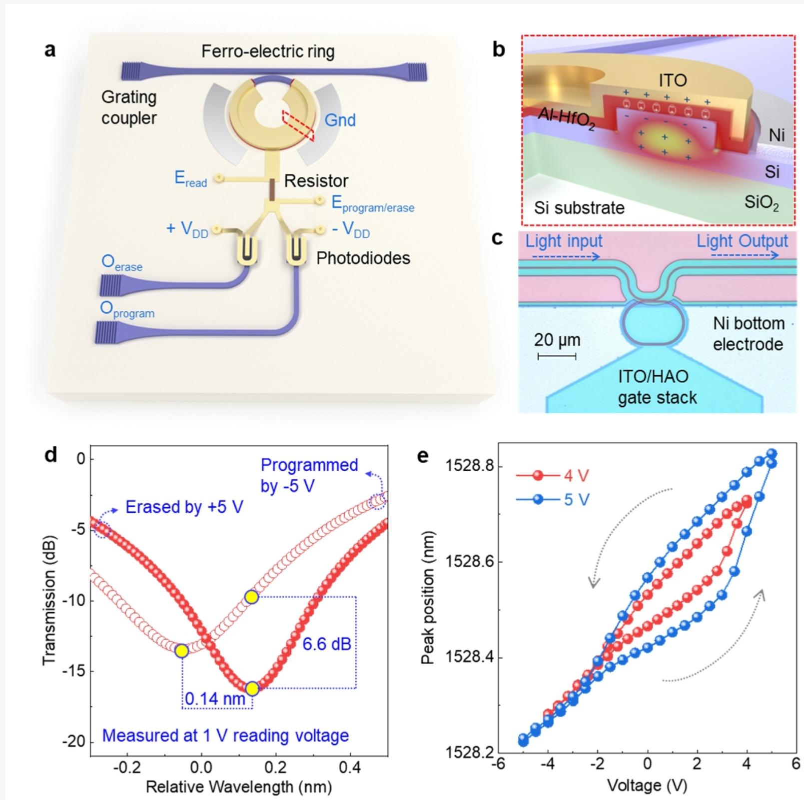
Thin film ferroelectric photonic-electronic memory

GA, UNITED STATES, September 9, 2024 /EINPresswire.com/ -- An international team led by Professor Gong Xiao from the National University of Singapore has developed a groundbreaking non-volatile photonic-electronic memory chip, published in Light: Science & Applications. This chip, based on three-dimensional integrated ferroelectric memory technology, enables dual-mode operation (electrical and optical) and is compatible with silicon-based semiconductor processes. It features low operating voltage, high endurance, and multi-level storage, marking a significant advancement in photonic-electronic integration and paving the way for next-generation computing technologies.



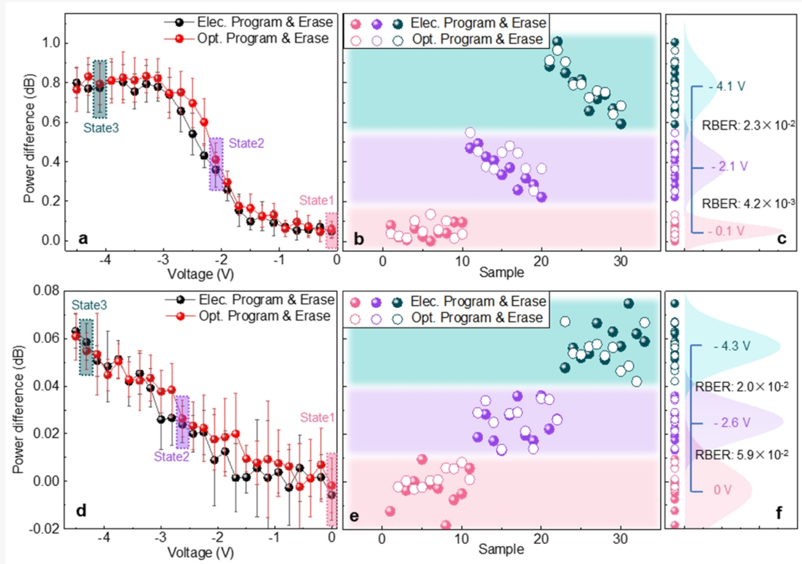
Ferroelectric Non-Volatile Photonic-Electronic Memory.

