RESEARCH ARTICLE

Suppressing nucleation and slow-kinetic epitaxial growth of large domain 2D nonlayered β-In^2S^3 nanoflakes via water molecules for optoelectronic devices

Liqi He[1], Luwei Zou[1], Zian Li[1], Xiulian Fan[1], Chenyang Niu[1], Xilong Zhou[1], Cheng Li[1], Wenlong Chu[1], Huanzhi Chen[1], Yuqi Zou[1], Lin Mei[2], Yu Zhou[1,2,3,*]

[1] School of Physics and Electronics, Hunan Key Laboratory of Nanophotonics and Devices, Central South University, Changsha 410083, China

[2] State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, China

[3] State Key Laboratory of Precision Measuring Technology and Instruments, Tianjin University, Tianjin 300072, China

Corresponding author. E-mail: [†]yu.zhou@csu.edu.cn

Received January 22, 2026; accepted March 3, 2026

Supporting Information

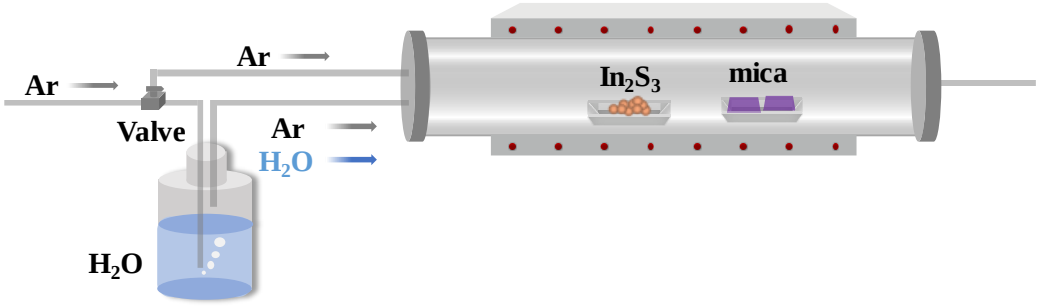

Figure S1. Experimental setup of water-assisted vapor deposition of 2D In_2S_3 nanoflakes, in which the valve can tune whether H_2O is introduced to growth system.

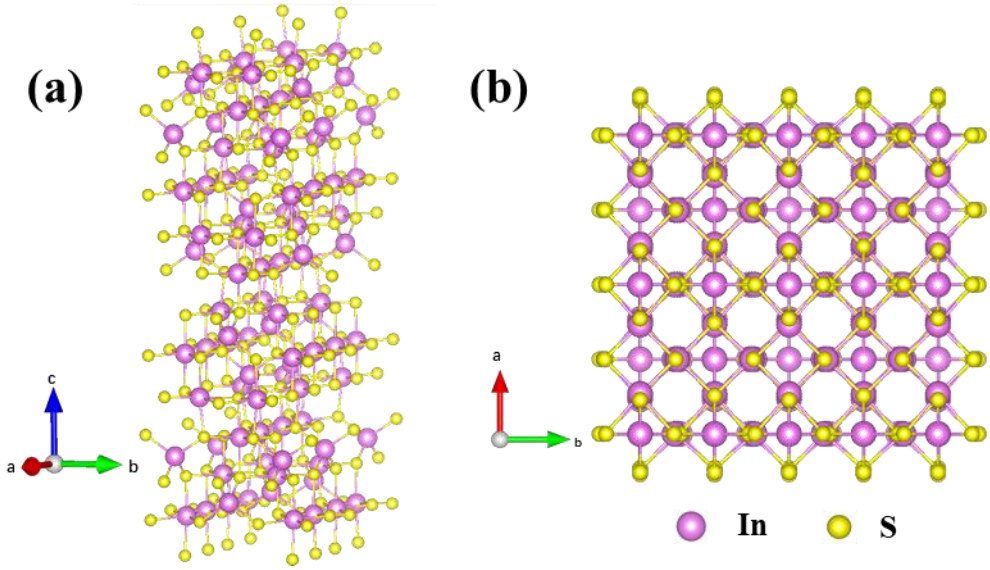

Figure S2. Atomic diagram of β-In_2S_3 crystal structure.

