The following publication Z. Luo et al., "The fabrication of large-area and uniform bilayer MoS2 thin films," 2017 International Conference on Electron Devices and Solid-State Circuits (EDSSC), Hsinchu, Taiwan, 2017, pp. 1-2 is available at https://doi.org/10.1109/EDSSC.2017.8126544.

# The fabrication of large-area and uniform bilayer MoS2 thin films

Zhi Luo [1 *], Yunli Lin[1] , Zhao Yang[1], Junqi Qian[1], Sheung Mei Ng[2] , Chi Wah Leung[2] , Hui Wang[2,3]

1 Department of electronic engineering, Jinan University, Guangzhou 510632, People's Republic of China.

2 Department of Applied Physics, The Hong Kong Polytechnic University, Hong Kong, P.R. China.

3 School of Materials Science and Engineering, Nanchang University, Nanchang, Jiangxi 330031, China Tel: +86-20-85222481,

*Email: zhluocn@gmail.com

**Abstract:**

Here, an approach for synthesizing large-area and high-quality $MoS_2$ flakes was developed. In addition, we made up the $MoS_2$ photoelectric detector and studied the photocurrent response of the detector. We firstly used the ceramic pieces to control $MoO_3$ evaporation for obtaining large-area $MoS_2$ . Our CVD reaction is hydrogen free, very simple operation, high repetition rate and cost saving. The obtained $MoS_2$ flakes exhibited large-area with lengths up to 400-500 micrometers. Through analyzing optical microscopy (OM), Raman and atomic force microscopy (AFM), we confirm the $MoS_2$ thin film is bilayer. And the photoelectric characteristic experiment shows that the photoelectric detector has sensitive photoelectric response with the fine stability.

**Key words**: MoS2 thin film; CVD; ceramic pieces; photocurrent response.

## Introduction

Two-dimensional transition metal dichalcogenides (TMDs) have received great attention because of their interesting electronic, optical, and chemical properties. Among various TMDs, molybdenum disulfide ($MOS_2$), because of intrinsic large bandgap (1.2-1.8 eV) and flexibility, has been most extensively investigated [1]–[2][3]. It is critical to produce high-quality MoS2 thin films with large-area for the practical application of MoS2 in electronics [4]. Recently, chemical vapor deposition (CVD), which was successful in growing high-quality graphene, has been utilized to synthesize Mos2 thin films on insulating substrates, such as SiO2 and sapphire. [5] Currently, some investigation had been made on CVD processes based on the precursor S and MoO3 powder to obtain Mos2 thin film. However, these methods are complex, and the size of obtained Mos2 is small. Therefore, more work is needed to establish a simple CVD process to grow large-area uniform MoS2 thin film reproducibly.

Here, we developed a modified CVD method based on S and MoO3 powders to grow large-area few-layers Mos2 thin films on $SiO_2$/Si substrates. Our experiment method is simple and repeatable. In addition, Mos2 photoelectric detector was fabricated and the photocurrent response was investigated. The results show that the Mos2 photoelectric detector has sensitive photoelectric response and fine stability.

## Results & Discussion

We used CVD to grow $MoS_2$ with a furnace to control the temperature of $MoO_3$ and transformer to control the temperature of S separately.

Fig 1 shows the CVD setup for Mos2 growth and the temperature curves for both precursors ($MoO_3$ and S powder). Briefly, the samples were grown by CVD with solid $MoO_3$ and S precursors. In contrast to the previous work,[6] we used a furnace to control the temperature of $MoO_3$ and transformer to control the temperature of S separately. What is more, we firstly used the ceramic pieces to control $MoO_3$ evaporation for obtaining large-area MoS2. Three ceramic pieces are stacked on the upside down of ceramic boat and 6.5 milligrams of $MoO_3$ powder was put in the hole of three ceramic pieces, where they are 1.6 centimeters from the front of ceramic boat. Then, a size of 0.4 cm∗0.4 cm unpolished silicon wafer cover on the hole of three ceramic pieces with a piece of $SiO_2$ substrate tightly aligned on the unpolished silicon wafer. Also, 486 mg of sulfur powder was put in a quartz boat and the boat placed upstream relative to the gas flow direction with controlled by transformer. The distance between the two boats is 17 cm. The CVD system was first flushed with 500 seem of Ar gas for 40 min when the temperature of the furnace and quartz boat were set to 150°C and 30°C, relatively. Then the furnace was heated at a rate of 15 °*C/min* to 760°C under a flow rate of 200 seem of Ar, held at the setting temperature for 30 min, and slowly cooled down to 570°C followed by a fast cooling under 500 sccm of Ar. The temperature programming for the quartz boat having S was as follows: temperature held at 30°C until the furnace was heated for 35 min, reaching a temperature of 680°C, and then increased to 150 °C and held until the furnace cool to 570°C to turn off the transformer.

