Optical memristors review: Shining a light on neuromorphic computing

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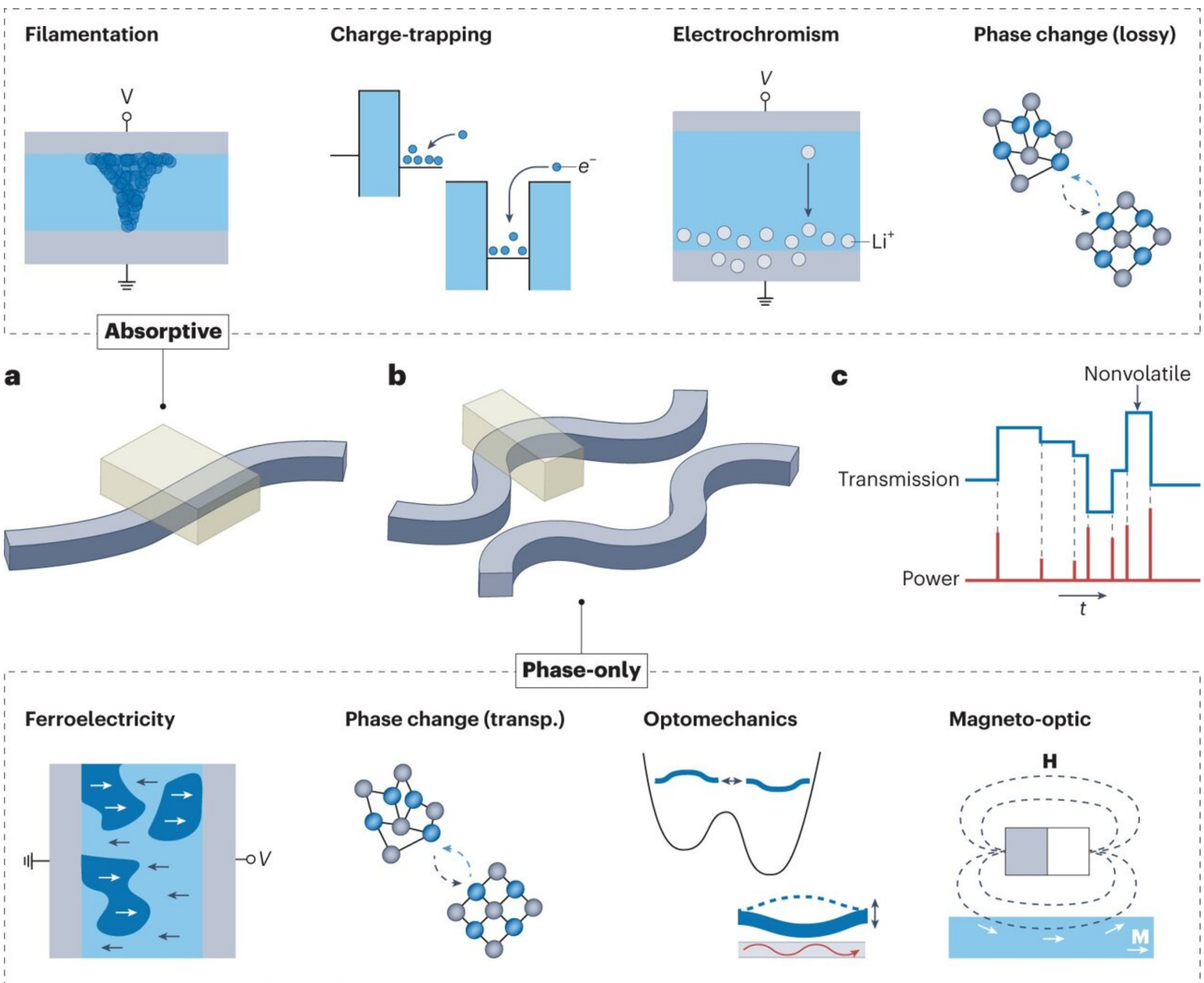

Optical memristive platforms for nonvolatile transmission modulation. Credit: *Nature Photonics* (2023). DOI: 10.1038/s41566-023-01217-w

AI, machine learning, and ChatGPT may be relatively new buzzwords in the public domain, but developing a computer that functions like the human brain and nervous system—both hardware and software combined—has been a decades-long challenge. Engineers at the University of Pittsburgh are today exploring how optical "memristors" may be a key to developing neuromorphic computing.

Resistors with memory, or memristors, have already demonstrated their versatility in electronics, with applications as computational circuit elements in neuromorphic computing and compact memory elements in high-density data storage. Their unique design has paved the way for in-memory computing and captured significant interest from scientists and engineers alike.

A new review article published in *Nature Photonics*, titled "Integrated Optical Memristors," sheds light on the evolution of this technology—and the work that still needs to be done for it to reach its full potential.

Led by Nathan Youngblood, assistant professor of electrical and computer engineering at the University of Pittsburgh Swanson School of Engineering, the article explores the potential of optical devices which are analogs of electronic memristors. This new class of device could play a major role in revolutionizing high-bandwidth neuromorphic computing, machine learning hardware, and artificial intelligence in the optical domain.

"Researchers are truly captivated by optical memristors because of their incredible potential in high-bandwidth neuromorphic computing, machine learning hardware, and artificial intelligence," explained Youngblood. "Imagine merging the incredible advantages of optics with local information processing. It's like opening the door to a whole new realm of technological possibilities that were previously unimaginable."

The review article presents a comprehensive overview of recent progress in this emerging field of photonic integrated circuits. It explores the current state-of-the-art and highlights the potential applications of optical memristors, which combine the benefits of ultrafast, high-bandwidth optical communication with local information processing. However, scalability emerged as the most pressing issue that future research should address.

"Scaling up in-memory or neuromorphic computing in the optical domain is a huge challenge. Having a technology that is fast, compact, and efficient makes scaling more achievable and would represent a huge step forward," explained Youngblood.

"One example of the limitations is that if you were to take phase change materials, which currently have the highest storage density for optical memory, and try to implement a relatively simplistic neural network on-chip, it would take a wafer the size of a laptop to fit all the memory cells needed," he continued. "Size matters for photonics, and we need to find a way to improve the storage density, energy efficiency, and programming speed to do useful computing at useful scales."

Using light to revolutionize computing

Optical memristors can revolutionize computing and information processing across several applications. They can enable active trimming of photonic integrated circuits (PICs), allowing for on-chip optical systems to be adjusted and reprogrammed as needed without continuously consuming power. They also offer high-speed data storage and retrieval, promising to accelerate processing, reduce energy consumption, and enable parallel processing.

Optical memristors can even be used for artificial synapses and brain-inspired architectures. Dynamic memristors with nonvolatile storage and nonlinear output replicate the long-term plasticity of synapses in the brain and pave the way for spiking integrate-and-fire computing architectures.

Research to scale up and improve optical memristor technology could unlock unprecedented possibilities for high-bandwidth neuromorphic computing, machine learning hardware, and artificial intelligence.

"We looked at a lot of different technologies. The thing we noticed is that we're still far away from the target of an ideal optical memristor –something that is compact, efficient, fast, and changes the optical properties in a significant manner," Youngblood said. "We're still searching for a material or a device that actually meets all these criteria in a single technology in order for it to drive the field forward."

More information: Nathan Youngblood et al, Integrated optical memristors, *Nature Photonics* (2023). DOI: 10.1038/s41566-023-01217-w

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