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Tunable photoconductive devices based on graphene/WSe_2 heterostructures

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Abstract Optoelectronic tunability in van der Waals heterostructures is essential for their optoelectronic applications. In this work, tunable photoconductive properties were investigated in the heterostructures of WSe2 and monolayer graphene with different stacking orders on SiO_2/Si substrates. Here, we demonstrated the effect of the material thickness of WSe_2 and graphene on the interfacial charge transport, light absorption, and photoresponses. The results showed that the WSe_2/graphene heterostructure exhibited positive photoconductivity after photoexcitation, while negative photoconductivity was observed in the graphene/WSe_2 heterostructures. The tunable photoconductive behaviors provide promising potential applications of van der Waals heterostructures in optoelectronics. This work has guiding significance for the realization of stacking engineering in van der Waals heterostructures.

1 Introduction

Photo-excited electron-hole pairs usually increase the carrier density in the semiconductor, thereby increasing the channel conductivity and resulting in positive photoconductivity (PPC)[1]–[3]. However, in some low-dimensional materials, such as graphene, two-dimensional (2D) heterostructures, and nanowires, the phenomenon of negative photoconductivity (NPC), a decrease in electrical conductivity under light illumination, has been observed[4]–[6]. It mainly originates from the trapping of photocarriers by intrinsic or interfacial defects. Tunable photoconductivity could broaden the application in low-power, high-speed frequency-responsive photodetectors, and may also be useful for potential applications in optical communications. In recent years, the transition between NPC and PPC has been demonstrated by controlling the doping concentration, gate voltage, wavelength, and laser power[7]–[9]. However, there are few studies on the effects of the stacking order and the thickness of 2D on photoconductivity switching.

Van der Waals (vdW) heterostructures composed of graphene (Gr) and transition metal dichalcogenides (TMDCs) can achieve strong optoelectronic responses and wide photo response regions[7], [10]–[12]. Gr/TMDCs heterojunction devices based on photogating effect provide ultra-high gain for devices due to the trapping effect of TMDCs on photogenerated carriers[13], [14]. The gate-tunable phenomenon of NPC caused by photogating has been reported in Gr/TMDCs heterojunctions as well as 2D p–g–n heterojunction. Liu *et al.*[15]constructed a $MoSe_2$/Gr. vdW heterojunction which shows gate bias and laser power dependence NPC. Kim *et al.*[16] fabricated $MoSe_2$/Gr heterostructure device, where the switching from one state to the other depends on the light intensity as well as gate bias. The Gr/h-BN/MoS_2 vdW heterostructure device is time and gate voltage-dependence of the photoconductance[10]. Xing *et al.* [17] found that the WSe_2/Gr heterostructure exhibits ultrafast interfacial charge transfer, and the stacking order of Gr and WSe_2 can induce terahertz photoconductivity switching after photoexcitation. However, this phenomenon exists only in ultrafast photoelectric responses through pump–probe technique, there is no report of tunable photoconductivity in WSe_2/Gr heterostructure-based photodetectors.

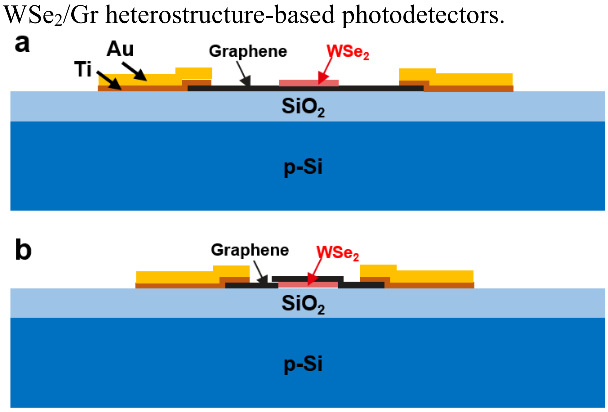

Fig. 1. Schematic diagram of the a) WSe_2/Gr and b) Gr/WSe_2 photoconductive devices.

In this work, we investigate the photoconductivity in 2D heterojunctions with monolayer (ML) graphene and few layer (FL) WSe_2 with different stacking orders and different thickness of WSe_2 on a SiO_2/Si substrate (**Fig. 1**). Firstly, we analyse the absorption of two kinds of

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heterojunctions comprising WSe_2/Gr and Gr/WSe_2 to find out the highest photoresponse wavelength. Next, we identify the neutral Fermi-Dirac point, output, and transfer curves at various gate bias (**Fig. 2**). Thus, the photo-doping level can be identified by analysing the responsivity of the devices under illuminations with different laser power.

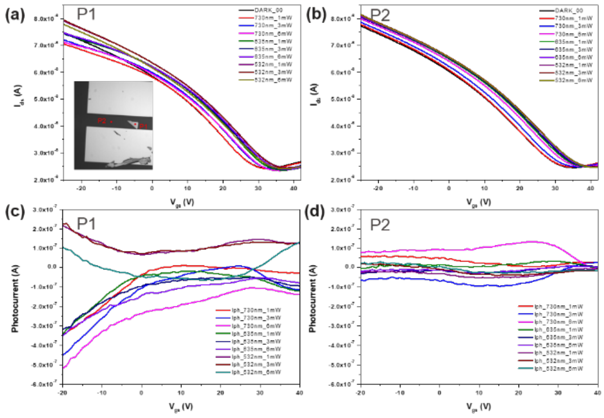

Fig. 2. The transfer curves of the a) graphene and b) Gr/WSe_2 heterojunction region in Gr/WSe_2 devices. The photocurrent of the a) graphene and b) Gr/WSe_2 heterojunction region in Gr/WSe_2 devices in different gate bias.

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