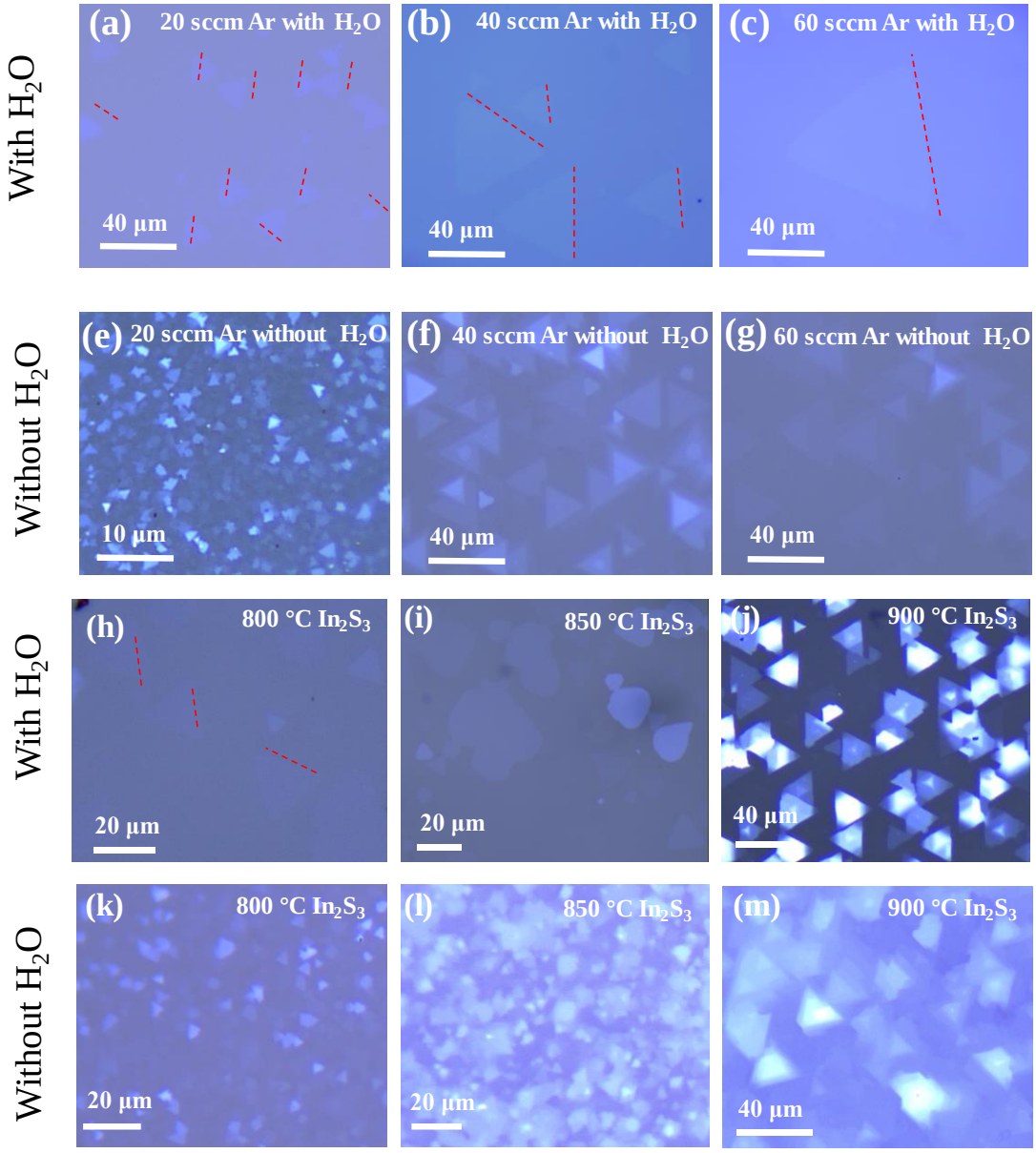

Figure S3. The nucleation density comparison of normal vapor deposition, water-assisted growth of 2D In_2S_3 nanoflakes.

