PHOTODETECTORS

Perovskite nanowires find an edge

Single-crystalline layered perovskite nanowires, which have a high resistance in their interior but a high photoconductivity at their edges, can be used to create sensitive photodetectors.

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Quantum-confined semiconductor systems such as quantum wells, wires and dots are key to optoelectronic devices, and can be used, for example, to build effective light sensors. The fabrication of high-quality single-crystalline quantum structures has typically relied on high-temperature epitaxy, and was only recently achieved using liquid processing[1]. Metal halide perovskites are solution-processed materials that have shown remarkable properties in optoelectronic applications[2]. Layered perovskites — periodic arrangements of two-dimensional perovskite layers intercalated between bulky organic cations — offer additional tunability compared with conventional perovskites, allowing, for example, manipulation of quantum-well energy landscapes in the conduction and valence bands. Writing in *Nature Electronics*, Yuchen Wu, Hongbing Fu, Xiang Zhang and colleagues now report a family of photodetectors that employ single-crystalline layered perovskite nanowires as the photoactive material[3]. The photodetectors offer a remarkable photoresponse and high sensitivity to visible light.

The researchers — who are based at the Chinese Academy of Sciences in Beijing, Tianjin University, the National Center for Nanoscience and Technology in Beijing, Beihang University, the University of the Chinese Academy of Sciences and the University of California, Berkeley — developed a fabrication method capable of producing single-crystalline layered metal-halide perovskite nanowires with a pure crystallographic orientation. Their approach uses a template with asymmetric-wettability properties to drive perovskite crystallization through capillary forces. This allows the team to create highly crystalline and oriented nanowires. Along the length of the nanowires, there are stacks of insulating organic cations and repeating perovskite units. This creates a large resistance in the interior of the nanowires, due to the presence of wide-bandgap organic barriers, while still maintaining a high photoconductivity at the edges of the crystals (Fig. 1).

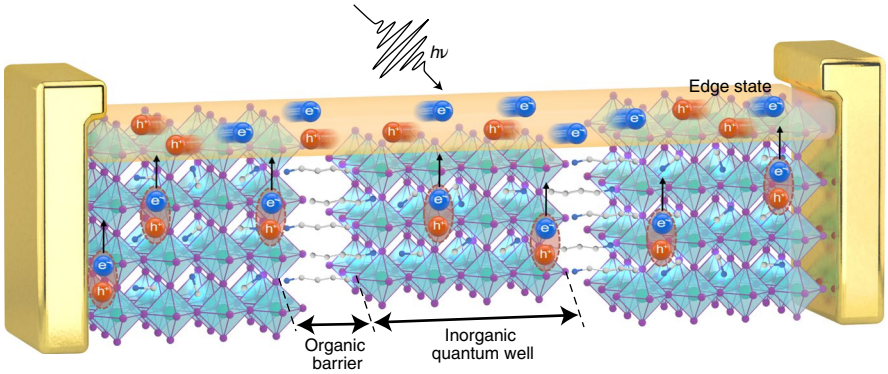

Fig. 1 | Photodetectors made from single-crystalline layered perovskite nanowires. The nanowires have a structure in which there are stacks of insulating organic cations (the organic barriers) and perovskite units (the inorganic quantum wells) along the length of the nanowire. This creates a low-conductive core for excitons (tightly bound electrons and holes), but high-photoconductivity crystalline edges for dissociated electrons and holes. As a result, the photodetectors offer an impressive photoresponse and sensitivity to visible light. Credit: adapted from ref.[3], Macmillan Publishers Ltd.

A threefold trade-off exists in conventional photodetectors between photoresponse, dark current (the current flowing through the device under no illumination) and speed. Recent work in the development of next-generation light sensors has sought to circumvent this problem[4]. One approach, for example, is to decouple the mechanisms responsible for the transport of photogenerated charges and dark current. This has led to the realization of photodetectors with a high photoresponse that simultaneously exhibit low noise and high sensitivity[5,6].

Layered perovskites, like those used by Wu and colleagues, can exhibit a prominent quantum confinement in the direction perpendicular to their surface that depends on the number of perovskite layers[7]. When a photon is absorbed, this leads to the generation of tightly bound electrons and holes — excitons. In the perovskite nanowires developed by Wu and colleagues, these excitons can diffuse to the edges of the perovskite layer to dissociate into free carriers, which then circulate under the action of an applied electric field. In this way, the material is highly resistive in the absence of illumination due to a low free carrier density and high-energy tunnelling barriers, but exhibits a high photoconductivity under illumination due to the recirculation of long-lived free charges arising from the dissociation of photogenerated excitons at the edges. The devices, therefore, exhibit a high responsivity (the ratio of amperes of photocurrent per watt of incident power) and a low dark current, which corresponds to an increased sensitivity.

Inevitably, a new approach such as this requires further steps before practical devices can be realized. First, the integration of the nanowires with current-readout integrated circuits based on complementary metal–oxide–semiconductors would be required. As it stands, the nanowires are sparsely distributed within the photodetector footprint. Their potential integration with appropriate photodetector schemes would need further work to improve the areal fill-factor (the fraction of the pixel that is photoactive) without compromising the material properties and

device performance. Another important aspect to take into account is the direction of charge transport. This is currently in-plane rather than vertical, as would be the case in most of the relevant integrated circuits.

From a performance standpoint, there also remains room for improvement. While the sensitivity and time response of these devices, which is on the order of milliseconds, is suitable for traditional consumer electronics imaging, new applications, such as Li-Fi in which light is used for wireless communication between devices, increasingly demand faster acquisition rates[8]. Extending the sensitivity of this material platform to the infrared at high-frame rates would also be very relevant to emerging applications such as lidar (light detection and ranging) technology in autonomous driving, machine vision and gesture recognition[4].

The work of Wu and colleagues offers an interesting avenue to overcome these challenges. The optoelectronic properties of single crystalline metal halide perovskites could be explored further to achieve fast photodiodes approaching the gigahertz operation regime, and could be implemented into hybrid photodetector architectures with added functionalities[9]. Further advances in this material platform that took advantage of features traditionally exploited by high-temperature epitaxial quantum sensors, such as intraband absorption[10], could also provide compelling new ways to overcome the present-day challenges of creating the next-generation of photodetectors. ❐

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