

Artificial Intelligence Unlocks the Full Potential of Flat Optics

Announcing a new publication from *Opto-Electronic Advances*; DOI 10.29026/oea.2026.250263

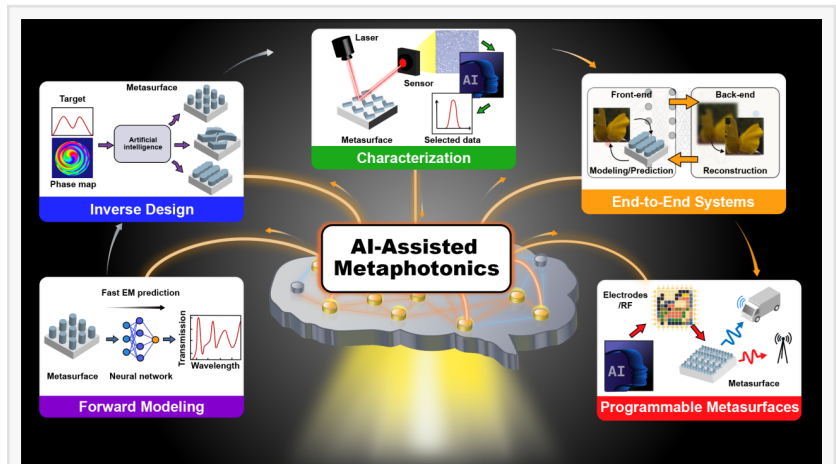
SHANNON, CLARE, IRELAND, April 29, 2026 /EINPresswire.com/ --

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For centuries, the manipulation of light has relied on bulky, heavy components like glass lenses and prisms. From the camera in a smartphone to the microscopes in a laboratory, traditional optics are constrained by physical laws that dictate the size and thickness.

However, a revolution is underway with the advent of "metasurfaces". They are ultra-thin, flat optical devices composed of millions of sub-wavelength structures that can bend, focus, and filter light at will, in ways that natural materials cannot. This has the potential to shrink bulky cameras down to the thickness of a sheet of paper. Yet, designing these metasurfaces is a task of immense complexity. A single device may contain millions of nano-pillars, each requiring precise engineering and fabrication. Navigating this infinite design space using traditional human intuition or standard computer simulations is a significant bottleneck.

This review article explores how artificial intelligence (AI) is shattering that bottleneck. Just as AI has transformed language processing and image recognition, it is now reshaping the field of optics, giving rise to "AI-Assisted Metaphotonics." Deep learning algorithms are proving to be the perfect partner for nanophotonics. Where a human engineer might take weeks to simulate a single design, AI-powered "surrogate models" can predict how light will interact with a nanostructure in milliseconds. More impressively, AI enables "inverse design." Instead of an engineer guessing a structure and checking if it works, they can simply tell the AI the desired optical property, such as a specific color or focal length, and the AI generates the exact complex geometry required to achieve it.



Schematic illustration of AI-assisted metaphotonic systems. AI acts as the central engine driving progress across inverse design, optical characterization, and the creation of fully autonomous, end-to-end optical systems.

But the synergy goes beyond just design. The review highlights how AI is being integrated into the optical systems themselves. Metasurfaces generate complex, multidimensional data that can be difficult to interpret. By coupling these optical sensors with neural networks, researchers are creating intelligent systems capable of "seeing" the invisible in data. These AI-enhanced systems can analyze hyperspectral data to detect diseases in blood samples, identify gases in the atmosphere, or reconstruct high-resolution 3D images for augmented reality (AR) glasses, all in real-time.

Furthermore, the authors discuss the emergence of "end-to-end" systems. In this paradigm, the physical hardware (the metasurface) and the software (the AI algorithm) are designed simultaneously. This holistic approach allows for cameras that correct their own imperfections and optical computers that perform calculations at the speed of light. As this review details, the convergence of AI and metaphotonics is not just an incremental improvement; it is a fundamental shift towards fully autonomous, intelligent optical systems that can adapt to their environment, paving the way for the next generation of smart technology.

The authors provide a critical roadmap for one of the most dynamic intersections in modern science: the convergence of metaphotonics and artificial intelligence. In this comprehensive review, the authors introduce the transformative impact of AI on optical engineering, explaining why this convergence is essential for the future of technology.

The importance of this work lies in its potential to solve real-world hardware limitations. As the demand for smaller, faster, and more efficient electronic devices grows, traditional optical components are hitting a wall. Virtual reality (VR) headsets are too heavy, medical endoscopes are too invasive, and autonomous vehicle sensors are too bulky. Metasurfaces offer a solution to the size problem, but their complexity has made them difficult to commercialize. This review demonstrates that AI is a key to unlocking the mass adoption of this technology. By automating the design process and ensuring fabrication constraints are met, AI reduces the barrier to entry, allowing for the rapid prototyping of devices that were previously thought impossible to build.

Furthermore, the authors highlight a shift from "static" optics to "intelligent" systems. Traditional optical devices are passive; a lens does not "know" what it is looking at. However, the systems reviewed in this article represent a leap toward cognitive sensing. The group discusses how programmable metasurfaces, controlled by AI "brains," can act as invisible cloaks that adapt to changing backgrounds or as smart transmitters for 6G communications that optimize signal paths in real-time. This has profound implications for the development of smart cities and the Internet of Things (IoT), where devices must sense and respond to their environments autonomously.

The review also addresses the sustainability and efficiency of AI itself. Current AI models run on massive server farms that consume vast amounts of electricity. The authors point to a future where "optical computing" uses light instead of electricity to perform AI calculations. By

processing data through metasurfaces at the speed of light with minimal energy consumption, metaphotonics could help with the energy crisis facing the global AI industry.

By consolidating state-of-the-art research on inverse design, data characterization, and end-to-end optimization, this work serves as a foundational text for engineers and scientists. It bridges the gap between computer science and physics, encouraging a multidisciplinary approach that is necessary to tackle the "grand challenges" of the 21st century, from non-invasive healthcare monitoring to quantum computing.

Keywords: metaphotonics, metasurfaces, metamaterials, artificial intelligence, machine learning

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ISSN: 2096-4579

CN: 51-1781/TN

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Kang MS, Choi SK, Fu KX et al. AI-assisted metaphotonics. Opto-Electron Adv 9, 250263 (2026).

DOI: 10.29026/oea.2026.250263

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