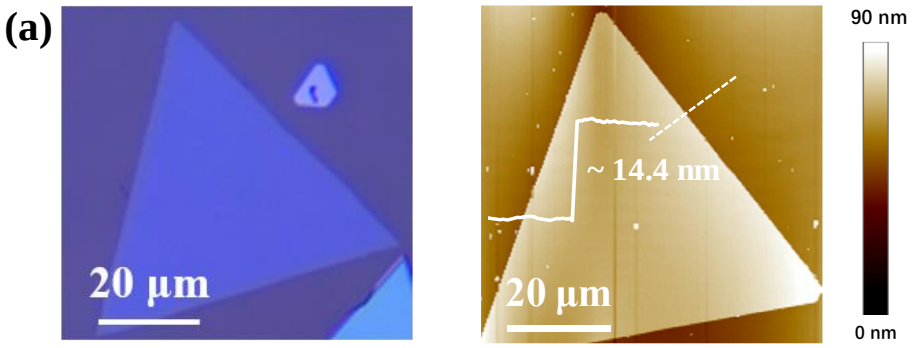

Figure S4. Optical image and corresponding AFM image of 2D β-In_2S_3 nanoflake of 14.4 nm on mica.

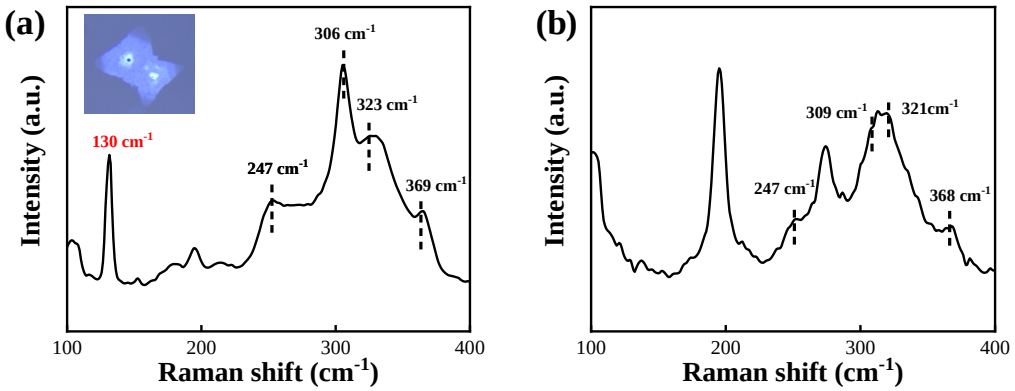

Figure S5. (a) Raman spectrum of β-In_2S_3 exposed to ambient air for six months. (b) Raman spectrum of β-In_2S_3 stored under vacuum for six months.

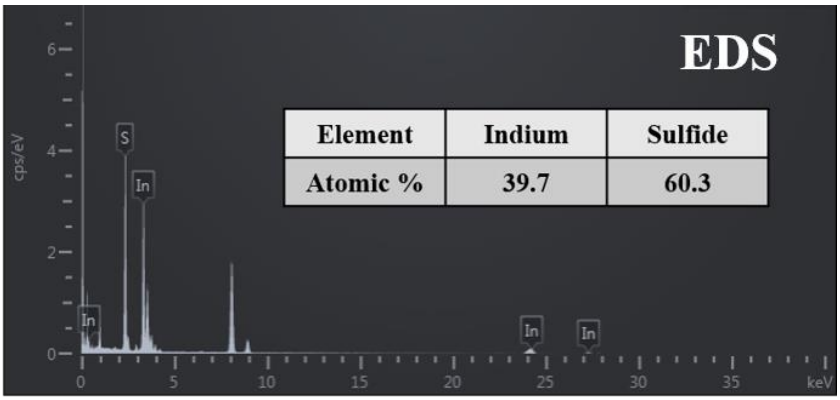

Figure S6. EDS elemental analysis of β-In_2S_3 nanoflakes.

