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NEWS AND VIEWS

Perovskite/organic-semiconductor heterojunctions for ultrasensitive photodetection

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Broadband photodetectors with unprecedented responsivity were reported. It widens the application of organometal halide perovskites in highly sensitive, low-cost and flexible photodetectors. The fundamental device physics revealed will have significant impact on the design of future ultrasensitive photodetectors and other optoelectronic devices.

Photodetectors with ultrahigh responsivity are highly desirable for a broad spectrum of practical applications, such as image sensing, process control and safety monitoring. To date, however, it has remained a challenge to produce ultrasensitive photodetectors at a low cost because of high requirements regarding the material quality, and due to the limitations on the sophisticated fabrication process with conventional device structures. Recently, this field has been greatly inspired by the emergence of organometal halide perovskite materials, which have a structure of ABX_3 (A = organic molecules; B = Pb^{2+} or Sn^{2+}; and X = Cl^-, I^- and/or Br^-). These materials have demonstrated an ensemble of appealing material properties, including exceptional light absorption capabilities, wide-range tunable bandgaps and micrometer-scale long carrier diffusion lengths. These excellent properties can provide benefits for the performance of most optoelectronic devices, including photodetectors, solar cells and light-emitting diodes. For instance, researchers have conducted investigations on photodetectors based on $MAPbI_{1-x}Br_x$ nanowires, which exhibit responsivities as high as 1.2×10^4 AW^{-1} to light wavelengths ranging from 400 nm to 780 nm[1]. The potency of perovskite materials to serve as excellent building blocks for ultrasensitive photodetectors has also been demonstrated. However, their responsivity is still relatively low compared to many reported ultrasensitive photodetectors[2,3]. Since the quality of currently available perovskite materials is already very high, it is challenging to further enhance the responsivity by simply improving the perovskite film quality. To this end, one particularly effective approach is to interface perovskite layers with other functional materials. For example, graphene/$MAPbBr_2I$ hybrid structure-based photodetectors were reported to demonstrate an improved photoresponsivity of 6×10^5 AW^{-1} [4]. Within this hybrid structure, perovskite only serves as light-absorbing media, while graphene functions as the effective charge transport channel. However, graphene does not represent the best candidate for a photodetector, as its high conductivity will result in a high dark current, which will then lead to a low on/off ratio and specific detectivity. Meanwhile, a perovskite/MoS_2 device structure has been demonstrated to possess a photoresponsivity of 1.94×10^6 AW^{-1} [5]. Although the performance is appreciable, a band structure mismatch still exists between MoS_2 and $MAPbI_3$. Therefore, additional efforts must be conducted to search for appropriate materials with which to improve the performance of perovskite photodetectors.

Recently, Yan and colleagues made significant progress in this regard. In their work, they present the first report of low-voltage, high-gain photodetectors based on perovskite/organic-semiconductor vertical heterojunctions, which demonstrate a high responsivity of $\sim10^9$ AW^{-1} and a specific detectivity of $\sim10^{14}$ Jones in a broadband spectrum ranging from ultraviolet to near-infrared[6]. These figures of merit are unprecedented for perovskite material-based photodetectors and are orders of magnitude higher than those of state-of-the-art commercial Si photodetectors whose peak responsivities are usually lower than 1 AW^{-1}. Figure 1 illustrates the device structure and working mechanism of Yan's ultrasensitive photodetectors. Generally, the high performance of this device is primarily ascribed to a pronounced photogating effect, which arises from the proper band alignment of perovskite/organic layers and is further enhanced by the long carrier lifetime and strong light absorption characteristics of perovskite materials. In particular, in order to fabricate the device, Cr/Au electrodes are patterned through photolithography, followed by the spin-coating of PEDOT:PSS and $MAPbI_{3-x}Cl_x$ layers. Thereafter, a vertical type II heterojunction is formed between the PEDOT:PSS and perovskite layers. Under illumination, a large number of photocarriers are generated in the perovskite layer, whereby the holes migrate from the perovskite layer to the PEDOT:PSS layer driven by the aforementioned type II heterojunction, leaving the electrons within the perovskite layer. The efficient separation of photocarriers can dramatically prolong the carrier lifetime, which allows the holes to recirculate multiple times within the PEDOT:PSS channel, thereby resulting in a

