GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO

Graphene online 2020 October 19-23

Fast-Response Single-Nanowire Photodetector Based on ZnO-WS_2 Core-Shell Nanowire Heterostructures

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ABSTRACT

The surface plays an exceptionally important role in nanoscale materials, exerting a strong influence on their properties. Consequently, even a very thin coating can greatly improve the optoelectronic properties of nanostructures by modifying the light absorption and spatial distribution of charge carriers. To use these advantages, ZnO-WS2 core/shell nanowires with a-few layers thick WS2 shell were fabricated. These heterostructures were thoroughly characterized by scanning and transmission electron microscopy, X-ray diffraction, and Raman spectroscopy. Then, a single-nanowire photoresistive device was assembled by mechanically positioning ZnO-WS2 core-shell nanowires onto gold electrodes inside a scanning electron microscope. The results show that a few layers of WS2 significantly enhance the photosensitivity in the short wavelength range and drastically (almost 2 orders of magnitude) improve the photoresponse time of pure ZnO nanowires. The fast response time of ZnO-WS2 core-shell nanowire was explained by electrons and holes sinking from ZnO nanowire into WS2 shell, which serves as a charge carrier channel in the ZnO-WS2 heterostructure. First-principles calculations suggest that the interface layer iWS2, bridging ZnO nanowire surface and WS2 shell, might play a role of energy barrier, preventing the backward diffusion of charge carriers into ZnO nanowire

