Supplementary Information

Waveguide-integrated self-powered van der Waals heterostructure photodetector with high performance at telecom wavelength

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S1. Tunable optoelectronic characteristics of the MZI-integrated BP/MoS_2 photodetector by simple electrostatic gatings.

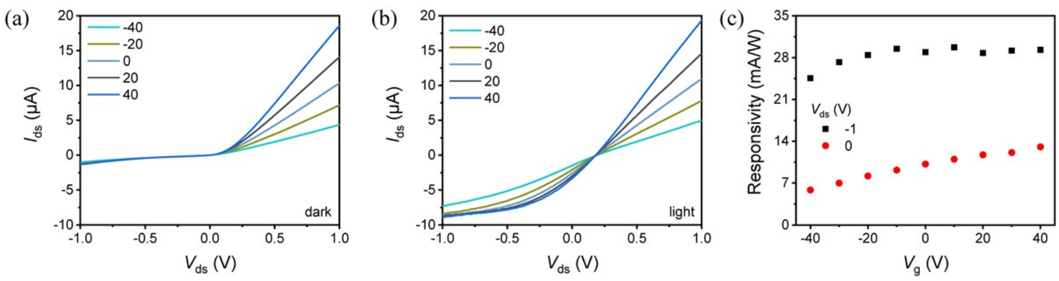

Figure S1. (a) and (b) Gate tunable *I-V* characteristics of the photodetector under dark and illuminated condition, respectively. (c) Responsivities of the device as a function of back gate voltages at -1 V and 0 V.

The gate-tunable electrical characteristics were investigated. Figure S1(a) and (b) present the output *I-V* characteristics under the dark condition and illuminated condition, respectively, in which the current gradually increased at voltages between -1 and 1 V in accordance with an increase in the gate voltage from -40 to 40 V.

We measure the responsivities of the photodetector under zero-bias and reverse bias of 1 V as a function of the gate voltage, as shown in Fig S1(c). In all cases, the responsivity increases with increasing the gate voltage. The responsivity is improved from 5.84 mA W^{-1} to 13.06 mA W^{-1} for the zero-bias case and 24.56 mA W^{-1} to 29.30 mA W^{-1} for the case of V_{ds}= -1 V. These results indicate that the photoresponse of the MZI-integrated BP/MoS_2 transistor can be actively controlled and gradually tuned by the electrical gate, which can be a promising adaptive photodetector/voltaic device.

S2. Comparison with BP/MoS_2 photodetectors operating in the free space.

Table S1. A summary of BP/MoS_2 heterojunction photodetectors.

Material	Wavelength	Response time	Ref.
BP/MoS_2	365 nm to 660 nm	>10 s	1
BP/MoS_2	532 nm 1.55	15 µs	2
BP/MoS_2	650 nm 1000 nm	13 µs	3
BP/MoS_2	582 nm	<1 s	4
BP/MoS_2	650 nm 808 nm	~50 µs ~50 ms	5
BP/MoS_2	1527.4 nm	2.08 µs/3.54 µs	This work

We compare the performance of our waveguide-integrated BP/MoS_2 photodetector with other reported BP/MoS_2 photodetectors operating in the free space, as shown in Table S1. Compared with the BP/MoS_2 photodetectors operating in the free space, our waveguide-integrated BP/MoS_2 photodetector has a faster response speed. This could be attributed to the enhanced light-matter interaction on the BP/MoS_2 van der Waals junction, which improves the light absorption as well as the photoresponse. Benefiting from the orthogonal directions in the path of photogenerated carriers and light propagation, the trade-off between the responsivity and rise/decay times in photodetectors can be overcome for high response and fast speed device. Moreover, the waveguide-integration architecture has much smaller device footprint, which therefore could reduce the dark current and promise much higher response speed.

S3. Theory of grating design of waveguide

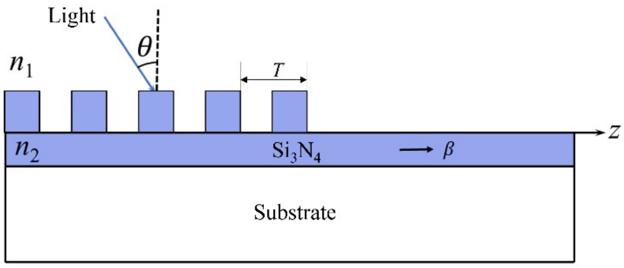

Figure S2. Schematic of light coupling into the grating coupler.

Figure S2 shows, the Bragg condition $\frac{2\pi}{\lambda}n_1\sin\theta + m\frac{2\pi}{T} = \beta$ should be satisfied when coupling, where λ represents the wavelength coupled into, n_1 is the refractive index of air, θ is the incident angle, T is the grating period, m is the diffraction order, and β is the propagation constant of traveling wave in the waveguide. When λ (m = 0 and θ, T, β are constants) is changed, owing to the mismatch of two sides of the Bragg condition, grating couplers could only support relative flat spectral coupling around the central wavelength $\frac{2\pi n_1\sin\theta}{\beta}$, i.e., there is a limited bandwidth.

References

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