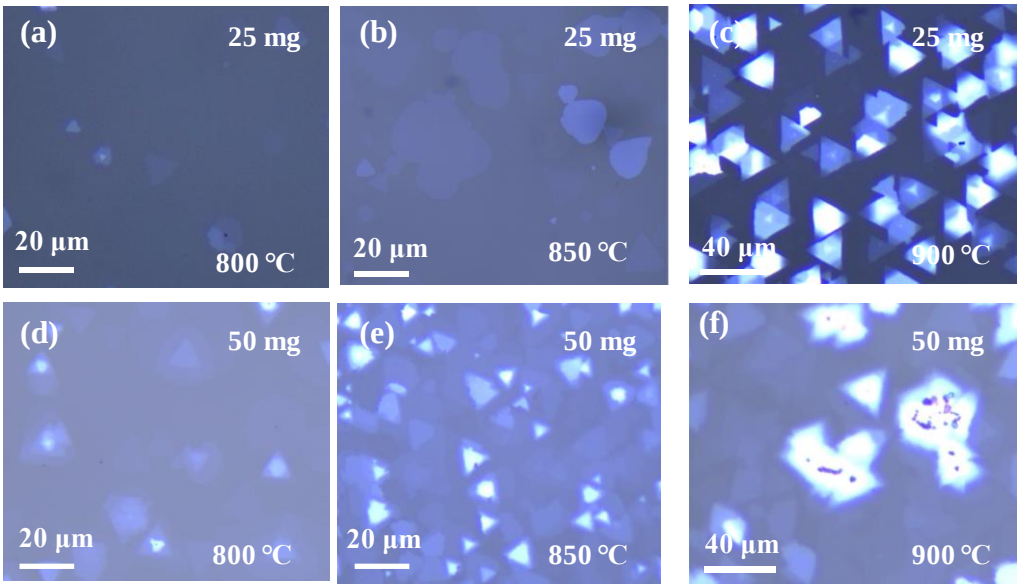

Figure S7. Optical images of In_2S_3 grown on mica by evaporation of 25 mg and 50 mg In_2S_3 powder at 800 °C, 850 °C and 900 °C.

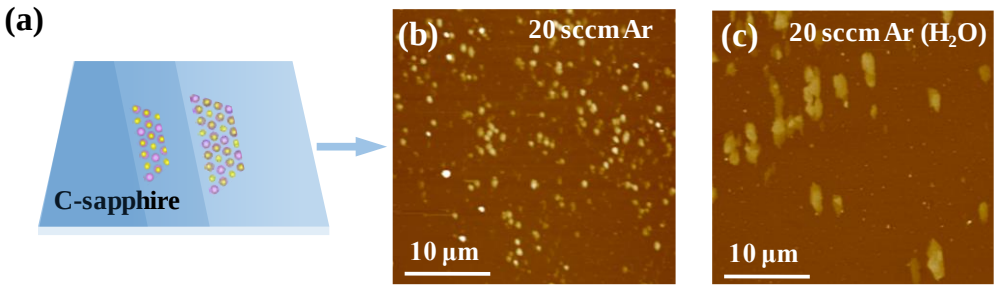

Figure S8. (a-c) Schematic illustration and the AFM images of 2D β-In_2S_3 grown on c-Al_2O_3 substrate obtained at 20 sccm Ar flowing with (or without) H_2O vapor.