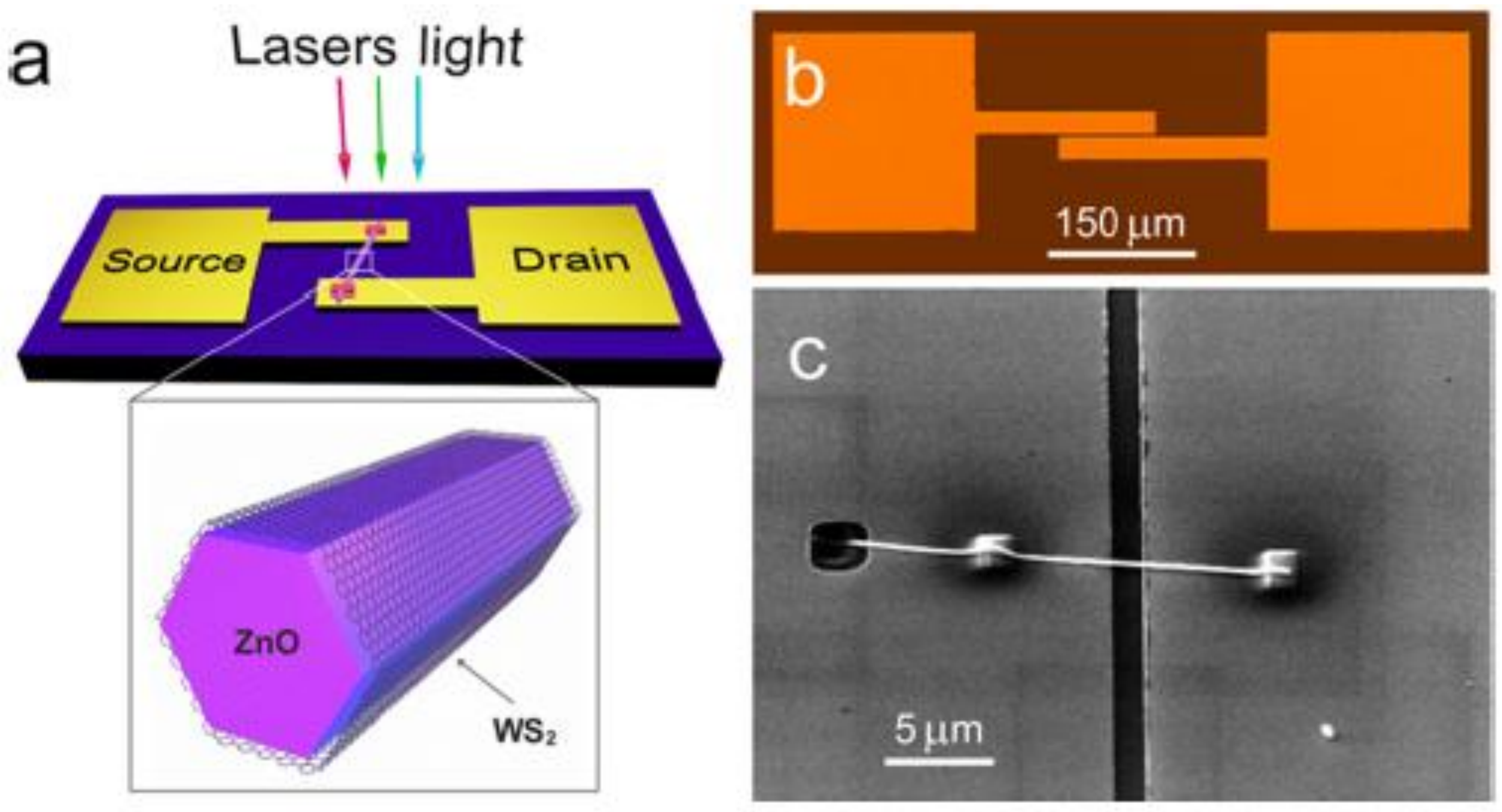

Figure 1. Schematics of ZnO/WS2 core/shell nanowire-based photodetector (a). Optical microscope image of gold microelectrodes on the oxidized silicon substrate (b). SEM image of a typical nanowire photoresistor (c).

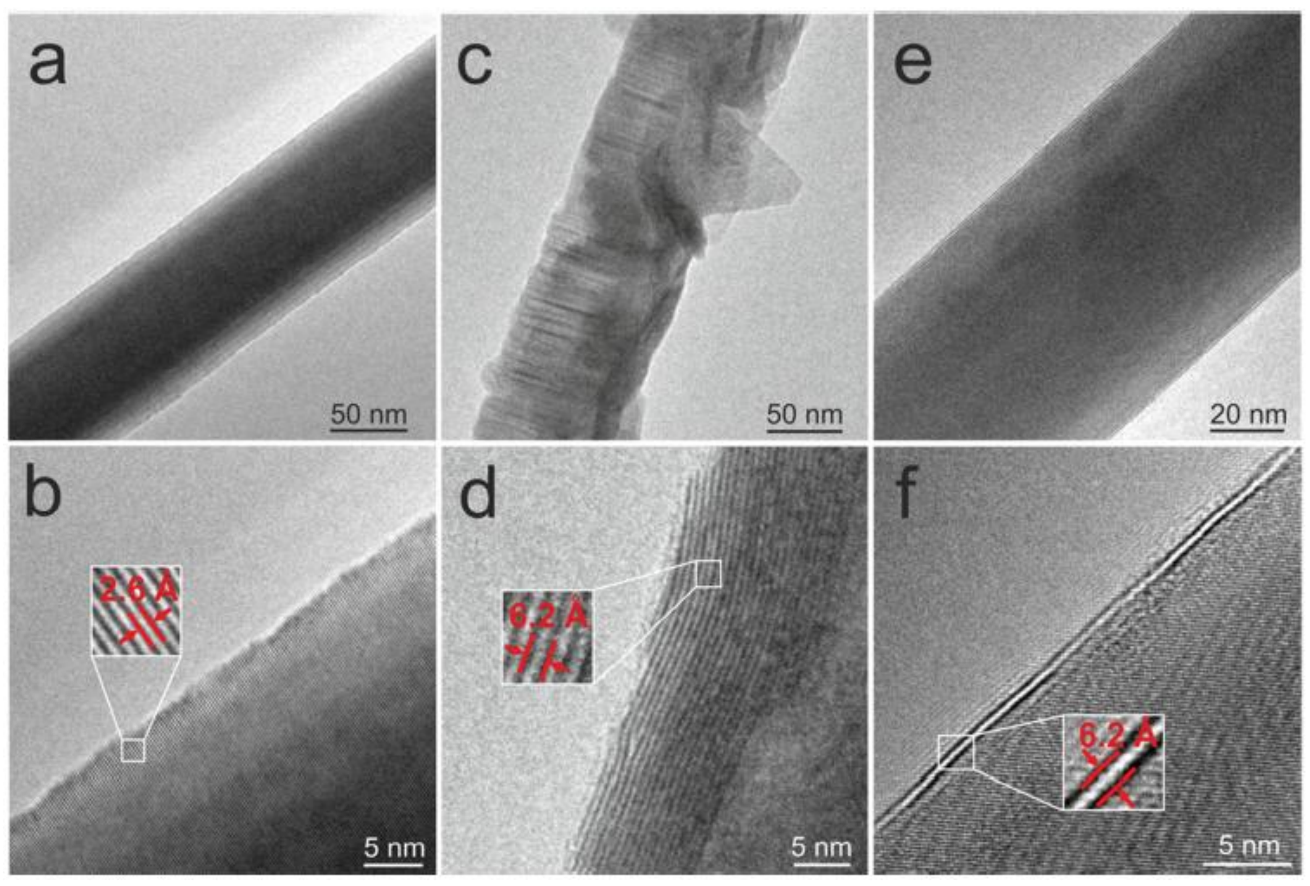

Figure 2. TEM images of pure ZnO nanowire (a, b), ZnO/WS2 nanowire annealed in sulfur atmosphere (c, d), and ZnO/WS2 nanowire additionally annealed in an inert atmosphere (e, f).

