APL Photonics

EDITORIAL | APRIL 16 2019

Introduction to the *APL Photonics* editorial series on the future of photonics

Special Collection: Editorial Series on the Future of Photonics

Editor-in-Chief: Benjamin J. Eggleton

APL Photonics 4, 040401 (2019)
https://doi.org/10.1063/1.5096517

APL Photonics EDITORIAL scitation.org/journal/app

Introduction to the *APL Photonics* editorial series on the future of photonics

Cite as: APL Photon. 4, 040401 (2019); doi: 10.1063/1.5096517
Submitted: 18 March 2019 • Accepted: 18 March 2019 •
Published Online: 16 April 2019

View Online Export Citation CrossMark

Benjamin J. Eggleton[1,2] *Editor-in-Chief*

AFFILIATIONS

[1] Institute of Photonics and Optical Science (IPOS), School of Physics, University of Sydney, Sydney, NSW 2006, Australia
[2] The University of Sydney Nano Institute (Sydney Nano), University of Sydney, Sydney, NSW 2006, Australia

https://doi.org/10.1063/1.5096517

I. INTRODUCTION

In the coming months, the editors of *APL Photonics* will put forth a series of editorials wherein they will reflect on the future of selected areas of the broad field of photonics. These concise installments will articulate the grand challenges and opportunities in the next several years for each area and speculate on developments even further into the future.

The editors feel that a series of this type will be useful to both experts in photonics and, importantly, interdisciplinary researchers with backgrounds in other fields who are working on photonics projects. We hope to generate a productive conversation across disciplines and inspire early career researchers to tackle the big problems of the future. For senior researchers native to the photonics world, we hope that the editorials will be useful in keeping abreast of the other subfields of our broad science and perhaps identifying areas for growth. Below, we will outline the recent trends, with some examples and historical perspectives, and provide a perspective on emerging and future directions in photonics research. Finally, we will identify the subfields we will cover in the first several editorials with some examples of groundbreaking work in the area.

II. THE HISTORY

Photonics deals with the generation, detection, and manipulation of photons (the building blocks of light) and traces back to the invention of the laser in the 1960s. Optics began much earlier, with the development of lenses by the ancient Egyptians and Mesopotamians, followed by theories on light and vision developed by ancient Greek philosophers and the now well-known developments of Arabic optics in roughly the area of present day Iraq.

The growth of the Internet in the late 1990s increased demand for network information capacity and transfer, driving massive investments in photonic technologies. Optical fiber communications became the backbone of all communications systems with related major advances in photonics science and technology: new optical fibers, new lasers and amplifiers, new components, and signal processing schemes, and improved understanding of light propagation and light-matter interaction drove dramatic increase in network capacity and bandwidth. This global investment transformed the field of photonics from an academic discipline into a pillar of Internet-enabled society, and it is now a major part of the industrial ecosystem.

With the economic downturn that followed, the massive technological capacity and infrastructure and the associated photonic solutions that had been developed for optical communications naturally pivoted into applications in new areas. Photonics research in 2010 continued to grow and enjoy positive visibility and funding, by leveraging the fundamental and applied solutions found for optical communications as the scientific and technological base for applications in health care, defense, sensing, energy harvesting, advanced manufacturing, and monitoring the environment.

UNESCO held the International Year of Light and Light-based Technologies (IYL) in 2015, when we celebrated several anniversaries: 1000 years of Arabic optics (beginning 1015), 200 years since the formulation of Fresnel's theory of diffraction (1815), 150 years since Maxwell's electrodynamics (1865), the Einstein Centenary of General Relativity (1915) (and gravitational waves were detected last year), and 50 years since the discovery of cosmic microwave background by Penzias and Wilson and Optical Fibers by Charles Kao (1965). In addition to these anniversaries, we looked to the future to a world that was enabled by photonics. Indeed, it seems that the 21st century will be the century of photonics.

We are all familiar with the basic principles of optics: we wear glasses that rely on refraction to bend light in ways that magnify and sharpen images, and we have used microscopes that see into the microscopic world and telescopes that look to the stars. Conversely, the general public is probably less familiar with photonics, its 5 trillion USD global industry footprint, and its ubiquitous and essential role in our society, communications, security, health, transport, energy, manufacturing, and the environment.

Think of the smartphone. We use lasers to make the phone, optics is central to the lithography that is used to print the microelectronics circuit, the display and built-in camera are photonic, and the network that connects the phones is based on optical fibers and lasers. Smart phones are now underpinning a new revolution enabled by photonics, with future devices incorporating new photonic-based functions such as sensing and physiological monitoring.

Fiber optics are an example of the ubiquity and transformational potential of photonic technologies in daily life. These silica glass wires the size of a human hair transmit vast amounts of information and form the backbone of today's Internet. Optical fibers were invented and first developed in the 1960s and 1970s and are now deployed around the world, linking major cities, towns, and suburbs of our world, bringing digital and analog information (and, in the near future, quantum information) to end-users. Optical fibers are truly breathtaking technologies. Made of pure glass with a small doped region in the center that traps light, these glass wires are so pure that you could see someone standing 50 km away through a plane of glass. They provide astonishing bandwidth capacity—the record transmission capacity is over ten petabit per second in a single glass optical fiber only 120 μm in diameter. That is ten million gigabits per second, which is the equivalent of delivering about one million feature-length DVDs per second.

