Compact on-chip polarimeter measures light polarization with high accuracy

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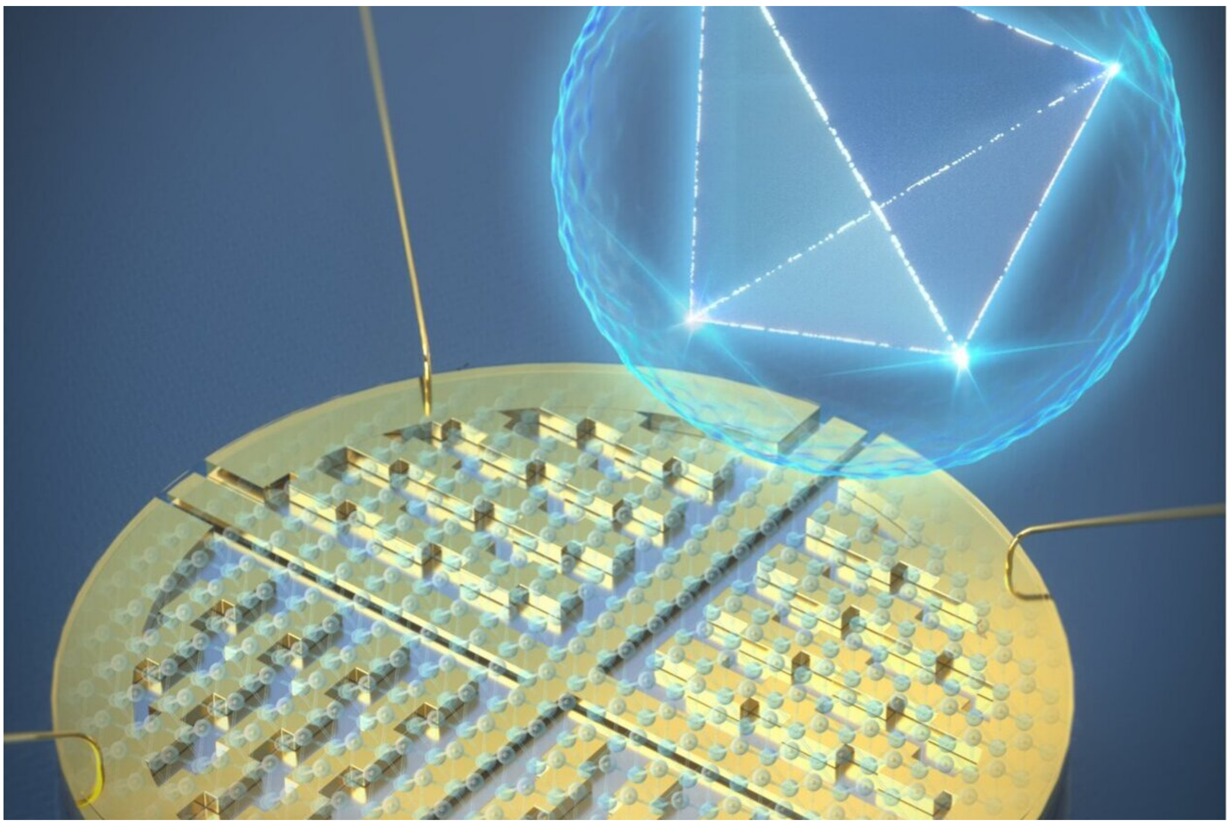


An artistic rendition of the schematic diagram for the on-chip full-Stokes polarimeter, highlighting the optoelectronic polarization eigenvectors. Credit: Deng et al.

Reliably measuring the polarization state of light is crucial for various technological applications, ranging from optical communication to biomedical imaging. Yet conventional polarimeters are made of bulky components, which makes them difficult to reduce in size and limits their widespread adoption.

Researchers at the Shanghai Institute of Technical Physics (SITP) of the Chinese Academy of Sciences and other institutes recently developed an on-chip full-Stokes polarimeter that could be easier to deploy on a large scale. Their device, presented in a paper in *Nature Electronics*, is based on optoelectronic polarization eigenvectors, mathematical equations that represent the linear relationship between the incident Stokes vector and a detector's photocurrent.

