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Supplementary information

High photosensitivity and broad spectral response of multi-layered germanium sulfide transistors

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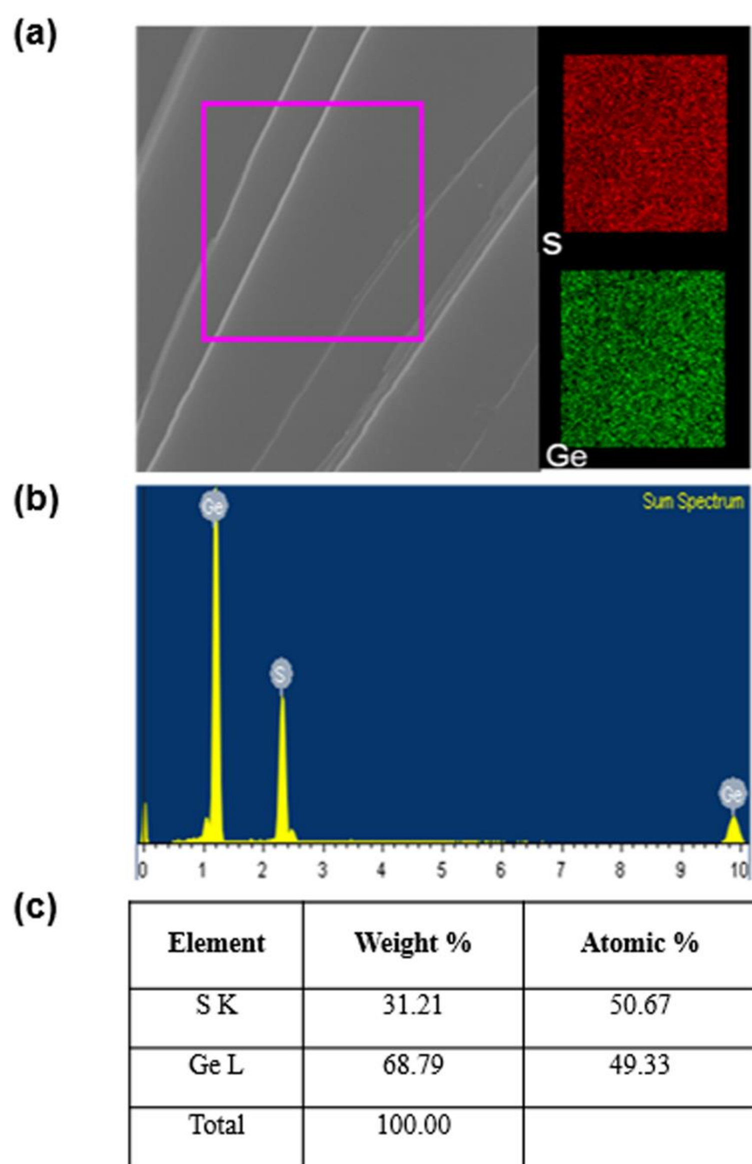
Table S1. Summary of performance metrics of the IV- VI group-based 2D photodetectors

Materials	Spectral window	Channel thickness/ length	Measurement condition	Incident power	R_λ (A/W)	τ_l/τ_t	EQE (%)	D* (Jones)	Response time	Ref.
Multi-layered SnS_2	Visible	~80 nm/ 2 μm	V_g = 0 V V_{ds} = 2 V	0.24 μW	8.8×10^{-3} (457 nm)	$\sim3.0\times10^{-1}$	NR	2×10^{9}	~5 μs	S1
Multi-layered SnS_2	Visible	~108 nm/ 5 μm	V_{ds} = 10 V	1 mW/cm^2	2 (450 nm)	$\sim5.1\times10^{1}$	NR	NR	~42 ms	S2
Multi-layered GeSe	IR	57 nm/ 10 μm	V_{ds} = 4 V	283 mW/cm^2	3.5 (808 nm)	$\sim9.4\times10^{2}$	530	NR	100 ms	S3
GeS nanoribbon	Visible	41 nm/ 5 μm	V_{ds} = 5 V	0.25 μW/cm^2	139.9 (530 nm)	$\sim8.0\times10^{3}$	3.37×10^{4}	NR	850 ms	S4
Multi-layered GeS	Visible	~28 nm/ 13 μm	V_g = 0 V V_{ds} = 10 V V_g = -80 V V_{ds} = 10 V	1.5 μW/cm^2 10 μW/cm^2	206 (633 nm) 655 (633 nm)	$\sim1.4\times10^{4}$	4×10^{4}	2.35×10^{13}	~7 ms	This work

V_g: back gate voltage; V_{ds}: source-drain voltage; R_λ: photoresponsivity; τ_l/τ_t: ratio of carrier lifetime (τ_l) to transit time (τ_t); EQE: external quantum efficiency; D*: specific detectivity; NR: not reported.



