Polarized photodetectors based on two-dimensional semiconductors

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Since the successful preparation of graphene in 2004 [1], two-dimensional materials have been rapidly developed [2-4]. In recent years, high-performance photodetectors based on two-dimensional (2D) semiconductors have emerged and covered a broad spectral band ranging from ultraviolet to infrared light [5-7]. Among them, the polarization-sensitive photodetectors based on anisotropic semiconductors introduce the polarization state into photodetection, which effectively increases the dimension of detection and obtain more comprehensive and accurate information of the detected objects.

These semiconductors can be grown by the chemical vapor transport method (CVT) and then mechanically exfoliated to 2D materials, or grown directly into 2D materials by chemical vapor deposition (CVD) [8]. Unlike traditional 2D semiconductors with high symmetry of crystal structures, such 2D semiconductors for polarized photodetection are characterized by their low-symmetry crystal structures, such as black phosphorus, black arsenic, ReS_2 , ReSe_2 , GeSe and GeAs [9-14].

Raman spectroscopy is a technique for studying the structural characteristics of materials. Due to these 2D semiconductors' structural anisotropy, the Raman intensity is strongly dependent on the polarization angle of the incident polarized light. The relationship between Raman intensity and polarization angle of different Raman modes shows

obvious anisotropy in polar coordinates, such as gourd shape or four-leaf shape.

Optically, their anisotropy can be clearly demonstrated by azimuth-dependent reflectance difference microscopy (ADRD) or polarizing microscopy. Yang et al. [15] studied the in-plane optical anisotropy of 2D GeSe . Their ADRD results show that the intensity of $N(\theta)$ (a physical quantity related to reflectance difference) exhibited its minimum value at 75° - 90° (dark blue color) while maximum value at 165° - 180° (dark red color). In addition to the anisotropy of the reflections described above, the dichroism is another physical quantity to describe the anisotropy of absorption. The dichroism is the ratio of the strongest absorbance of a 2D semiconductor to the light with one certain polarization angle to the weakest absorbance to the light with another polarization angle. Wang et al. [11] studied the anisotropy of optical absorption of 2D GeSe . The absorption spectra results plotted in polar coordination at different wavelengths (532, 638, 808 nm), showed obvious two-lobed shapes and the corresponding absorption ratio (dichroism) ≈ 1.09 at 532 nm, 1.26 at 638 nm, and 3.02 at 808 nm. All of the optical testing techniques described above can clearly and quantitatively exhibit the in-plane optical anisotropy of a 2D semiconductor.

In view of their excellent optical anisotropy, these 2D semiconductors have been extended to applications as photodetectors to detect polarized light. At present, the structure of photodetectors used for polarized photodetection is

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dominated by a structure with semiconductor as active layer in the middle of two metal electrodes. In addition to this, there are also heterojunction-type polarized photodetectors and field-effect polarized photodetectors [10,12]. The incident laser passes through a polarizer and a half-wave plate (HWP) and then illuminates the photodetector. The polarization direction of the incident laser is changed by rotating the HWP while ensuring that the laser's intensity does not change. When a voltage is applied between the source and drain electrodes, the photocurrents under illumination in different polarization directions are measured to obtain angularly resolved photocurrent (I_{ph}). The photoelectric current, similar to the absorption spectrum, has a two-lobed shape in polar coordinates. This two-lobed angularly resolved photocurrent is characterized by a greatest photocurrent (I_{pha}) at a polarized light with a certain polarization angle (α) and a weakest photocurrent ($I_{ph\beta}$) with another polarization angle (β , generally perpendicular to α). Therefore, the ratio $I_{pha}/I_{ph\beta}$ becomes an important parameter for polarized photodetection. This ratio reaches 2.16 for the 2D-GeSe-based photodetector under 808 nm laser [11], and reaches 4.4 for the 2D-GeAs-based photodetector under 830 nm laser [9]. High dichroic ratio provides a good basis for polarized light detection. Some researchers have studied the source of photocurrents for polarized photodetection through photocurrent mapping tests. Long et al. [12] proved that photocurrent of the b-As_{0.83}P_{0.17} field-effect photodetectors mainly comes from photogenerated carriers of 2D semiconductor. Zhou et al. [9] proved that photocurrent of the 2D-GeAs-based photodetector mainly comes from the Schottky junction between the Au electrode and the 2D GeAs.

As summary, 2D semiconductors have many advantages, such as in-plane anisotropy, ultra-thin thickness and easy modification, which make them have good application prospects in the field of polarized photodetection. At present, 2D based polarized photodetection is mainly concentrated in the visible and near infrared bands. More investigations are still

needed to expand the detection band. At the same time, new technologies need to be further explored to enhance stability and anisotropy of 2D-semiconductors-based polarized photodetectors.

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