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# Mid-infrared 2D Photodetector based on bilayer PtSe<sub>2</sub>

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**Abstract:** In this work, large crystal atomic layer PtSe<sub>2</sub> with a narrow band gap is synthesized by chemical transfer method. We then demonstrated, for the first time, mid-infrared photodetectors based on bilayer PtSe<sub>2</sub> with fast response time and high responsivity up to 4.5 A/W under mid-infrared illumination (10 μm) at room temperature.

**OCIS codes:** (040.5160) Photodetectors; (040.6070) Solid state detector; (040.3060) Infrared

## 1. Introduction

Two-dimensional crystals have attracted tremendous interests due to the wide electric and optoelectronic properties. The first successful example is graphene, however, the low absorption (2.3%) and short carrier life time (~picoseconds) remain to the major issues for high performance mid-infrared photodetectors.[1] One typical example is transition metal dichalcogenides (TMDC) MX<sub>2</sub> (M=Mo, W; X= S, Se and Te) and other 2D elemental materials (silicene, germanene and phosphorene), however they are not suitable for mid-infrared wavelengths devices because of the relatively large bandgap and low carrier mobility. In the large family of TMDs, many other single layer or multilayer materials with a bandgap of ~0.1 eV were proposed as promising candidates for the mid-infrared photonic and optoelectronic applications. However, the massive synthesis of high-quality narrow bandgap TMD crystals and demonstration of photonic and optoelectronic devices remain a crucial challenge. Here, we present for the first time an efficient strategy to synthesis PtSe<sub>2</sub> crystals, as a demonstrative example, by chemical vapour transport (CVT) method. This allows the fabrication of PtSe<sub>2</sub> field effect transistors (FET) with various numbers of layers. Bilayer PtSe<sub>2</sub> that is demonstrated to retain a narrow bandgap and relatively high carrier mobility shows remarkable photoresponse in a broadband region from visible to mid-infrared wavelengths [2].

## 2. Results and discussion

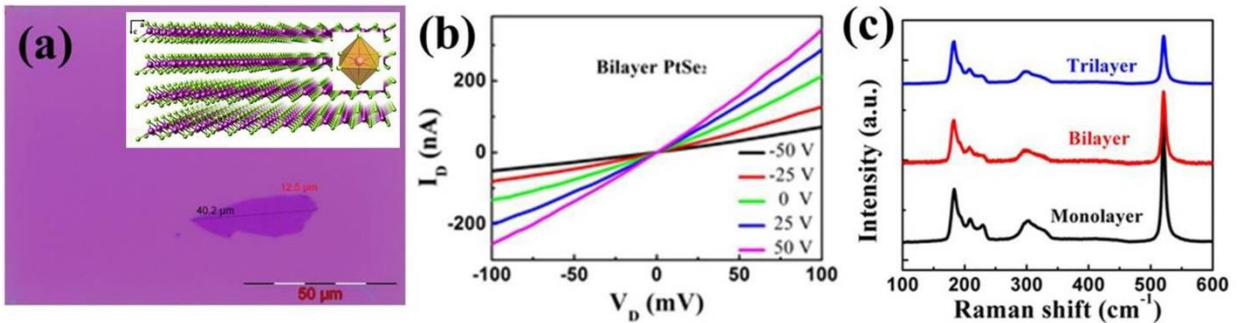


Figure 1 (a) Optical image of bilayer PtSe<sub>2</sub>. (b)  $I_D$ - $V_D$  characteristic of bilayer PtSe<sub>2</sub> FET. (c) Raman spectrum of atomic layers of PtSe<sub>2</sub> on Si/SiO<sub>2</sub> substrate.

Large well-formed plate-like single crystals of PtSe<sub>2</sub> were grown by chemical vapor transport method (CVT) with the help of sulfur, phosphorus and iodine as the catalysts and the transporting agency, respectively. The optical image of the exfoliated bilayer PtSe<sub>2</sub> is shown in fig. 1(a). The electrical contacts made of Ti/Au (20 nm/80 nm) were deposited by the electron beam evaporation after standard photolithography. The heavily doped Si substrate was used as a backgate. The  $I_D$ - $V_D$  and  $I_D$ - $V_G$  curves were measured by the Agilent probe station as shown in fig. 1(b). The synthesized bulk PtSe<sub>2</sub> and atomic layers show two main Raman peaks near 200 cm<sup>-1</sup> and 300 cm<sup>-1</sup> as shown in fig. 1(c), which were defined as E<sub>g</sub> mode and A<sub>1g</sub> mode vibration, respectively. The soft mode near 320 cm<sup>-1</sup> is caused by the substrate. The relatively low mobility of bilayer PtSe<sub>2</sub> FET is related to the differences of the surrounding conditions or the charge transfer from neighboring adsorbates and the substrate. Basically, monolayer PtSe<sub>2</sub> suffers from a stronger substrate effect compared to thicker ones acting as graphene and MoS<sub>2</sub>. The

