<https://www.kettering.edu/academics/departments/physics/research/photonics-and-fiber-optics-lab/photonics-applications>

**Optics and Photonics - An Enabling Technology**

The overall economic impact of optics and photonics is two-fold:

* The direct impact stems from the fact that photonic and optics components and systems constitute economic markets in their own right, growing at rates that far surpass the average growth rate of any other areas of the economy.
* Much more important is the huge secondary impact, resulting from the use and applications of photonics and optics components, systems, tools and techniques in practically all other sectors of the economy.

The 1998 report prepared by the National Research Council “Harnessing Light: Optical Science and Engineering for the 21st Century” recognizes optics as an enabling technology, i.e. a technology playing a supporting role in several areas of national interest.

Below are the seven areas identified by the report, in which photonics has already made and is expected to make an even larger impact in the future, along with examples of photonics applications in those respective fields. This list is a selective one rather than all inclusive, as there is virtually no field of human activity on which optics and photonics has not made an impact, and new applications are emerging at an amazing pace. At the same time, the boundaries between these fields are rather fluid and blurry, as more often than not the same photonic components, techniques and/or systems are used or adapted for use in many more than only one field. Therein lies the strength of the interdisciplinary nature of photonics, and the tremendous opportunities it opens.

* Information Technology and Telecommunications
* Health Care and the Life Sciences – Biophotonics
* Optical Sensing, Lighting, Energy and Displays
* Optics in Manufacturing
* National Security and Defense
* Manufacturing of Optical Systems and Components
* Education and Research

**Information Technology and Telecommunications**

Less than 20 years ago, only 10 percent of all transcontinental calls in the United States were carried over fiber-optic cables, and the internet was still in its infancy. Today, virtually all calls are carried by optical signals propagating along optical fibers, and high-speed broad-band internet connection has become the norm. There is virtually no computer that does not come with a CD/RW unit and the DVD is increasingly displacing the VCR. Optical networks represent the infrastructure on which this modern information society is built. Progress in optical communications, data storage and computing has been driven by the ever increasing demand for data capacity and speed (both transmission and storage). This in turn has been allowed and has scaled up with the tremendous advances in several specific photonic components and techniques spanning several multi-billion dollar industries, such as:

Semiconductor lasers:

* the CD has displaced the tapes and records because of cost-effective volume production of infrared semiconductor lasers
* the DVD is displacing the VCR because of cost-effective volume production of red semiconductor lasers
* the arrival of the blue-ray disk has been allowed by major advances in the production of blue laser diodes
* high-quality infrared laser diode transmitters for optical networks has allowed the explosion of the transmission capacity through a single fiber by using Dense Wavelength Division Multiplexing (DWDM)
* Micro-Electro-Mechanical Systems (MEMS) devices allow for tunable Vertical Cavity Surface Emission Lasers (VCSELs), allowing for flexible and reconfigurable optical networks

Optical, electro-optic and opto-electronic materials and devices:

* semiconductor opto-electronic materials as well as various linear and non-linear optical materials are key in the manufacturing of semiconductor lasers, detectors, optical modulators and other components of the optical networks
* planar-technology such as silica-on-silicon allows the manufacturing of integrated photonics devices such as Array Waveguide Gratings (AWGs)
* MEMS technology allows for the implementation of a wide range of devices in a microscopic footprint, such as optical switches, attenuators, etc.

Optical fibers and fiber components:

* high-quality, low loss optical fiber allow for long-hauls communications
* erbium-doped fibers are the key-component in the Erbium-Doped Fiber Amplifiers (EDFA’s) used to boost the signal level in long-haul communications
* fiber components and modules such as splitters, combiners, Fiber-Bragg gratings, add-drop modules, Raman-amplifiers, etc. are key components in optical networks

New display technologies

* the Liquid Crystal Display (LCD) has displaced the cathode ray tube, and novel concepts based on inorganic and organic light emitting diodes (LED’s) and electroluminescent displays are emerging
* nano-photonic materials promise to revolutionize the display applications even further
* far from being confined to the information technology and communications, the new display technologies have a myriad of applications in the even broader consumer markets (displays for the cell phones, digital cameras and camcorders, electronic organizers, game consoles, etc.) as well as in the most advanced security and defense applications

Information storage media and devices:

* from CD, to DVD, to blue-ray disks, the progress in photonics has allowed a tremendous increase in the data storage capacity
* further developments are underway, such as holographic storage media

**Health Care and the Life Sciences - Biophotonics**

The use of light in the areas of Health Care and Life Sciences has evolved into a subfield of photonics with its own identity:Biophotonics. Coupled with the emerging field of nanotechnology, biophotonics promises tremendous growth possibilities, as it is estimated that less than 20% of all possible applications have yet been tackled. The applications of light in health care and life sciences entail several main aspects:

* Light as a diagnostic and monitoring tool
* Light as a treatment and intervention tool
* Light as a readout tool of genetic/protein information of biological samples

The properties of light in general and of laser light in particular, make light a tool uniquely suited for all these classes of applications. It is no accident that since the invention of the microscope, optical technologies have always played a key role in life sciences and health care. Indeed, light is particularly suited for use as a non-invasive or minimally invasive in-vivo diagnostic tool, and a minimally invasive, extremely clean and precise treatment and intervention tool.

