Photonic Sensing Technology

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Abstract- Photonic sensing technologies based on spectroscopic, fiber optics, and LIDAR approaches are increasingly being used in the energy sector for a variety of measurement and monitoring applications in the wind, oil & gas and geothermal industries—among others. Photonic sensors play a major role towards a sustainable, green future by helping control process more efficiently and reduce polluting emissions in a variety of applications in the exploration, generation, distribution, and conservation of energy. In this paper a review of the various applications of photonic sensors, their types and associated benefits will be made, along with socio-economic and benefits they provide.

I. INTRODUCTION

With its many superior qualities, photonic sensing technology is increasingly used in early-detection and early-warning systems for biological hazards, structural flaws, and security threats. *Photonic Sensing* provides for the first time a comprehensive review of this exciting and rapidly evolving field, focusing on the development of cutting-edge applications in diverse areas of safety and security, from biodetection to biometrics [1].

A number of specific areas of safety and security monitoring are covered, including background information, operation principles, analytical techniques, and applications. Topics include

- Document security and structural integrity monitoring, as well as the detection of food pathogens and bacteria
- Surface plasmon sensors, micro-based cytometry, optofluidic techniques, and optical coherence tomography
- Optic fiber sensors for explosive detection and photonic liquid crystal fiber sensors for security monitoring
- Photonics-assisted frequency measurement with promising electronic warfare applications [3].

We are at the beginning of a photonics revolution. Photonic devices have become ubiquitous in everyday life but often go unnoticed. Light sources such as LEDs and laser diodes have found their way into countless applications where light must be created. These devices are relatively cheap, extremely lightweight and compact, and are quite rugged with a long usable life span. In addition, these solid-state sources generate less heat and require less power compared with more traditional light sources [2]. LEDs are being deployed widely as a replacement source technology due to their significant energy and replacement cost savings.

Photonics represent a growing opportunity for designing and manufacturing devices, systems and integrated circuits for applications in high-speed data communications, advanced sensing, and imaging. Photonic technologies promise orders-of-magnitude speed improvements with reduced power consumption for data transmission and ultrasensitive sensing capabilities in multiple domains [2].

Photonic-based detectors such as CMOS image sensors (CIS) have transformed how we take photographs and have all but replaced film as a media for capturing images. CIS share some of the same benefits as solid state sources in that they are small, rugged, and lightweight. One of the biggest advantages over traditional film is their light sensitivity and compact size. This allows for much smaller optics to create a usable image on the detector. This has enabled compact, high-quality cameras being added to everything from cell phones to automobiles [1].

By combining sources and detectors with other means of manipulating light, photonics engineers have transformed our digital world with fiber optic communications, scanners, medical devices, agricultural advances and a whole host of other applications.

II. APPLICATIONS

Photonics devices effect a very wide range of applications. Telecommunications is heavily dependent on photonics devices for fiber optic networks that greatly increase the capacity and speed of internet communications all the way down to the home. Lighting has been transformed with the advent of affordable, powerful LEDs that cut power consumption while providing high-quality, flexible lighting solutions [3]. Solid-state lasers are now commonly found in applications from medical to industrial. Light weight, compact light sensors are found in devices as diverse as cellphone cameras, bar code scanners, printers, DVD players and automotive sensors. Finally, the emerging field of photonic computing is working towards the goal of supplementing or replacing traditional electronic-based printed circuit boards and integrated circuits with optoelectronic circuits.

Photonics have uses in almost every aspect of our life, ranging from daily life to highly innovative science. For instance, information processing, telecommunications, light detection, metrology, lighting, spectroscopy, photonic computing, holography, medical field (surgery, vision correction, health monitoring and endoscopy), fighting machinery, visual art, agriculture, laser material processing, robotics, and biophotonics. Similar to the way electronics have been used extensively since the creation of earlier transistors of 1948, the exceptional use of photonics continuously increases [4]. Economically significant uses of photonic devices include fiber optic telecommunications, optical data storage, displays, optical pumping of high-power lasers and laser printing. Prospective applications of photonics are practically limitless and include medical diagnostics, organic synthesis, information, and communication, as well as fusion energy [5].