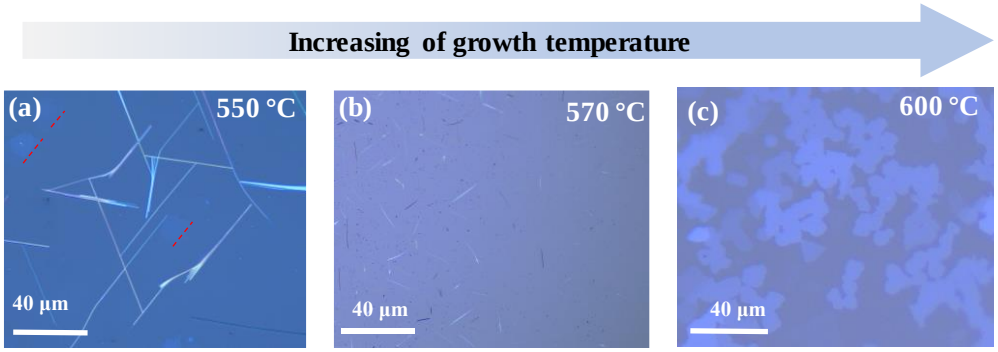

Figure S9. Optical images of In_2S_3 obtained at different growth temperatures of 550 °C (a), 570 °C (b), 600 °C (c), respectively.

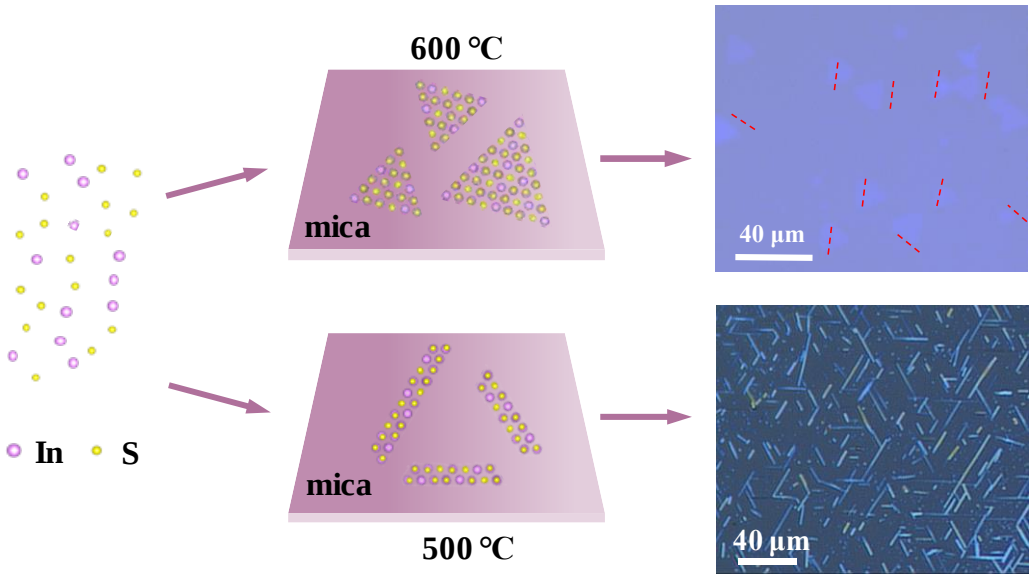

Figure S10. Schematic illustration of 2D β-In_2S_3 grown on mica substrates at different temperatures.

