**communications** materials



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# Machine vision system by optically tunable 2D magnetic junctions



**Combining in-memory sensing and computing is key to the realization of machine vision systems in artificial intelligence applications. Now, non-volatile magnetic memory and optical sensing capabilities are integrated in two-dimensional $Fe_3GaTe_2/WSe_2/Fe_3GaTe_2$ junctions operating at room temperature.**

Magnetic tunneling junctions (MTJs) are key components in magnetic random-access memory, where multiple magnetic configurations and resistance states allow users to store and process information within the same device unit. This integration of memory and computing, known as in-memory computing, has been explored in MTJs to overcome the so-called von Neumann bottleneck of traditional computer architectures, where data fetching and processing cannot occur at the same time. However, traditional MTJs are realized using metallic ferromagnets and insulating barriers, such as $AlO_x$ and MgO, which are insensitive to optical signals. This limitation prevents their use in developing machine vision, an integral part of artificial intelligence for robotics and self-driving automotive applications, where in-memory photo-sensing and computing are required. Now, writing in *ACS Nano*[1], Wenxuan Zhu and collaborators have successfully integrated non-volatile magnetic memory and optical sensing in two-dimensional $Fe_3GaTe_2/WSe_2/Fe_3GaTe_2$ junctions at room temperature, demonstrating their interactive regulation.

In the design realized by Zhu et al.[1], an all-2D three-layer heterojunction is built by sandwiching an ultrathin semiconductor $WSe_2$ flake, acting as barrier layer, between two ferromagnetic $Fe_3GaTe_2$ thin flakes, as schematically depicted in Fig. 1a. The key principles of this device are the high photosensitivity of the $WSe_2$ barrier layer and its wide and clean band gap: "it is crucial to minimize the intrinsic dark current in the junction," comments Yuyan Wang, one of the coordinators of this project. In the absence of light irradiation, the wide band gap of the semiconducting barrier and its cleanness, ensuring no intermediate impurity energy levels, prevent transport of spin-polarized carriers through the junction. In this configuration, the junction is therefore switched "off", corresponding to the high resistance state (HRS) illustrated in the bottom panel of Fig. 1a. Upon illumination, the junction can be turned "on" by light excitation of photogenic carriers, leading to the low resistance state (LRS) shown in the top panel of Fig. 1a. The optical tunability of the MTJ transport properties is illustrated in Fig. 1b, where the current under parallel/antiparallel magnetic configurations (bottom panel) and the corresponding magnetoresistance (top panel) display a nonlinear behavior as a function of the irradiation power intensity. "Magnetoresistance exhibits a dependence on the light intensity, influenced by the tunable tunneling barrier of spin due to photogenic carriers. Conversely, the photocurrent is also non-volatilely determined by the magnetic configurations. This reconfigurable optoelectronic device facilitates a machine vision system with in-memory sensing and computing, enhancing the performance of traditional optical neural networks," explains Wang.

To demonstrate the potential of the above reconfigurable sensor in machine vison systems, Zhu et al.[1] construct a diffraction-based optical neural network architecture, schematically shown in Fig. 1c, where an in-memory sensor

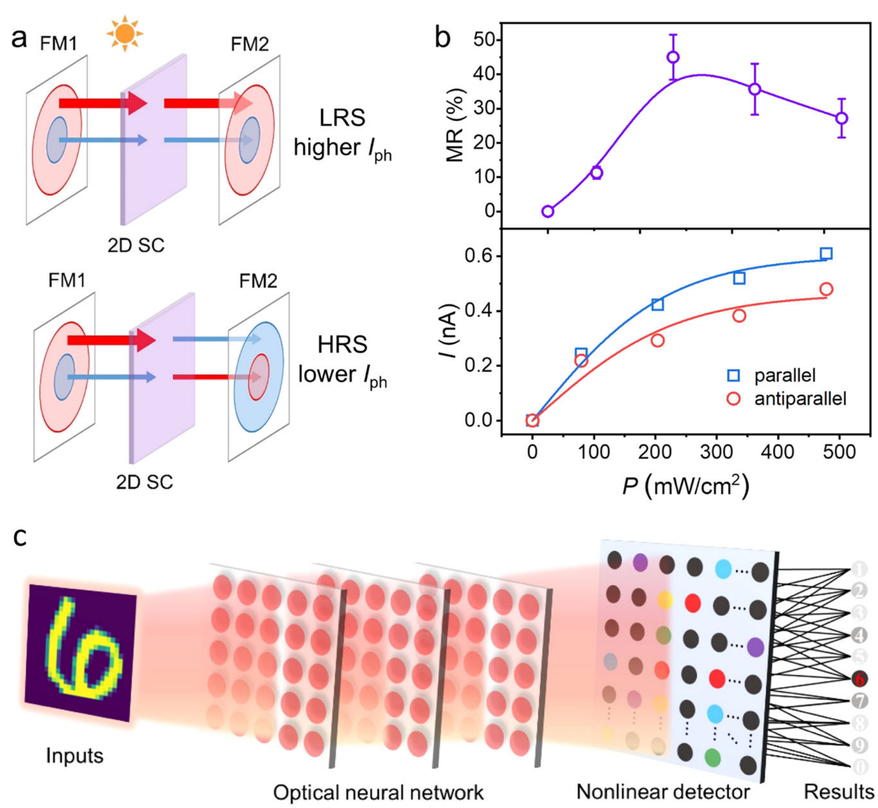


**Fig. 1 | Combining magnetic memory and optical sensing in 2D junctions for machine vision.** **a** Interactive regulation between spin transport and photoresponse. **b** Power intensity-dependent magnetoresistance (MR) and junction current under parallel and antiparallel magnetic configurations. **c** Implementation of an optical neural network integrated with in-memory reconfigurable sensing. Reprinted (adapted) with permission from Ref. 1 (https://doi.org/10.1021/acsnano.4c09735). Copyright 2024 American Chemical Society.

array for nonlinear computing and feature capture is fabricated using their 2D MTJs. When benchmarked against different machine vision data sets, the multiple nonlinearities introduced by the in-memory sensing array provide a peak accuracy of 98.3%, outperforming state-of-the-art optical neural networks.

While representing an important step-forward in integrating sensing and computing capabilities of optical neural networks, this study marks only the beginning of a new generation of machine vision systems. According to Wang, "future work that aims to enhance the scalability and photoresponsivity of these magneto-optoelectronic devices is expected. The current limitations stem from the large-scale production of uniform 2D magnetic materials. As the devices are fabricated through exfoliation and transfer processes, consistency among devices can hardly be ensured. Additionally, the sandwich structure of MTJs may partially obstruct light due to the top metallic layer. Reducing the thickness of the magnetic layers could mitigate this issue, but this presents a challenge since thinner 2D magnets often have a decreased Curie temperature. Thus, synthesizing 2D magnets with stronger magnetism is essential. We believe that advancements in 2D magneto-optoelectronics will be propelled by breakthroughs in the synthesis of 2D magnets soon."

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## References

1. Zhu, W. et al. Photoresponsive Two-Dimensional Magnetic Junctions for Reconfigurable In-Memory Sensing. *ACS Nano* **18**, 27009 (2024).

## Competing interests

The author declares no competing interests.