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Photonics and its Economic Impact

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Abstract – Photonics is the science of light. It is the technology of generating, controlling, and detecting light waves and photons, which are particles of light. The properties of light in general and of laser light in particular, make light a tool uniquely suited for all these classes of applications. Businesses in the field of photonics and light-based technologies work on solving key societal challenges, such as energy generation and energy efficiency, healthy ageing of the population, climate change, and security. Photonic technologies have major impact on the world economy with a current global market of €300 billion and projected market value of over €600 billion in 2020. Growth in the photonics industry more than doubled that of the worldwide GDP (gross domestic product) between 2005 and 2011.

Keywords: Photonics, Light, Light Based Techniques, Economic Impact of Light.

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INTRODUCTION

Light and color have fascinated the mankind from its early beginning. We see the optical instrumen ts of all: the human eye the history of human kind is dotted with attempts to understand light, control it and use it to better human lives

WHAT IS PHOTONICS

Photonics is the science of light. It is the technology of generating, controlling, and detecting light waves and photons, which are particles of light. The characteristics of the waves and photons can be used to explore the universe, cure diseases, and even to solve crimes. Scientists have been studying light for hundreds of years. The colors of the rainbow are only a small part of the entire light wave range, called the electromagnetic spectrum. Photonics explores a wider variety of wavelengths, from gamma rays to radio, including X-rays, UV and infrared light.

ECONOMIC IMPACT

Businesses in the field of photonics and light-based technologies work on solving key societal challenges, such as energy generation and energy efficiency, healthy ageing of the population, climate change, and security. Photonic technologies have major impact on the world economy with a current global market of €300 billion and projected market value of over €600 billion in 2020. Growth in the photonics industry more than doubled that of the worldwide GDP (gross domestic product) between 2005 and 2011.

PHOTONICS: THE SCIENCE OF HARNESSING LIGHT

It was the development of the laser in the 1960's and of the low-loss optical fibers that placed Optics at the center of the next technological revolution, and opened the door of a new age in technology: the age of Photonics. Since light is made up of photons – the fundamental particle of light and a fundamental building block of the universe – the word photonics was born, in a similar way that the word "electronics" is derived from electron, the fundamental particle and quanta of electric charge According to the Photonics Dictionary, published by Laurin Publishing – an authoritative source in the field – "Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The science includes light emission, transmission, deflection, amplification and detection by lasers and other light sources, optical components and instruments, fiber optics, electro-optical instrumentation, related hardware and electronics, and sophisticated systems. The range of applications of photonics extends from energy generation to detection to communications and information processing."

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 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 systems, tools and techniques in practically all other sectors of the economy. In 1998 a report prepared by the National Research Council "Harnessing Light: Optical Science and Engineering for the 21st Century" recognizes, 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.

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, 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
- 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

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

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

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
- 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

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

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.

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 tenability 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.

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

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

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.