Abstract

An international research team led by Professor Gong Xiao from the National University of Singapore has made a significant breakthrough in the field of photonic-electronic integration. Their research (doi: https://doi.org/10.1038/s41377-024-01555-6), titled "Thin film ferroelectric photonic-electronic memory," was published in the journal Light: Science & Applications. Postdoc Zhang Gong and PhD student Chen Yue were the co-first authors. They successfully developed a non-volatile photonic-electronic memory chip based on a micro-ring resonator with integrated thin-film ferroelectric material. This innovative solution overcomes the challenge of achieving dual-mode operation in non-volatile memory. The materials used are compatible with silicon-based semiconductor processes, making large-scale integration possible. The chip features low operating voltage, large memory window, high endurance, and multi-level storage capability. This milestone is expected to drive the development of next-generation photonic-electronic systems and play a key role in optical interconnects, high-speed data communication, and neuromorphic computing.

Main Article

In the era of big data and artificial intelligence, traditional electronic computers face significant challenges in handling data-intensive and large-scale parallel tasks. Photonic computing is emerging as a potential solution. However, the complexity of the interface between photonic and electronic chips has long been a major obstacle. Traditional storage solutions cannot meet the dual mode (electrical and optical) read/write demands simultaneously. Using optical-electrical-optical (OEO) conversion introduces losses, delays, and energy consumption issues, hindering all-optical computing development. Therefore, the global research community has been seeking a storage device that efficiently exchanges data between electronic and photonic chips. Developing a non-volatile memory accessible by both electrical and optical means is crucial for connecting electronic and photonic chips.



(a-c) Writing using both electrical and optical signals. Then, reading using optical signals. (d-f) Writing using both electrical and optical signals. Then, reading using electrical signals.

The discovery of ferroelectricity in doped hafnium oxide thin films has brought significant opportunities for emerging ferroelectric memory technologies. Compared to ferroelectric materials in complex perovskite systems, doped hafnium oxide is highly compatible with silicon-based semiconductor processes, offers high scalability, long retention, and maintains ferroelectric properties in a few nanometers thickness. The non-volatile multi-level photonic memory demonstrated in this study is poised to become a key technology for linking electronic and photonic circuits.

The research team led by Professor Gong Xiao from the Department of Electrical and Computer Engineering at the National University of Singapore has successfully developed a non-volatile photonic-electron memory based on integrating hafnium oxide-based ferroelectric material with Si photonics. As shown in Figure 1, this memory can control the remnant polarization within the ferroelectric layer under external voltage, enabling data programming and erasing. The change in remnant polarization alters the memory's capacitance and the refractive index of Si waveguide, allowing information to be read both electrically and optically. Additionally, by precisely adjusting the programming voltage, the polarization state of the ferroelectric layer can be finely tuned to achieve multi-level storage. This memory, based on a silicon micro-ring resonator, can be programmed and erased using both electrical and optical modes, exhibiting high optical extinction ratio, low operating voltage, and high endurance.

Furthermore, detailed analysis of its multi-level storage capability showed a very low error probability, confirming the memory's stability and multi-level storage function. The team also systematically evaluated the memory cell's durability and retention time, which have been lacking in previously reported non-volatile photonic memories.

This research achievement marks an important step towards realizing high-performance, low-energy photonic-electronic integrated systems, providing essential infrastructure for the development of photonic-electronic systems. It is expected to drive innovation in next-generation data centers, high-speed communication networks, neural network computing, and high-performance computing. In the future, with improved integration and mature manufacturing processes, these chips are expected to become core components of photonic-electronic systems, leading information technology into a new era.

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