III. RECENT TRENDS

The investment in telecommunications stimulated more fundamental research, and new photonic platforms that support current research and technology. In particular, nanophotonics and integrated optics have become a major priority. Related to these directions, new conceptual approaches to manipulating light were introduced and developed, such as photonic crystals, then metamaterials, and more recently, topological photonics, in which geometrical and topological ideas are exploited to design and control the behavior of light, drawing inspiration from the discovery of the quantum Hall effects and topological insulators and exploitation of synthetic dimensions, which alter one of the most fundamental properties in nature, the dimension of space, allowing, for example, a real three-dimensional system to act as effectively four-dimensional.

The additional degrees of freedom provided by these conceptual advances offered new possibilities for controlling and manipulating light at the scale of the wavelength of light itself. Nanoscale structures derived from these new concepts are being created to trap light in even smaller volumes and for even longer times, so as to boost light-matter interaction, offering more efficient methods for sensing, light sources, or nonlinear optics. One important example is the generation of broadband optical frequency combs that are the basis for advanced sensors and broadband communication systems. These new concepts have also given rise to new ways of controlling light down to the single photon level, opening the field of quantum optics. The quantum states of light can be controlled and manipulated in unprecedented ways.

At the other extreme, fundamental research in ultrafast lasers and nonlinear optics at extreme intensities has led to the demonstration of attosecond pulses and coherent tabletop X-ray sources or ultracompact laser plasma accelerators with future applications for hadron therapy. In addition to the development of novel structures for controlling light, new material systems have emerged that offered interesting optical properties beyond the traditional silica for optical fibers and silicon for integrated optics. For example, novel soft-glasses, phase transition materials, epsilon-near-zero materials, and other semiconductor materials have transformed fiber optics, nonlinear optics, and more recently, integrated optics, and there are even possibilities for integrating photonic components with biological systems.

Fundamental material science led to new single atom layer material systems with unprecedented opto-electronic properties that could lead to the ultimate level of integration and promises significant device performance improvement. In parallel to these developments, extending the wavelength range beyond the visible and into the mid-infrared opened entirely new possibilities for the sensing of harmful substances or leaks in pipelines, as well as for bio-molecular fingerprinting and a new field referred to as astrophotonics. Moreover, the link with terahertz waves provided new applications for material science investigations, security, and healthcare.

IV. FUTURE PERSPECTIVE

Addressing many of the global societal challenges prompts and necessitates an interdisciplinary, multidisciplinary, and even transdisciplinary approach to research, bringing together teams of physicists, chemists, biologists, and engineers, and other disciplines as well as end-users and industry. Currently, photonics research programs around the world include bio-photonics and medical photonics, photonics for sensing, such as air quality sensors, wearables and structural health monitors, defense, manufacturing, energy harvesting, etc. There continues to be strong basic research in optical communications but with a broader perspective that extends beyond traditional digital optical communications into microwave (analog) communications, referred to as microwave photonics, and photonics plays a central role in the development of quantum technologies, for quantum computing, communications, cryptography, or sensing.

Optics and photonics play a key role in other significant areas such as gravitational astronomy, with recent advances in quantum squeezing offering improved sensitivity, new LIDAR technologies that are going to enable remote vehicles and drones, and even the possibility of photonics-based brain inspired computing (neuromorphic computing) that might allow for low-latency machine learning operations to be implemented all-optically, not to mention that optics might be capable of controlling our own neurons through the progress of optogenetics.

Contemporary photonics research can be classified into several broad thematic areas:

- New conceptual understandings of light grounded in optical physics. New topics such as topological photonics, quantum optics, and structured light exemplify recent research that is likely to open new technological opportunities for controlling light.

- New photonic platforms, such as integrated photonics, silicon photonics, graphene and other two-dimensional materials, and microcavities being exemplars of recent developments. The investment in the USA through the AIM Photonics illustrates the potential translation.
- End-user driven technological advances that are addressing the grand global challenges—energy, environment, disease, aging population, transport corridors of infrastructure, defense, manufacturing, and safe-guarding. Examples of major investments include the XFELS and ELI and the US photonics initiative.

V. UPCOMING EDITORIAL TOPICS

The topics of the upcoming editorials, briefly outlined below, are the topics that the editors of *APL Photonics* consider the most exciting and integral topics for the field and for the journal.

Integrated Photonics Beyond Silicon
Living Optics
New Paradigms in Photonics
Industrial Perspectives
Ultrafast and X-ray Applications
Biomedical Photonics
2D Optical Materials
Photonics in Automation and Virtual Reality

VI. CONCLUSION

The growth in photonics research and applications has stimulated the formation of new journals, including *APL Photonics*. As the Editor-in-Chief, I view *APL Photonics* as the home for significant advances in fundamental and applied **multidisciplinary** research anchored in photonics, and the platform for next-generation innovations in the field. We hope that this series will promote multidisciplinary work and push the field forward. We hope that you will watch the journal's table of contents for our editorials in the coming months.