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Wafer-scale Growth of Molybdenum Disulfide Films for High-performance Electronics Devices

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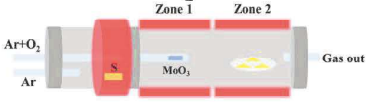
Abstract

The wafer-scale growth and transfer of molybdenum disulfide (MoS_2) are critical for advancing next-generation electronics and optoelectronics. We develop a method to grow 2-in. wafer-scale MoS_2 films by chemical vapor deposition (CVD). The as-grown MoS_2 film exhibits high uniformity and a clean surface. Such 2-in. MoS_2 films can be transferred onto SiO_2 substrates via a wet-transfer method. Field-effect transistors (FETs) fabricated from the transferred MoS_2 demonstrate excellent performance, achieving an on/off current ratio of 10^6. Furthermore, monolithic 3D (M3D) inverters were demonstrated by vertically integrating a CVD-synthesized monolayer WSe_2 p-type FET atop monolayer MoS_2 n-type FET arrays (2.5 × 2.5 cm^2), using semiconductor industry techniques, including transfer, e-beam evaporation, and plasma etching. The resulting devices exhibit an on/off current ratio exceeding 10^6 and an average voltage gain of ~9 at V_{DD} = 2 V. The integrated M3D inverter also achieves ultra-low power consumption of 0.112 nW at V_{DD} = 1 V. Statistical analysis confirms the high reliability of these devices, demonstrating their suitability for large-area applications. This work highlights the immense potential of 2D TMD-based M3D inverters for future integrated circuits.

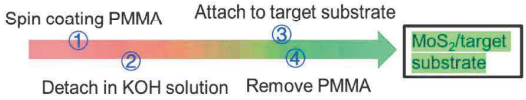
Experiments

◆ Wafer-scale Growth of MoS_2 Films



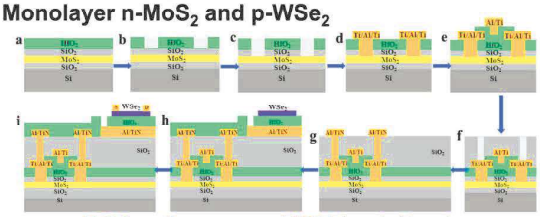
☐ Schematic diagram of the multisource CVD setup

◆ Wafer-scale Transfer of MoS_2 Films



☐ Schematic processes of transferring MoS_2 films

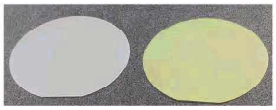
◆ Monolithic 3D Integrated Complementary Inverters Based on Monolayer n-MoS_2 and p-WSe_2



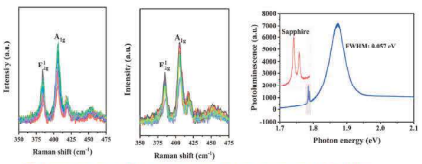
☐ Schematic processes of M3D integrated inverter

Results and Discussions

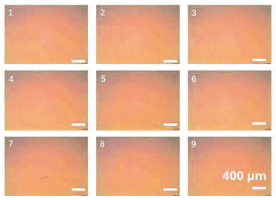
◆ Wafer-scale MoS_2 Films



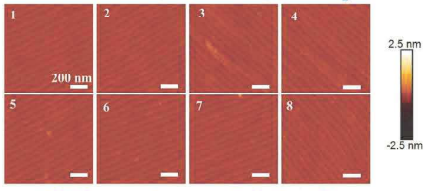
☐ Photograph of as-grown MoS_2 film



☐ Raman and PL spectrum of as-grown MoS_2 film

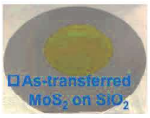


☐ OM images of as-grown MoS_2 film

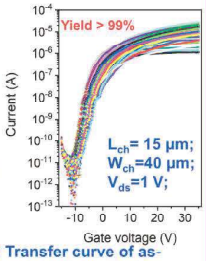


☐ AFM images of as-grown MoS_2 film (100% coverage of the wafer)

◆ Wafer-scale MoS_2 FETs

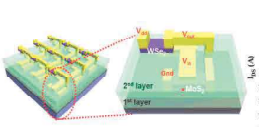


☐ OM and photography of MoS_2 FET array

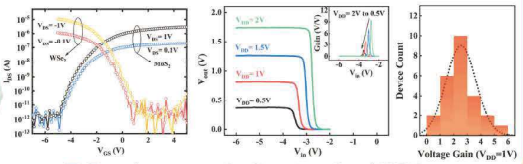


☐ Transfer curve of as-fabricated MoS_2 FET array

◆ Monolithic 3D Integrated Complementary Inverters



☐ Structural schematics of M3D inverter



☐ Transfer curve and voltage transfer of M3D inverter

Conclusions

- The 2-in. wafer-scale MoS_2 film, grown by CVD method, shows high uniformity and a clean surface.
- The as-grown MoS_2 films can be transferred with high fidelity.
- The fabricated MoS_2 FET arrays show high performance with a on/off of 10^6.
- The integrated M3D inverter based on as-grown MoS_2 film shows an average voltage gain of ~9 at V_{DD} = 2 V and an ultra-low power consumption of 0.112 nW at a V_{DD} of 1 V.