A LOOK AHEAD

Optics in 2025 & Beyond

Each December, OPN looks at interesting research results of the past year. But what about the year ahead? We asked several contributors to our "Optics in 2024" feature for thoughts on areas that might advance in 2025.

OPTICAL FREQUENCY COMBS

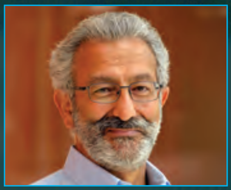
Ever-advancing optical frequency combs, originally used as light frequency rulers, are driving innovation in precision metrology. In 2025 and beyond, their accuracy and narrow laser lines spanning a wide bandwidth will unlock new insights and the exploration of counterintuitive applications, enhanced by novel multiplexed or parallel techniques. Precision measurements will benefit novel fundamental physics, optical imaging and sensing, quantum technologies and perhaps even biophotonics. Chip-scale devices will facilitate widespread deployment.

Nathalie Picqué, *Max Born Institute, Berlin, Germany*

SPATIAL LIGHT MODULATORS

Spatial light modulators (SLMs) are digitally programmable devices that can generate light fields by dynamically modulating the wavefront of a coherent light beam, promising rich applications in virtual reality, augmented reality and spatial computing. I predict that the limited spatial resolution of today's SLMs will be overcome by the development of higher-resolution SLMs within the next five years. These higher-bandwidth SLMs could help usher in the spatial computing revolution.

Ethan Tseng, *Princeton University, Princeton, NJ, USA*



PHOTONICS-BASED AI

The 2024 Nobel Prizes in Physics and Chemistry for foundational discoveries related to artificial intelligence (AI) signal the growing importance of AI and machine learning (ML) in our daily lives. In the coming years, we will witness the significant roles nanophotonics can play in expanding and enhancing optics-based AI and ML. I believe merging light-based computation with data science will shift the AI paradigm to a whole new mindset that will open new chapters in various fields of science and technology.

Nader Engheta, *University of Pennsylvania, Philadelphia, USA*

OPTOACOUSTIC IMAGING

Significant advancements in real-time, *in vivo* imaging technologies, particularly optoacoustic imaging, are expected to transform embryonic and fetal medicine. This method will revolutionize our understanding of developmental biology by enabling earlier and more precise detection of congenital conditions. Looking ahead three to five years, the integration of optics with artificial intelligence will refine these diagnostics further, accelerating and enhancing medical imaging to enable faster and more accurate assessments.

Maryam Hatami, *University of Houston, Houston, USA*

DRONE-BASED MEASUREMENTS

Aerial drone photography utilizing phase information for accurate displacement measurement is set to play an increasingly important role in assessing the condition of aging infrastructures by enabling automated inspections in inaccessible areas. In 2025 and beyond, commercial drones are expected to be widely used for bridge deflection measurements, with applications expanding to inspect thermal power plants, dams and other critical structures, significantly improving monitoring and maintenance capabilities.

Shien Ri, *National Institute of Advanced Industrial Science and Technology, Tokyo, Japan*

TWO-PHOTON VISION

In the near future, significant strides will be made in two-photon (2P) psychophysics, particularly in color perception, contrast sensitivity and visual acuity. These advances will extend clinical visual tests into the infrared domain, offering distinct advantages for aging or nearly opaque eyes. Early retinal disease diagnoses could greatly benefit from this complementary data. Looking further ahead, wearable devices will expand the reach of 2P vision beyond laboratories into clinics and consumer applications, including 2P displays.

Pedro Gil, *University of Murcia, Murcia, Spain*

OPTICAL LAGRANGE POINTS

Multimode nonlinear waveguides and cavities—whether integrated on-chip, in free space, or fiber-based—offer scalable solutions for enhancing power output. However, their inherently chaotic and highly complex behavior has made them challenging to harness effectively. Recently, new methodologies rooted in optical thermodynamics and statistical physics have emerged, providing deeper insights into and greater control over these systems. These efforts may have broader implications, for example, in computing and machine learning.

Mercedeh Khajavik, *University of Southern California, Los Angeles, USA*

Photos: Courtesy of the researchers
Infographic: John Zavada and Alessia H. Kirkland