions of 2011 listed by *TIME* magazine included optics as a key component.

Liquid-crystal displays (LCDs) have become ubiquitous, showing up in everything from cell phones and e-readers to computers and TVs. LCD technology consumes a substantial amount of energy: backlighting alone uses 25%-40% of total display power. Although they are less developed than LCDs, the use of organic light emitting diodes (OLEDs) is growing, and these devices promise much-reduced energy consumption.

Flexible displays, made from thin polymer films or other thin-film technologies, are an emerging technology with the potential to replace paper in media like newspaper, magazines, and reports. These lightweight, reusable displays could communicate with servers to download and display information. Flexible displays remain a relatively unexplored opportunity with considerable potential in consumer and defense applications.

Although primarily used for military applications today, 3D holographic displays are another area where we expect to see strong growth in areas like entertainment and telemedicine as the technology becomes more widely available and costs decline.

Traditional LCD display manufacturing has migrated outside the U.S., but future display technologies could provide new leadership opportunities, including energy efficient backlighting, OLED and flexible displays, and real-time holographic displays. While touch display technology has already reached the marketplace, significant innovations and improvements are under development that will create other opportunities. Future displays of all types will have to incorporate materials that are low-cost, durable, “green,” and easy to process.

“brain” symbol – Samuel Dion-Girardeau,
from thenounproject.com collection

WHAT ARE OPTICS AND PHOTONICS?

Optics and photonics is the science and application of light. More specifically, optics is a branch of physics that examines the behavior and properties of light and the interaction of light with matter. This includes the entire spectrum of visible light and other invisible light, such as microwaves and x rays. Photonics is the science and technology of generating, controlling, and detecting photons, which are particles of light.

Professionals in the field of optics and photonics examine the behavior and properties of light, and how light interacts with all kinds of materials – even human tissue. They work with devices and instruments that detect, manipulate, and otherwise control it, conducting research and applying discoveries to the design and development of such technologies as advanced manufacturing, robotics, medical imaging, next-generation displays, battlefield technologies, entertainment, biometric security, image processing, communications, astronomy, and much more.

New discoveries in these fields open the door to addressing and solving the challenges of a modern world, enhancing the quality of life by creating jobs; safeguarding health, safety, and security – and much more.

Based on the National Academies booklet "Harnessing Light for America's Technological Future," and the full report "Optics and Photonics, Essential Technologies for our Nation."

SPIE / 1000 20th St / Bellingham WA 98225 USA
+1 360 676 3290 / www.opticsandphotonics.org

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