Element	Weight %	Atomic %
S K	31.21	50.67
Ge L	68.79	49.33
Total	100.00	

Fig. S1 (a) Elemental mapping of the as-synthesized bulk GeS crystal. (b) EDS spectrum of the bulk GeS crystal. (c) Analysis of the weight and atomic percentages of the GeS crystal reveals the stoichiometric ratio of Ge:S of ~ 1:1.

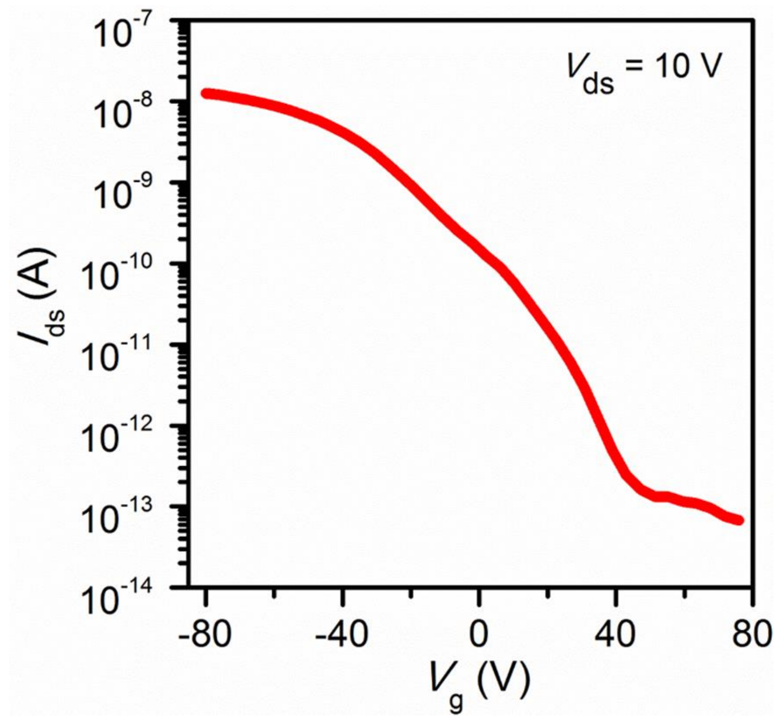


Fig. S2 The measured I_{ds}–V_g curve of a multi-layered GeS-FET indicates the on/off current ratio of ~10^5.

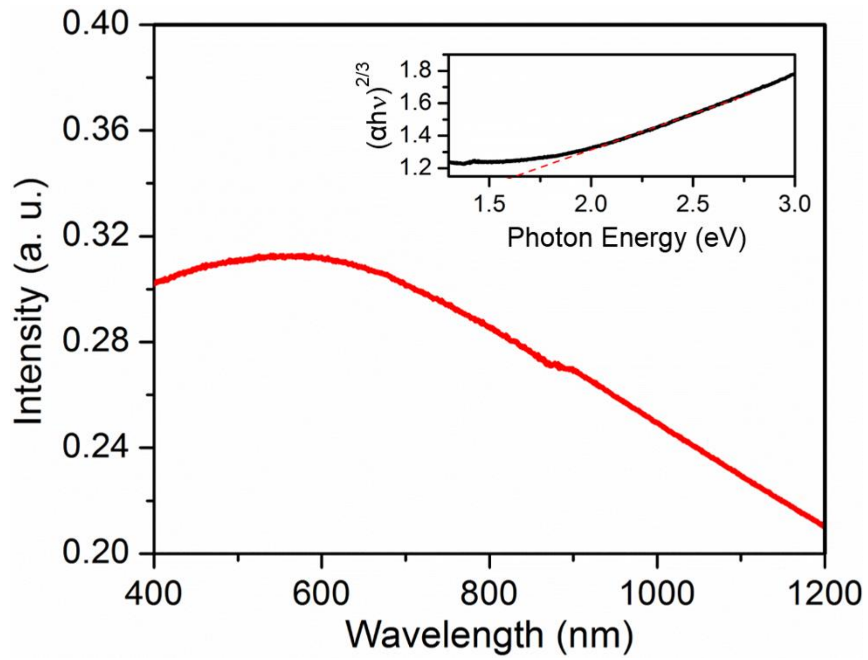


Fig. S3 An absorption spectrum of bulk GeS crystal was observed. In the inset, the band gap of the bulk GeS crystal is estimated to be ~1.63 eV by fitting the measured data to a Tauc's plot.

