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Synthesis of Large-Area and Highly Crystalline InS Atomic Layers on Insulating Substrates

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ABSTRACT:

Group-III monochalcogenides of two-dimensional (2D) layered materials have attracted widespread attention among scientists due to their unique electronic performance and interesting chemical and physical properties.[1] However, studies on the synthesis of highly crystalline, large-area, and atomically thin-film Indium sulfide (InS) have not been reported thus far. Here, we reported the chemical vapor deposition (CVD) synthesis method of atomic InS crystals on the insulating substrates.[2] The direct chemical vapour phase reaction of metal oxides with chalcogen precursors to produce a large-sized hexagonal crystal structure and atomic-thickness InS flakes or films on the mica. The ion-gel gated InS field-effect transistors (FETs) reveal n-type transport behavior, and have an on-off current ratio of > 10^3 and a room-temperature electron mobility of ~ 2 cm^2/Vs. Moreover, our CVD InS can be transferred from mica to any substrates, so various 2D materials can be reassembled into vertically stacked heterostructures.

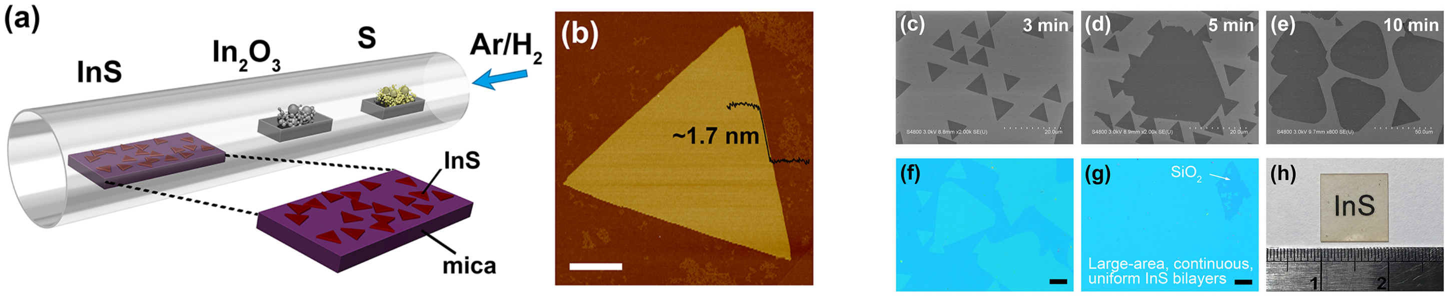

Figure 1. (a) Schematic diagram of experimental setup for CVD synthesis of InS atomic layers. (b) AFM image of bilayer InS flake. Scale bar, 10 µm. (c-e) Low-magnification SEM images of the bilayer InS flakes at growth times of 3, 5, and 10 min. Scale bar, 10, 10, 25 µm respectively. (f, g) OM images of the InS bilayer flakes and films. Scale bar, 10 µm. (h) Photograph of centimeter-scale bilayer InS film synthesized on a transparent mica substrate, showing highly uniform.

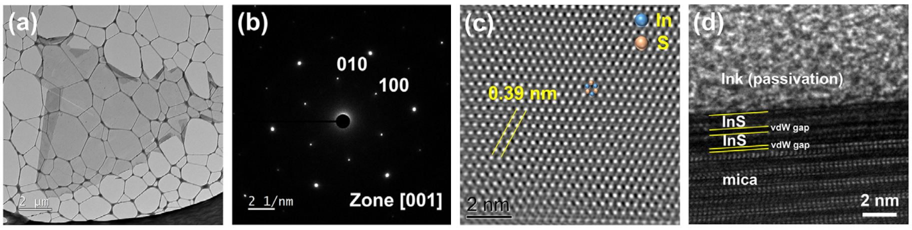

Figure 2. (a) Low-resolution TEM image of the trilayer InS flakes with triangular nanostructure and (b) its SAED pattern. (c) High-resolution HAADF STEM image of trilayer InS, where the In and S atoms are identified. (d) Cross-section TEM image of a bilayer InS film.