Several major areas of applications can be identified:

Imaging technologies

* Imaging is a first priority for medicine
* Increased digital cameras resolution is made possible by advances in photonic and optoelectronic materials and devices
* Endoscopy makes use of optical fibers and digital cameras to enable minimally invasive surgery (laporoscopy) reducing the risks for the patient
* Miniaturization of photonic devices has resulted even in the development of a “pill cam”. Swallowed by the patient, the pill cam travels through the entire alimentary canal, recording pictures and transmitting them to a receiver.
* Digital imaging of skin lesions and wounds allows a rigorous assessment and monitoring of lesion evolution and healing
* Precursors of cancers can be identified by optical methods ranging from fluorescence, reflectance, Raman spectroscopy, to holography to optical coherence tomography
* 3D organ image reconstruction
* 3-dimensional optical microscopy
* Non-linear optical microscopy such as photon absorption
* Optical technology can be used for ''needleless" glucose monitoring for people with diabetes
* Scattering infrared light in the joints for the early detection of arthritis

Understanding life from cellular down to molecular level

* Nano-biophotonics: new bio-photonic materials called photonic markers are being developed (using nanotechnology) that are optically active and allow the monitoring and understanding of the processes inside living cells at molecular level
* Through optical techniques one can device methods of recording a live movie of the metabolism in a living cell, without changing it
* Lasers are used as essential tools in the sequencing of the DNA
* Optical manipulation such as optical tweezers and scissors
* Various forms of microscopy, spectroscopy, and fluorescence techniques are used to understand life at molecular and sub-molecular level

Applications in the pharmaceutics industry

* Optical methods allow fast and cost-effective analysis of substances and drugs in the drug industry

Light as a therapy/intervention tool

* Laser surgery: there is no doubt that laser light is the cleanest possible tool for a surgical intervention, wherever possible. Laser eye surgery and heart surgery are common practices in our days
* Photodynamic therapy: an alternative to chemotherapy, by use of photosensitive substances that accumulate selectively in the tumors. Irradiated with light precisely delivered through optical fibers at the tumor site only, they become a poison that destroys the tumor without affecting healthy cells.

Other

By most accounts, the applications listed above are representative for the applications currently known. Yet, it is estimated that these known applications represent less than 20% of all potential applications in life sciences. We are only skimming the surface yet. Photonics coupled with nanotechnology and ever increasing computing power has a tremendous potential in all areas of health and life sciences.

**Optical Sensing, Lighting, and Energy**

Lighting Applications and Displays

* Inorganic and organic light emitting diodes (OLEDs)
* Electroluminescent lighting
* Large area displays for signage, advertisement, as well as flexible displays
* Backlighting for Liquid Crystal Displays (LCDs)

As widely used as it is, the incandescent light bulb is also highly inefficient in producing light. The dramatic advances in so-called solid-state lighting devices such as inorganic and organic Light Emitting Diodes (LEDs) and electroluminescent displays are poised to significantly reduce the one-fifth of U.S. electricity consumption now devoted to lighting, while offering extraordinary flexibility in shape and significant tunability in brightness and color.

Optical Sensing

* Infrared lasers with wavelength suitable for detecting various molecular species
* Infrared detectors and cameras
* High resolution digital cameras

Innovative optical sensors are augmenting human vision, showing details and revealing information never seen before: infrared cameras that provide satellite pictures of clouds and weather patterns; night vision scopes for use by law enforcement agencies; infrared motion detectors for home security, real-time measurements of industrial emissions, on-line industrial process control, and global environmental monitoring. High-resolution digital cameras are about to revolutionize and computerize photography and printing.

Solar Energy

* High-efficiency solar panels for industrial and domestic applications

Improvements in photovoltaic cells may permit solar energy to provide up to half of world energy needs by the middle of the next century. These developments will affect energy and environmental concerns on a national scale.

