Long-Wave Infrared Photodetectors Based on Platinum Diselenide

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Abstract: We demonstrate long wave infrared photodetectors based on the transition metal dichalcogenide platinum diselenide (PtSe₂) in its bulk form for the first time to our knowledge. Fabricated devices show sub-millisecond response times. © 2019 The Author(s)

Introduction

Long-wave infrared (LWIR, 8-12 μm) photodetectors have important applications that include thermal imaging and spectroscopy. Two-dimensional (2D) materials offer numerous advantages over traditional semiconducting materials for photodetection [1]; hence, recently, there has been an effort to explore this family for the LWIR spectral range. Platinum diselenide (PtSe₂) has been found promising for this purpose.

PtSe₂ is a layered material which can be exfoliated into thin layers that are stable in air [2]. First-principles calculations reveal that monolayer and bilayer PtSe₂ are semiconductors with indirect bandgaps of 1.2 eV and 0.3 eV, respectively, and that thicker layers are metallic with zero bandgap [3, 4]. Yu et al. [3] recently reported a photodetector based on bilayer PtSe₂ with a responsivity and detectivity of 4.5 A/W and 7×10^8 Jones, respectively, for illumination at a wavelength of 10 μm . To achieve this, they introduced Se vacancies in the PtSe₂ crystals using their customized chemical vapor transport (CVT) system to further narrow the bandgap of bilayer PtSe₂ to 0.11 eV. The work of Yu et al [3] represents an impressive demonstration of what can be achieved using PtSe₂ for LWIR detection. From a manufacturing standpoint, however, it may prove challenging to produce PtSe₂ bilayers containing Se vacancies of the appropriate density in the reproducible manner needed for devices such as image sensors. Here we experimentally demonstrate, for the first time to the best of our knowledge, LWIR photodetectors based on PtSe₂ that is not in bilayer form. Indeed, the thicknesses used in this work is such that the PtSe₂ flakes might be considered to be in bulk form. Characterizations reveal that the devices have sub-millisecond response times to illumination at a wavelength of 8.35 μm .

Experimental

CVT-grown PtSe₂ crystals were purchased from the HQ Graphene company [5]. PtSe₂ flakes were exfoliated onto SiO₂/Si substrate using the mechanical exfoliation approach. The thermally grown SiO₂ layer was 300 nm thick. The source/drain electrodes (Cr/Au 20/80 nm) were fabricated using the photolithography/e-beam evaporation/lift-off method. Finally, the chips were wire-bonded into chip carriers for optical and electrical characterization. In the photocurrent measurements, the signal from the photodetector was amplified using a current preamplifier, with the output monitored on an oscilloscope.

Results and Discussions

Fig. 1 (a) presents an optical microscope image of a PtSe₂ photodetector. An atomic force microscope (AFM) image of this device is included as Fig. 1 (b). Fig. 1 (c) plots the height profile of the PtSe₂ flake along the three dashed lines in Fig. 1 (b). According to Fig. 1 (b) and (c), this flake has an uneven thickness that ranges from ~30 nm to ~160 nm.

Fig. 1. (a) Optical microscope image of PtSe₂ photodetector after fabrication of metal electrodes. (b) Atomic force microscope image of device. (c) Height profiles along three dashed lines of panel b.

The drain current-gate voltage (I_d - V_g) characteristic of this device is presented in Fig. 2 (a). The drain-source voltage (V_d) is kept at 50 mV in all of the following measurements. As mentioned above, bulk PtSe₂ is a metallic material, so there is no gate control over drain current. The response of this device to the LWIR laser (wavelength 8.35 μ m) is shown in Fig. 2 (b), where the laser is pulsed at 700 Hz. The photocurrent is defined as $I_{ph}=I_{\text{illuminated}}-I_{\text{dark}}$. The rise time and fall time of the photocurrent are ~ 120 and 210 μ s, respectively. The photocurrent as a function laser power density is shown in Fig. 2 (c). We see that the behavior is approximately linear, which is desirable for photodetectors. The responsivity of the photodetector as a function of laser power density is plotted in Fig. 2 (d). The responsivity is defined as $R=I_{ph}/P_{in}$, where I_{ph} is the photocurrent and P_{in} is the power incident on the device. A maximum responsivity of ~ 23 mA/W is observed. Another important figure of merit of a photodetector is its detectivity, which represents its ability to differentiate the signal from noise. It is defined as $D=(A\Delta f)^{1/2}/NEP$, where A is the device area, Δf is the sampling bandwidth, and NEP is the noise equivalent power. Detectivity can also be estimated as $D=R.(A)^{1/2}/(2eI_{\text{dark}})^{1/2}$ [6], where R is the responsivity, e is the unit charge, and I_{dark} is the dark current. We calculated the detectivity using the latter equation, with the result shown as Fig. 2 (d). This device shows a maximum detectivity of $\sim 1.13 \times 10^6$ Jones ($\text{cm Hz}^{1/2} \text{W}^{-1}$).

Fig. 2. (a) Drain current vs gate voltage characteristic of the PtSe₂ device. (b) Photocurrent as a function of time when the 8.35 μ m laser is pulsed at 700 Hz. (c) Photocurrent as a function of laser power. (d) Responsivity and detectivity as functions of laser power.

Conclusion

Here we demonstrate LWIR photodetectors based on bulk PtSe₂, which is obtained from standard CVT-grown crystals by mechanical exfoliation. Our devices show a maximum responsivity of ~ 23 mA/W, a maximum detectivity of $\sim 1.13 \times 10^6$ Jones, and a rise time of ~ 120 μ s to LWIR illumination (at a wavelength of 8.35 μ m). The responsivity and detectivity values are lower than the ones reported in a recent study [3]. Our devices, however, may be more practical from a manufacturing standpoint as they do not require the PtSe₂ to be in bilayer form and do not require it to contain Se vacancies.

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