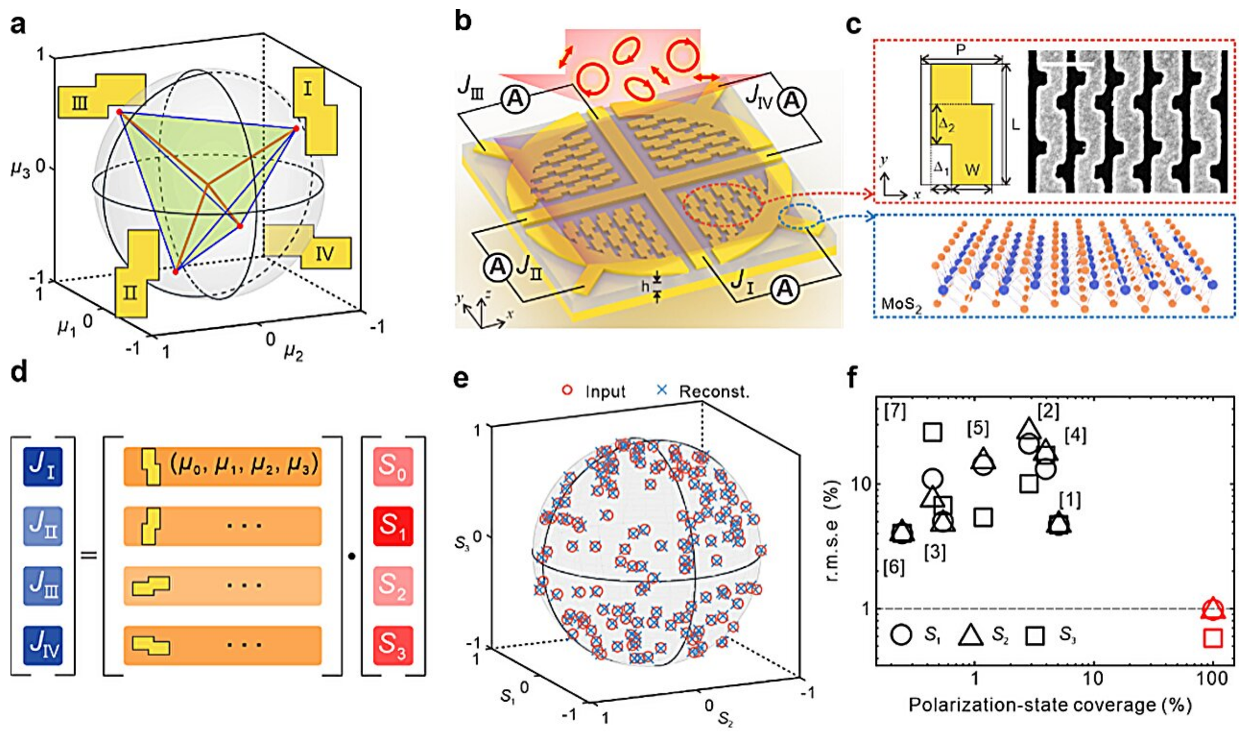
"This work was driven by the growing demand for compact, high-performance polarization analysis devices in optoelectronics," Jing Zhou, corresponding author of the paper, told Phys.org. "Traditional polarimeters, which rely on discrete bulky optical components, present significant challenges to miniaturization and limit their broader applicability. Our main goal is to develop an on-chip solution capable of direct electrical readout to reconstruct full-Stokes polarization states."

Zhou and his colleagues uncovered a new strategy to measure the polarization of light. This strategy is based on a new physical concept known as an optoelectronic polarization eigenvector (OPEV), which mathematically expresses the linear relationship between the incident Stokes vector and the photocurrent flowing in a detector.

"We then establish a novel high-accuracy full-Stokes polarization detection method by configuring four OPEVs to constitute an optimized optoelectronic conversion matrix (OCM)," said Zhou.

"Ultimately, we developed an on-chip full-Stokes polarimeter based on this approach and achieved high-accuracy full-Stokes reconstruction in a compact form, bridging the gap between traditional bulky setups and modern smart optoelectronic systems. The device was designed and optimized based on the concept of optoelectronic polarization eigenvectors."

The device developed by the researchers encodes polarization information into electrical signals via metasurface-enabled eigenvectors. This process allows it to capture the full-Stokes parameters by solving an inverse problem, essentially reconstructing arbitrary unknown polarization states from the four measurable photocurrents of subpixels.



(a) Geometric representation of the optoelectronic polarization eigenvector corresponding to the metasurface-integrated subpixel; (b) Schematic of the onchip full-Stokes polarimeter; (c) The scanning electron microscopy image of the Z-shaped metasurface for subpixel I. Scale bar, 500 nm (red dashed box). The lattice structure of the MoS2 (blue dashed box); (d) Matrix representation of the optoelectronic conversion matrix (OCM); (e) Some random selected input and reconstructed polarization states over the full Poincaré sphere; (f)

Performance comparison on polarization-state coverage and reconstruction accuracy. Credit: Deng et al.

"In the reconstruction process, a machine learning algorithm (Gaussian process regression) is also employed," said Zhou. "The core innovation lies in the manipulation of these eigenvectors via metasurfaces within the framework of Stokes parameter space, addressing symmetry requirements, geometry and their arrangement. This approach eliminates the need for external optical components commonly required in conventional polarimetric systems. Additionally, the metasurface enhances the photoresponse of infrared detection materials through localized optical fields."

The device developed by Zhou and his colleagues has various advantages over conventional polarimeters. Most notably, it can be miniaturized, while also achieving high accuracy levels and fast operation speeds. In addition, it is compatible with focal plane arrays, thus it could pave the way for more interesting polarimetric applications in the infrared spectrum.

"One of our most notable findings is the establishment of a clear and concise linear mapping relationship between Stokes vector of incident light and the photocurrent of a photodetector," said Zhou.

"This relationship, which we term the optoelectronic polarization eigenvectors, serves as a crucial framework for exploring various optoelectronic conversions related to optical polarization. This relationship generally works for all square-law detectors, whose photoresponse is proportional to the received light power."

In initial tests, the device developed by the researchers achieved remarkable results, reconstructing the entire range of polarization states at arbitrary light intensities with a root mean square error of less than 1%. The new polarimeter could be used to collect accurate polarization measurements in real-time, which could be advantageous for various applications, including optical communication, remote sensing, cosmology and biomedical diagnostics.

"Our future research will continue to focus on enhancing the efficiency and robustness of the device, extending its application to more mainstream infrared detection materials—such as MCT, QWIP, InGaAs, and T2SLs—and exploring its potential in emerging fields such as quantum communication and autonomous sensing systems," added Zhou.

"Additionally, we plan to pursue further advancements in spectropolarimetry, emphasizing the optoelectronic conversion and electrical readout of multi-dimensional light information and light-matter interactions."

More information: Jie Deng et al, An on-chip full-Stokes polarimeter based on optoelectronic polarization eigenvectors, *Nature Electronics* (2024). DOI: 10.1038/s41928-024-01287-w.