semiconducting behavior and relatively high carrier mobility, combined with the opening of a bandgap, suggest that bilayer and monolayer PtSe<sub>2</sub> have huge potential in future optoelectronic applications. In this work, we mainly focused on the photodetection properties of bilayer PtSe<sub>2</sub> in the mid-infrared range.

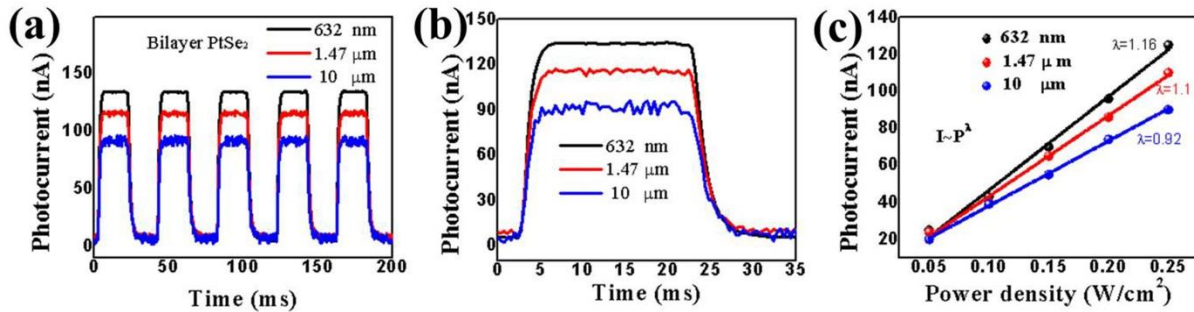


Figure 2 The optoelectronic properties of the fabricated monolayer and bilayer PtSe<sub>2</sub> FET devices. (a) Time-resolved photoresponse of the bilayer PtSe<sub>2</sub> FET devices for a bias voltage of 0.1 V and zero gate voltage under laser illumination, the wavelength of the lasers are 632 nm, 1.47 μm and 10 μm, respectively. (b) Photocurrent dynamics of one period of the time-resolved photoresponse. The laser illuminations of in a, b are kept in a constant of 0.25 W/cm<sup>2</sup> for the three different lasers. (c) Power dependence of the devices under laser illumination recorded at V<sub>D</sub>=0.1 V.

We measured the photodetection performances of bilayer PtSe<sub>2</sub> FET, which exhibited a much higher photoresponse compared with the monolayer PtSe<sub>2</sub> FET, as shown in fig. 2(a). For instance, the responsivities in the visible and near infrared are about 6.25 A/W and 5.5 A/W, respectively. Importantly, we also observed a clear photoresponse in the mid-infrared ( $\lambda=10 \mu\text{m}$ ) as shown in fig. 2(b) and a photoresponsivity of  $\sim 4.5$  A/W, which are in contradiction to the previous theoretical results. Furthermore, the rise time ( $\tau_1 = 1.1$  ms) and fall time ( $\tau_2 = 1.2$  ms) are consistent with the former fitted values. The response times of both samples do not show significant change under different laser illuminations. In addition, the photoresponse can be expressed by a power law of  $I_{\text{PC}} = CP^\gamma$  ( $C$  is a constant and  $P$  is the illumination power) as shown in fig. 2(c). The value of  $\gamma$  was 1.16, 1.1 and 0.92 for 632 nm, 1.47 μm and 10 μm for bilayer PtSe<sub>2</sub> FET, respectively. The relatively high value of  $\gamma$  might be attributed to the less trapping and substrate effects compared to monolayer samples, which can be explained the reduction of the numbers of photogenerated carriers which are available to be extracted under high photon flux due to the Auger process or the saturation of recombination/trap states that influence the lifetime of the generated carriers [3].

### 3. Conclusions

We successfully synthesized a narrow bandgap semiconducting two-dimensional PtSe<sub>2</sub> crystals and obtained large area PtSe<sub>2</sub> with atomic layer for the first time. The photodetection properties of bilayer PtSe<sub>2</sub> FET devices were demonstrated that bilayer PtSe<sub>2</sub> FET devices were suitable for broadband infrared photodetectors.

### 4. Acknowledgements

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