**Optics in Manufacturing**

* Laser-assisted manufacturing: welding, cutting, micromachining, ablation
* Machine (computer) vision for process automation
* Optical metrology – light as a measuring tool
* Photolithography for semiconductor chip manufacturing
* Analysis and diagnostic tool in the chemical industry

Optics has had a dramatic economic influence in manufacturing, particularly since the advent of reliable low-cost lasers and laser-imaging systems. Optical techniques have become crucial in such diverse industries as semiconductor manufacturing, construction, and chemical production. Every semiconductor chip mass produced in the world today is manufactured using optical lithography. Just making the equipment for this business is a $1 billion industry, and it ultimately enables a $200 billion electronics business. Other applications include laser welding, cutting and micromachining, laser 3D model generation fro rapid prototyping, laser repair of semiconductor displays, curing of epoxy resins, diagnostic probes for real-time monitoring and control of chemical processes, optical techniques for alignment and inspection, machine vision, metrology, and even laser guidance systems for building tunnels. Optics plays an important role in ensuring a healthy U.S. manufacturing enterprise. (from the National Research Council Report)

**National Defense**

* Laser warning systems
* Laser guided missiles and projectiles
* Night vision systems
* Detection of bio-threats
* Surveillance
* Advanced imaging and display technology
* Advanced simulators
* Laser radar, fiber lasers for laser detection and range finding

Optics and photonics provide the components and subsystems of the military’s most advanced weapons, guidance, communications and visualizations systems. Optics and photonics technology has become ubiquitous in national security and defense, from low cost components to highly complex and sophisticated systems, from the battle field to the security of ports, airports and harbors at home. It has dramatically changed the way wars are fought, and is making an enormous contribution to the proactive identification of threats to national security at all levels. Sophisticated satellite surveillance systems are a keystone of intelligence gathering. Night vision imagers and missile guidance units allow the U.S. armed forces to "own the night." Lasers are used for everything from targeting and range finding to navigation, and may lead to high-power directed-energy weapons. The Department of Defense has a significant stake in optics and photonics, and virtually all applications of optics and photonics mentioned in all other areas are present in the highly sophisticated systems used in national security and defense.

**Manufacturing of Optical Systems and Components**

* Optical materials: glasses, polymers, semiconductors
* Non-linear optical materials and nano-optics
* Optical components: lenses, mirrors, prisms, beam-splitters, filters, polarization optics
* Micro-optics
* High-precision opto-mechanics: vibration control systems, optical mounts, motion stages, motion control
* Integrated automated opto-mechanical systems for manufacturing
* Ray tracing and non–tracing software for optical simulations and prototyping

As the impact of optics has increased, changes have become necessary in how optical components and systems are designed and made. The manufacture of mass-market optics is now dominated by companies in Asia, but some recent developments are enabling U.S. industry to recapture selected market segments. One example is the emergence of new classes of numerically controlled optical grinding and polishing machines. Another is a better understanding of the characteristics of optical materials, from glasses to polymers to metals, thus permitting broader use of these automated technologies. Advanced optical components cannot be considered commodity items, and even though they represent only a small fraction of the value of the optical systems they enable, their availability is essential for the success of new high-level applications that rely on those systems. The U.S. optics industry is currently strongest in the design and manufacture of high-performance specialty products. A key U.S. strength is in optical design, which is being revolutionized by the development of fast and affordable ray-tracing software. The United States can preserve a presence in world markets for optical components and systems by focusing on areas where domestic capabilities are strong and by addressing the process by which international standards are set. (from the National Research Council Report)

**Education and Research**

Although the dollar figure associated with this area of optics and photonics may be significantly smaller than those of the previously discussed areas, there is no doubt that, in many ways, it is the most important area that will allow the United States to maintain a leadership position and stay competitive in the global knowledge economy. Indeed, underpinning the explosive growth of optics and photonics are investments in education and research. One should not forget that when the laser was invented in the 1960s, it was deemed as “a solution in search of a problem”. Yet, in only 40 years lasers and all the applications they have enabled have completely reshaped the global economic landscape and, in the process, have changed our lives in more ways than one could have ever imagined.

Education and research continues to lead to extraordinary discoveries. Although the field of optics and photonics is growing rapidly and its impact is both pervasive and far-reaching, it remains a multidiscipline with components in many university departments, industries and government programs. The presence of optics and photonics in these diverse programs reflects its pervasiveness but also reveals an Achilles' heel. Trends and developments in optics can easily be missed in such a disaggregated enterprise. Educational and research organizations therefore play a critical role in ensuring the dissemination of knowledge across disciplines and in training the highly qualified staff with the required multidisciplinary scientific-technical background required by such an advanced field. Recognizing this aspect, the European Initiative for Photonics states:

“Taking into account the fierce global competition with talented and well-educated scientists in Asia and the US, it is crucial for the optics and photonics community in Europe to build on its leadership position [..]. This issue must be addressed in a coherent approach, starting well before university, by making photonics and optics part of the curricula at all educational levels. We need to fascinate pupils at school in the very early stages. The triggering of enthusiasm and interest for the field of photonics is relatively easy, as the fruits of this technology are ubiquitous: lighting, displays, CDs, DVDs and lasers”. The same statement holds true, word for word, for the education in optics and photonics in the United States, and the Photonics and Fiber Optics Lab at Kettering University is proud and enthusiastic to be part of the education and research efforts for the advancement of Optics and Photonics.

The content of this page was prepared by Dr. Corneliu Rablau, Associate Professor of Physics at Kettering University, Director of the Photonics and Fiber Optics Lab.