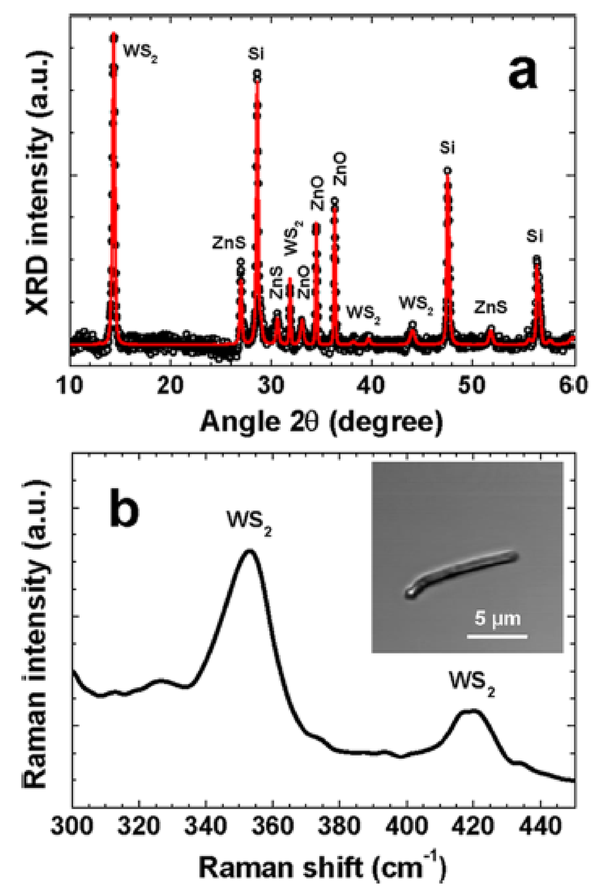

Figure 3. X-ray diffraction pattern of the ZnO/WS2 sample (a). Raman spectrum of the ZnO/WS2 NWs (b).