TABLE I. Summarization of the InS Samples from EDLT Measurements

InS samples	Polarity	V_{th} (V)	On-off ratio	μ (cm^2/Vs)
Bilayer	n-type	1.75	10^3	0.24
Trilayer	n-type	2	10^3–10^4	0.93*

* The highest mobility reached 2 cm^2/Vs

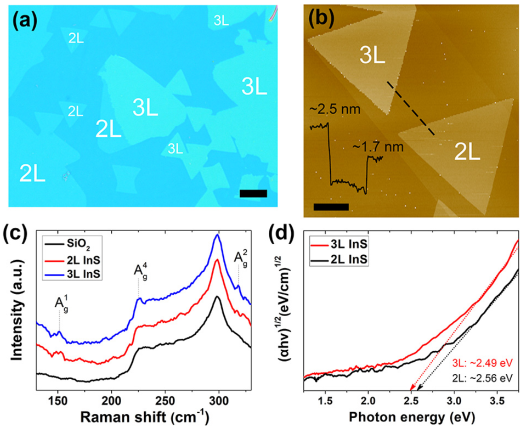

Figure 3. (a) OM and (b) AFM images of trilayer InS grown on certain of those bilayer top. Scale bar, 10 µm. (c) Raman spectra of bi- and trilayer InS flakes, excited by a 488 nm laser. (d) Plots of the $(\alpha h\nu)^{1/2}$ versus photon energy ($h\nu$) for indirect interband transitions of the continuous bi- and trilayer InS films whose x-intercepts represent the band gap energy.

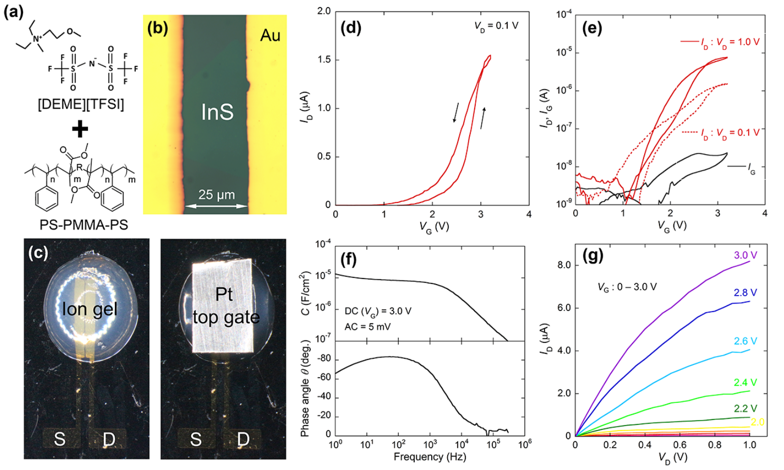

Figure 4. (a) Schematic molecular structures of the [DEME][TFSI] and PS-PMMA-PS for ion gel. (b) Top view OM image of the InS EDLT constructed on a SiO_2/Si substrate, where the Au source/drain electrodes were stacked on trilayer InS flakes. (c) Top view OM image of the InS EDLT device, which were taken before and after the ion gel and top gate stacking. (d) Linear scale and (e) Logarithmic-scale transfer curves of the InS EDLT. The V_D of 0.1 V and 1.0 V were shown by red, and the I_G for V_D of 0.1 V was also displayed by gray. (f) The frequency dependence of the specific capacitance and the phase angle for InS EDLT. (g) Output characteristics of the InS EDLT with Au top-contact electrode. The V_G was varied from 0 V to 3.0 V.

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REFERENCES

1. Han-Ching Chang, Chien-Liang Tu, Kuang-I Lin, Jiang Pu, Taishi Takenobu, Chien-Nan Hsiao, Chang-Hsiao Chen*, Small, 14 (2018) 1802351.
2. Chien-Liang Tu, Kuang-I Lin, Jiang Pu, Tsai-Fu Chung, Chien-Nan Hsiao, An-Ci Huang, Jer-Ren Yang, Taishi Takenobu, Chang-Hsiao Chen*, Nanoscale, 12 (2020) 9366-9374.

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