Supplementary Information for

Layered-material WS$_2$/topological insulator Bi$_2$Te$_3$ heterostructure photodetector with ultrahigh responsivity in the range from 370 to 1550 nm

Jiandong Yao, Zhaoqiang Zheng & Guowei Yang *

State Key Laboratory of Optoelectronic Materials and Technologies, Nanotechnology Research Center, School of Materials Science & Engineering, Sun Yat-sen University, Guangzhou 510275, Guangdong, P. R. China.

*Corresponding author: stsygw@mail.sysu.edu.cn
S1. The (002) diffraction peaks of WS$_2$ grown on Bi$_2$Te$_3$ with different thickness and their full width at half maximum (FWHM).

Figure S1. (a) The (002) diffraction peaks of WS$_2$ grown on Bi$_2$Te$_3$ with different thickness and their (b) FWHM. Thickness of WS$_2$: 15 nm.
S2. AFM thickness profiles of PLD grown WS$_2$ and Bi$_2$Te$_3$.

Figure S2. AFM images of PLD-grown (a) WS$_2$ specimen of 10000 pulse and Bi$_2$Te$_3$ specimen of (a) 26, (b) 52 and (c) 78 pulse.
S3. Long-term stability of the WS$_2$/Bi$_2$Te$_3$ photodetectors

Figure S3. Photoswitching curve of the WS$_2$/Bi$_2$Te$_3$ photodetector in response to long-term periodic 635-nm illumination (~2000 s, 33 cycles).
S4. Absorption spectrum of the pure WS$_2$ film and WS$_2$/Bi$_2$Te$_3$ heterojunction film

Fig. S4 presents the absorption spectrum of the pure WS$_2$ film (black) and WS$_2$/Bi$_2$Te$_3$ heterojunction film (red). To exclude the absorption from the substrates, transparent mica was exploited as substrates. Note that the periodic oscillation of absorption spectrum comes from the interference effect of the layered mica substrates, which, however, doesn’t hinder us from drawing the conclusion. Obviously, absorption edge appears at around 1000 nm for the pure multilayer WS$_2$ film. After the addition of a Bi$_2$Te$_3$ layer, no absorption edge can be observed in the whole measured range extending from 400 to 2000 nm, which is benefit from the small bandgap of Bi$_2$Te$_3$ (0.15 eV). Therefore, the above results provide convincing evidence that the photoresponse to the 1550-nm illumination of the WS$_2$/Bi$_2$Te$_3$ heterojunction photodetector originates from the Bi$_2$Te$_3$ layer.

![Absorption Spectrum](image)

Figure S4. Absorption spectrum of the pure WS$_2$ film and WS$_2$/Bi$_2$Te$_3$ heterojunction film.
S5. Dark current of the device with different thickness of Bi$_2$Te$_3$.

The dark current of the devices with different thickness of Bi$_2$Te$_3$ is summarized in Fig. S5. In general, the dark current increases as the thickness of Bi$_2$Te$_3$ increases. Note that the dark current of WS$_2$/Bi$_2$Te$_3$ (2 nm) is slightly larger than that of WS$_2$/Bi$_2$Te$_3$ (4 nm), which seems to be counterintuitive. However, it is actually reasonable. When the thickness of Bi$_2$Te$_3$ is thinner than ca. 4 nm, the dark current of Bi$_2$Te$_3$ is relative smaller on account of its discontinuous nature. Thus, the WS$_2$ channel dominants the dark current of the WS$_2$/Bi$_2$Te$_3$ photodetector. Since the quality of WS$_2$ increases as the thickness of Bi$_2$Te$_3$ increases, its defect doping thus decreases, resulting in the decrease of the dark current of the WS$_2$ channel. Thus, the dark current of WS$_2$/Bi$_2$Te$_3$ (2 nm) is slightly larger than that of WS$_2$/Bi$_2$Te$_3$ (4 nm). As the thickness of Bi$_2$Te$_3$ increases to 6 nm, it becomes totally continuous and its dark current is much larger than that of WS$_2$. As a result, the dark current WS$_2$/Bi$_2$Te$_3$ (6 nm) is much larger. Other parameters such as the variation of the contact barrier between the electrode and the channel may also affect, which demands further investigation.

![Figure S5. Dark current of the WS$_2$/Bi$_2$Te$_3$ photodetectors.](image-url)
S6. Application of the interface engineering methodology to PLD-grown MoS$_2$

Figure S6. (a) (002) diffraction peaks of the MoS$_2$ grown on SiO$_2$ and Bi$_2$Te$_3$. (b) Voltage dependent photocurrent of the MoS$_2$ and MoS$_2$/Bi$_2$Te$_3$ photodetectors.