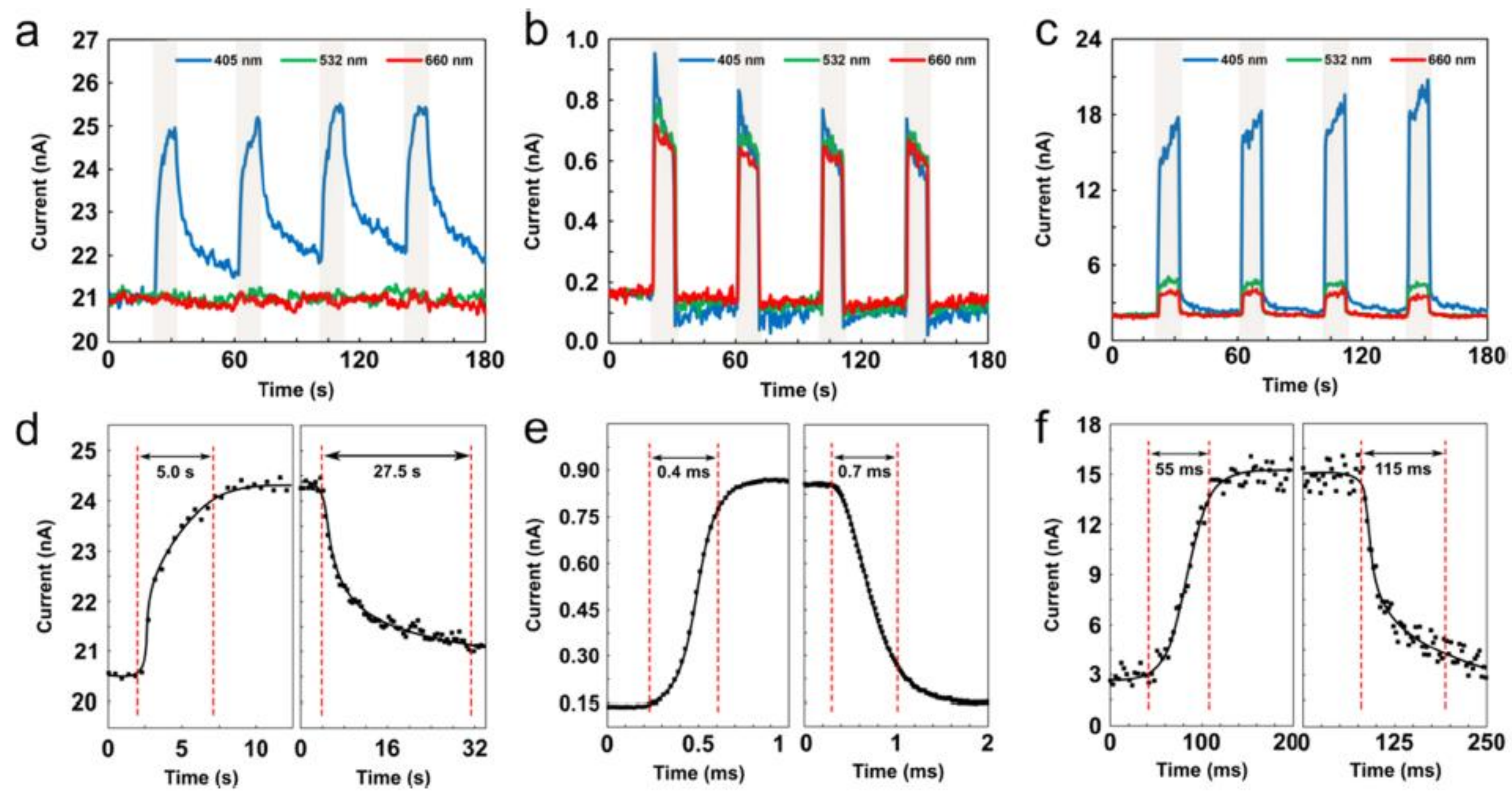

Figure 4. On–off photoresponse measurements of ZnO nanowire (a, d), WS2 flakes (b, e), and ZnO/WS2 nanowire (c, f) photoresistors at 1 V bias voltage and light illumination using 0.5 W/cm2 light intensity of 405, 532, and 660 nm wavelengths.

Table 1. Characteristic Parameters of Photodetectors Fabricated from Pure ZnO and ZnO/WS2 Core/Shell NWs as well as WS2 Flakes

Table 1. Photoresponse (Rise and Decay) Time of Photodetectors Fabricated from Pure ZnO and ZnO/WS_2 Core/Shell NWs as well as WS_2 Flakes

	ZnO NWs		WS_2 flakes		ZnO/WS_2 NWs	
wavelength (nm)	rise (s)	decay (s)	rise (ms)	decay (ms)	rise (ms)	decay (ms)
405	5	27.5	0.4	0.7	55	115
532			0.3	0.65	21	95
660			0.53	1.35	22	50