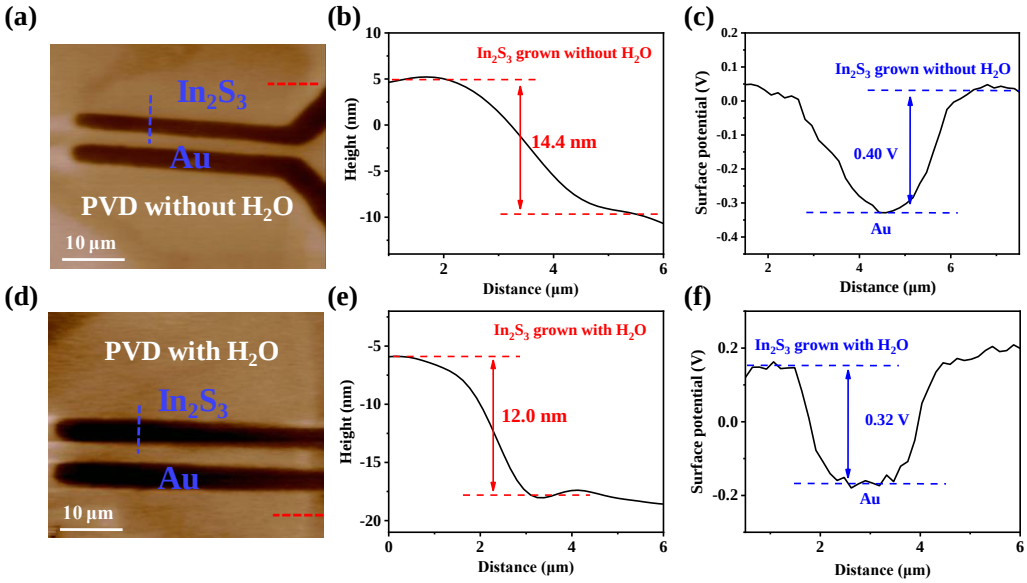

Figure S11. (a) KPFM mapping image of β-In_2S_3 nanoflakes grown without H_2O. (b) Height statistics along red line in (a) showing β-In_2S_3 thickness is 14.4 nm. (c) Surface potentials along blue line in (a) demonstrating a difference of 0.40 V between Au and β-In_2S_3 nanoflakes grown without H_2O. (d) KPFM mapping image of β-In_2S_3 nanoflakes grown with H_2O. (e) Height statistics along red line in (d) showing β-In_2S_3 thickness is 12.0 nm. (f) Surface potentials along blue line in (d) demonstrating a difference of 0.32 V between Au and β-In_2S_3 nanoflakes grown with H_2O.

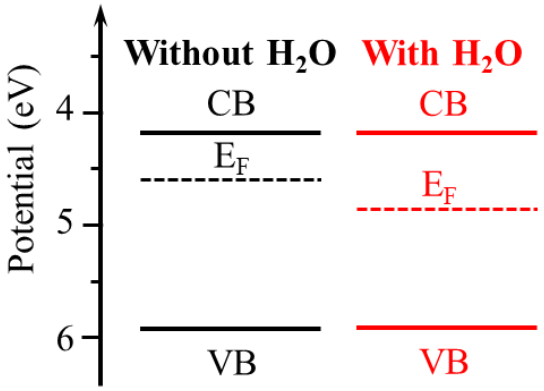

Figure S12. Band structure diagram of β-In_2S_3 nanoflakes grown with (or without) water.

Table S1. Key parameters of In_2S_3 based photodetectors of this work and previously researched devices. The response time can be roughly estimated by $t = \frac{2l^2}{u_n \cdot V}$, where l is the channel length, V is the bias voltage and u_n is the mobility of carriers.

Device	Bias (Gate) (V)	Wavelength (nm)	Channel length (μm)	Responsivity (A/W)	Rise/decay time (ms)	Reference
CVD In_2S_3/graphene	1	808	5	4.9×10^{-4}	-	[1]
CVD In_2S_3	1	450	-	137	6/8	[2]
PVD In_2S_3	1(-10)	532	14	11.2	90/80	[3]

PVD In_2S_3	**-2**	**405**	**50**	**-**	**460/40**	**[4]**
PVD In_2S_3	**1**	**650/520**	**6**	**44**	**6/7**	**This work**

References

[1] Chen, L., Li, Z. & Yan, C. High-performance near-infrared Schottky-photodetector based graphene/In_2S_3 van der Waals heterostructures. *RSC Advances* **10**, 23662-23667 (2020). https://doi.org/10.1039/d0ra02033h

[2] Huang, W. *et al.* Controlled Synthesis of Ultrathin 2D β-In_2S_3 with Broadband Photoresponse by Chemical Vapor Deposition. *Advanced Functional Materials* **27**, 1702448 (2017). https://doi.org/10.1002/adfm.201702448

[3] Yu, D. *et al.* Growth of large-area two-dimensional non-layered β-In_2S_3 continuous thin films and application for photodetector device. *Journal of Materials Science: Materials in Electronics* **31**, 18175 (2020). https://doi.org/10.1007/s10854-020-04366-8

[4] Lu, J. *et al.* Epitaxial growth of large-scale In_2S_3 nanoflakes and the construction of a high performance In_2S_3/Si photodetector. *Journal of Materials Chemistry C* **7**, 12104-12113 (2019). https://doi.org/10.1039/c9tc03795k