- Telecommunication: optical down-converter to microwave, and optical fiber communications.
- Medical applications: laser surgery, poor eyesight correction, tattoo removal and surgical endoscopy.
- Manufacturing processes in industries: involves the use of laser in welding, cutting, drilling, and many surface modification techniques.
- Building and construction: smart structures, laser range finding, and laser leveling.
- Space exploration and aviation: including astronomical telescopes.
- Military operations: command and control, IR sensors, navigation, mine laying, hunt and salvage, and discovery.
- Metrology: range finding, frequency and time measurements.
- Photonic computing: printed circuit boards, and quantum computing.
- Micro-photonics and nanophotonics.

III. NANOPHOTONICS

Nanophotonics or nano-optics is the study of the behavior of light on the nanometre scale, and of the interaction of nanometer-scale objects with light. It is a branch of optics, optical engineering, electrical engineering, and nanotechnology. It often involves dielectric structures such as nanoantennas, or metallic components, which can transport and focus light via surface plasmon polaritons [6].

- Optoelectronics and microelectronics

If light can be squeezed into a small volume, it can be absorbed and detected by a small detector. Small photo detectors tend to have a variety of desirable properties including low noise, high speed, and low voltage and power.

Small lasers have various desirable properties for optical communication including low threshold current (which helps power efficiency) and fast modulation (which means more data transmission). Very small lasers require subwavelength optical cavities. An example is spasers, the surface plasmon version of lasers [6].

Integrated circuits are made using photolithography, i.e. exposure to light. In order to make very small transistors, the light needs to be focused into extremely sharp images. Using various techniques such as immersion lithography and phase-shifting photomasks, it has indeed been possible to make images much finer than the wavelength—for example, drawing 30 nm lines using 193 nm light. Plasmonic techniques have also been proposed for this application [7].

Heat-assisted magnetic recording is a nanophotonic approach to increasing the amount of data that a magnetic disk drive can store. It requires a laser to heat a tiny, subwavelength area of the magnetic material before writing data. The magnetic write-head would have metal optical components to concentrate light at the right location [7].

- Solar cells

Solar cells often work best when the light is absorbed very close to the surface, both because electrons near the surface have a better chance of being collected, and because the device can be made thinner, which reduces cost [6]. Researchers have investigated a variety of nanophotonic techniques to intensify light in the optimal locations within a solar cell.

- Controlled release of anti-cancer therapeutics

Nanophotonics has also been implicated in aiding the controlled and on-demand release of anti-cancer therapeutics like adriamycin from nanoporous optical antennas to target triple-negative breast cancer and mitigate exocytosis anti-cancer drug resistance mechanisms and therefore circumvent toxicity to normal systemic tissues and cells [7].

- Spectroscopy

Using nanophotonics to create high peak intensities: If a given amount of light energy is squeezed into a smaller and smaller volume ("hot-spot"), the intensity in the hot-spot gets larger and larger [7]. This is especially helpful in nonlinear optics; an example is surface-enhanced Raman scattering. It also allows sensitive spectroscopy measurements of even single molecules located in the hot-spot, unlike traditional spectroscopy methods which take an average over millions or billions of molecules.

- Microscopy

One goal of nanophotonics is to construct a so-called "superlens", which would use metamaterials (see below) or other techniques to create images that are more accurate than the diffraction limit (deep subwavelength). In 1995, Guerra demonstrated this by imaging a silicon grating having 50nm lines and spaces with illumination having 650nm wavelength in air. This was accomplished by coupling a transparent phase grating having 50nm lines and spaces (metamaterial) with an immersion microscope objective (superlens) [8].

Near-field scanning optical microscope (NSOM or SNOM) is a quite different nanophotonic technique that accomplishes the same goal of taking images with resolution far smaller than the wavelength. It involves raster-scanning a very sharp tip or very small aperture over the surface to be imaged.

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CONCLUSION

Photonics, put simply, is the science of light. This innovative technology determines how to produce, control and detect waves of light and particles of light (known as photons). It was during the 1960s that the technology was first utilized, but it was not until fiber optics were invented, in the 1980s, when that the term began to be employed more frequently.

Photonics has been extensively utilized in industries around the world since then. Photonics significantly enhanced the world we live in; whether it is transforming manufacturing, LED lighting, powerful biometric security systems or revolutionary healthcare devices that use light to detect diseases. The scope of photonic devices was expanded with the Covid-19 outbreak.

The possibilities for the future appear almost endless as technology continues to develop and evolve, and the utilization of photonics is going to play a vital part in the innovation of many fields.

Photonics is helping to transform every aspect of our life, for example, in security, optical data, communication and healthcare, with big things coming in the future.

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