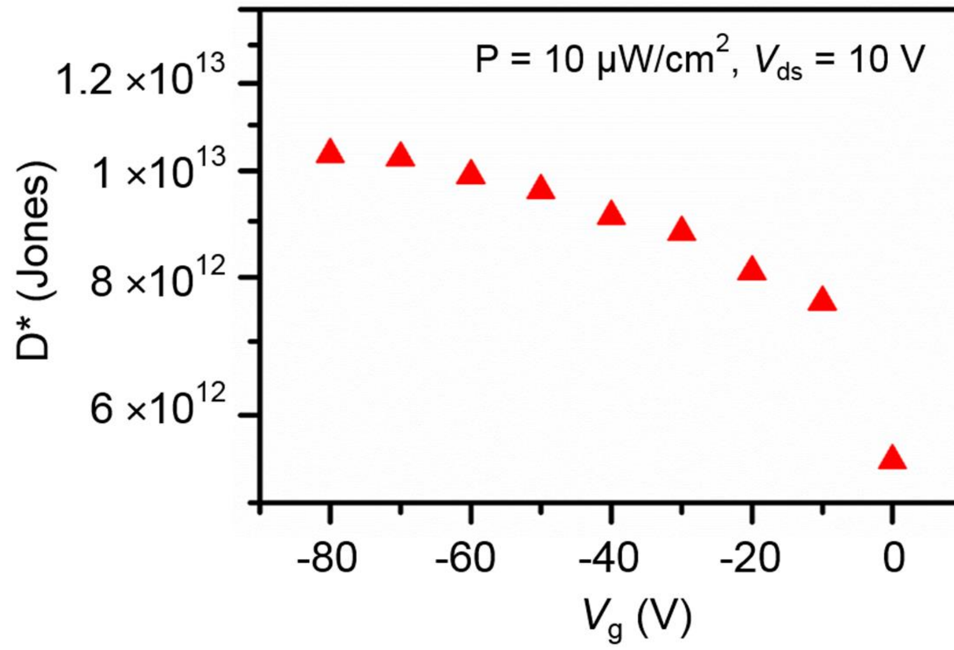


Fig. S4 D* of a multi-layered GeS photodetector as a function of V_g was measured at V_{ds} = 10 V and P = 10 μW/cm^2 at 633 nm.

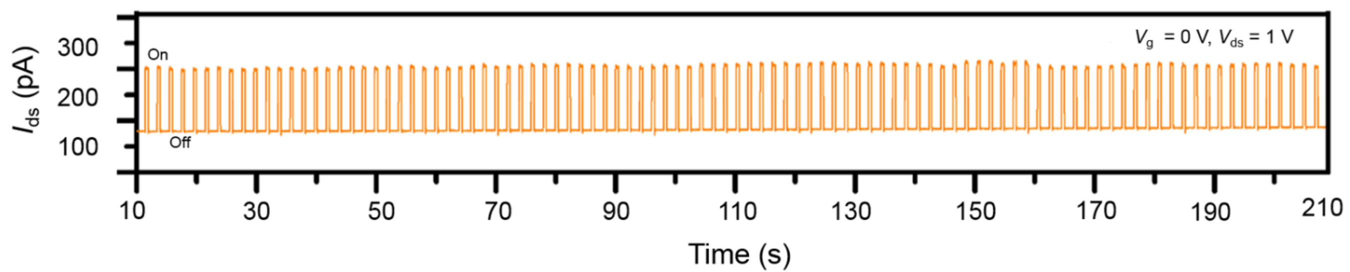


Fig. S5 Photoswitching stability of a GeS photodetector in response to a long train (~100 cycles) of pulsed illumination at P = 12.7 mW/cm^2 (λ = 633 nm), V_g = 0 V, and V_{ds} = 1 V.

REFERENCES

S1 G. Su, V. G. Hadjiev, P. E. Loya, J. Zhang, S. Lei, S. Maharjan, P. Dong, P. M. Ajayan, J. Lou and H. Peng, *Nano Lett*., 2015, **15**, 506.

S2 J. Xia, D. Zhu, L. Wang, B. Huang, X. Huang and X.-M. Meng, *Adv. Funct. Mater*., 2015, **25**, 4255.

S3 B. Mukherjee, Y. Cai, H. R. Tan, Y. P. Feng, E. S. Tok and C. H. Sow, *ACS Appl. Mater. Interfaces*, 2013, **5**, 9594.

S4 C. Lan, C. Li, Y. Yin, H. Guo and S. Wang, *J. Mater. Chem. C*, 2015, **3**, 8074.