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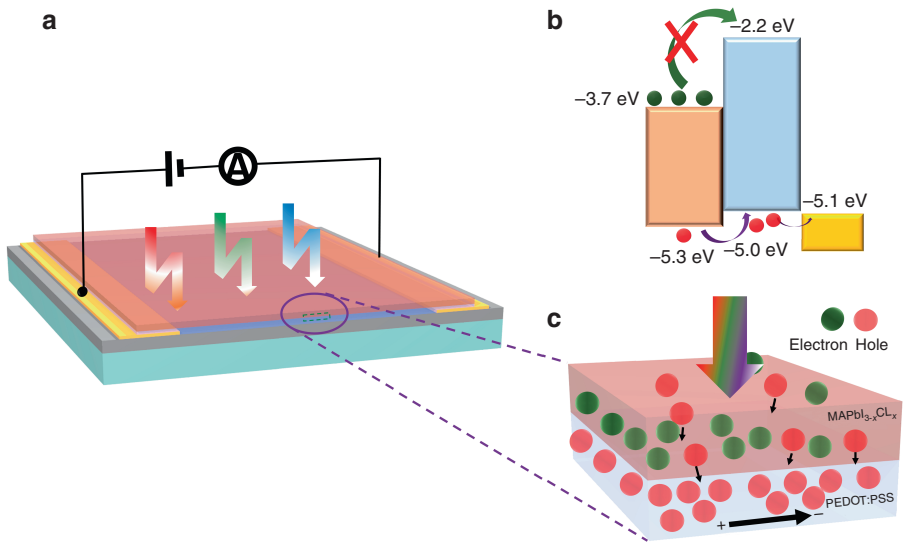

Figure 1 Device schematic (**a**), band alignment (**b**) and operation mechanism (**c**) of Yan and colleagues' ultrasensitive perovskite/organic-semiconductor heterojunction photodetectors.

high photoconductive gain and responsivity. In addition, the accumulated electrons inside the perovskite layer can function as a negatively biased gate electrode, which can further prolong the carrier lifetime and enhance the hole concentration in the PEDOT:PSS layer, giving rise to even higher photoconductive gains and responsivities. Yan and colleagues have revealed that the ultrahigh responsivity and gain of their photodetectors can be summarized by four explanations: (1) the long hole lifetime and diffusion length of $MAPbI_{3-x}Cl_x$ film can reduce recombination within the perovskite layer and consequently enhance the migration of holes from the perovskite layer from the $MAPbI_{3-x}Cl_x$ to the PEDOT:PSS layer; (2) the band alignment of these two materials allows for efficient carrier separation; (3) the high dielectric constant of $MAPbI_{3-x}Cl_x$ allows for additional charge accumulation within the perovskite layer under the same band bending conditions; (4) the high hole mobility in the PEDOT:PSS layer ensures fast hole transportation, and thus enhances the efficiency of carrier collection. These descriptions of device physics are instrumental and can serve as guidelines for the selection of appropriate materials for the future design of ultrasensitive photodetectors. In addition to the high performance of the photodetectors, the low temperature fabrication process makes it compatible with flexible substrates. Yan and colleagues have demonstrated flexible photodetectors exhibiting a high responsivity of 8.9×10^8 AW^{-1}, the performance of which can be maintained after 300 bending cycles, indicating a potential application for wearable and flexible electronics.

The work conducted by Yan and colleagues has demonstrated that broadband photodetectors based on a $MAPbI_{3-x}Cl_x$/PEDOT:PSS vertical heterojunction will demonstrate record-high values of the photoconductive gain and responsivity. This opens up future possibilities for applications of organometal halide perovskites within highly sensitive, low-cost and flexible photodetectors. More importantly, the fundamental physics revealed in this work can inspire the design of future high-performance photodetectors and other optoelectronic devices, including solar cells and light-emitting diodes.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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