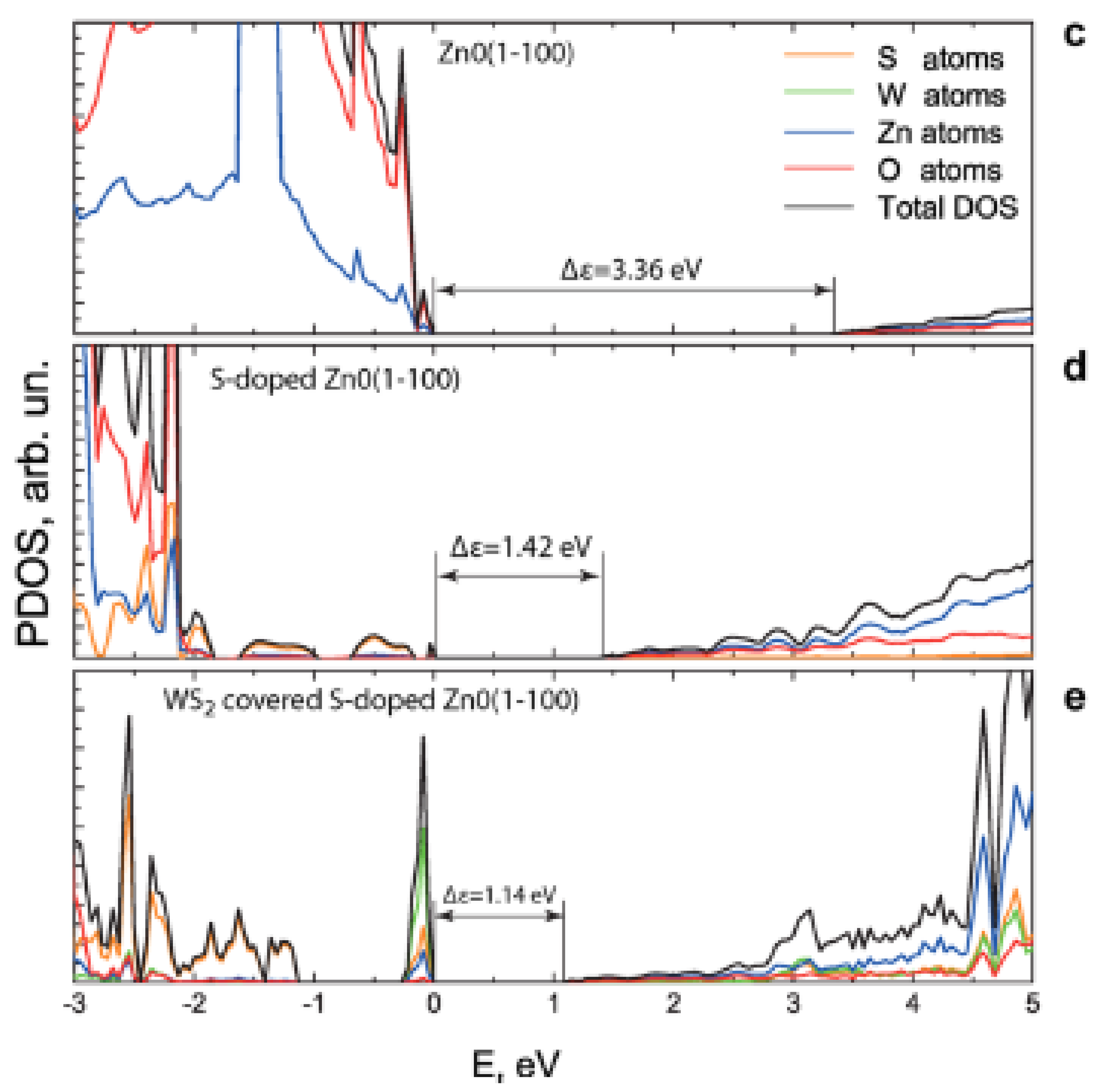

Figure 5. Simplified band diagram of the ZnO/WS2 core–shell NW (a). Atomic structure of ZnO/WS2 interface (b). Total and projected densities of states (DOSs) of (c) n-type ZnO ($\bar{1}$100) substrate, (d) S-doped ZnO ($\bar{1}$100) substrate, and (e) WS2 covered S-doped ZnO ($\bar{1}$100) substrate as calculated by means of density functional theory. Zero energy corresponds to the top of the valence band.

In summary, an effective photodetector based on ZnO/WS2 core/shell nanowire (with a few layers of WS2) is demonstrated in this work. The photodetector responds to illumination at the wavelengths of 660 nm (Rλ = 1.75), 532 nm (Rλ = 2.25), and 405 nm (Rλ = 7). The ZnO/WS2 core/shell nanowire-based device shows a clear advantage over pure ZnO nanowire-based photodetector in terms of both higher responsivity (4.6-fold) and faster operation (90-fold) for 405 nm illumination. The photodetector band diagram was supported by the first principles calculations, suggesting that the interface layer i- WS2, bridging ZnO nanowire surface, and WS2 shell, might play an important role in preventing backward diffusion of charge carriers into the ZnO nanowire, whereas WS2 shell serves as a charge carrier channel in the ZnO/WS2 heterostructure. The obtained results clearly show the potential of combining layeread 2D TMDs materials with semiconducting nanowires to create novel core/shell hetero- structures with advanced optoelectronic properties

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REFERENCES

[1] E. Butanovs, S. Vlassov, A. Kuzmin, S. Piskunov, J. Butikova, B. Polyakov. Fast-response single-nanowire photodetector based on ZnO/WS_2 core/shell heterostructures. ACS Appl. Mater. Interfaces. 10, 13869-13876 (2018)

[2] B. Polyakov, K. Smits, A. Kuzmin, J. Zideluns, E. Butanovs, J. Butikova, S. Vlassov, S. Piskunov, Y. Zhukovskii. Unexpected epitaxial growth of a few WS_2 layers on {11-00} facets of ZnO nanowires. J. Phys. Chem. C. 120, 21451-21459 (2016)

Graphene online 2020