As shown in the Fig 2, large-area Mos2 film about 458 um was observed. The results are reasonable. We used the unpolished silicon wafer to cover the hole of ceramic pieces to reduce the evaporation of $MoO_3$. Along the direction of Ar, the concentration of $MoO_3$ is low to obtain Mos2 film. To make sure that the domains imaged by OM in Fig 2 were indeed bilayer Mos2, we characterized them using Raman spectroscopy and AFM (Fig 3 and Fig 4). Two characteristic Raman vibration modes can be seen in the spectra in Fig 3, the E12g mode representing the in-plane vibration of molybdenum and sulfur atoms and the Alg mode related to the out-of-plane vibration of sulfur atoms. [7] The frequency difference between two modes depends on the number of layers of $MoS_2$.

Here, the fitting results show that these two modes are located at 384.2 and 404.2 cm-1, respectively, giving a frequency difference $\Delta k$ of 20 cm-1. The full width at half-maximum (fwhm) of the E12g peak is 3.8 cm-1, which is close to that of the exfoliated Mos2, 3.7cm-1, suggesting good crystalline quality of the CVD-synthesized domains. Fig 4 give a typical AFM measurement, showing the thickness of the domain is ∼1.63 nm. This layer thickness indicate that we obtain MoS2 is bilayer.

In addition, we used the MoS2 film to make the photoelectric detector. We used the PMMA transfer methods to obtain the detached MoS2 film. Then, we used the glass to undertake the Mos2 film. After PMMA transfer, we used mask method to manufacture the MoS2 channel (Fig 5).

Fig 6 shows the photocurrent response of the single wavelength. We can clearly see the current increases rapidly when there is light on the Mos2 channel. Once there is no light, the current decreases rapidly. At the same time, the effect of different light power on the wavelength of 405 nm was studied. The higher power, the greater is the current. the total number of photons increase and the number of electronic excitation also increases, as the total energy increases with the incident light power, but single photon energy is the same under the same wavelength. This leads to current increase.

**Conclusion**

In summary, we present an approach for synthesizing Mos2 atomic layers. In addition, MoS2 photoelectric detector was fabricated and its photocurrent response was studied.

The obtained $MoS_2$ flakes exhibited large-area with lengths up to 400–500 micrometers. This simple and reliable approach opens a new way for producing highly crystalline TMDs atomic layers in a controlled manner.

**ACKNOWLEDGMENT**

Z. Luo thanks the Fundamental Research Funds for the Central Universities and The National Natural Science Foundation of China (Grant NO. 11204105) for the support.

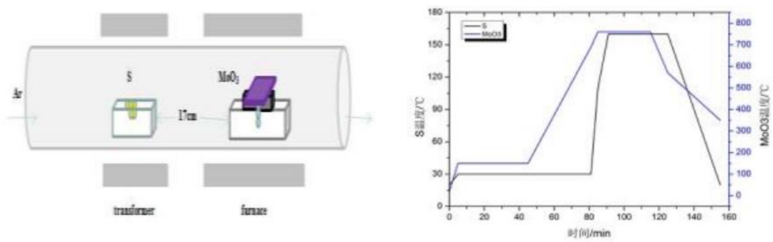

Fig. 1 Schematic illustration of CVD system and Temperature programming.

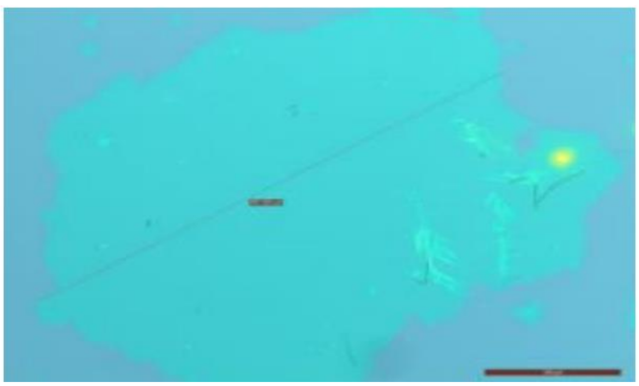

Fig. 2 OM images of large-area MoS2 film

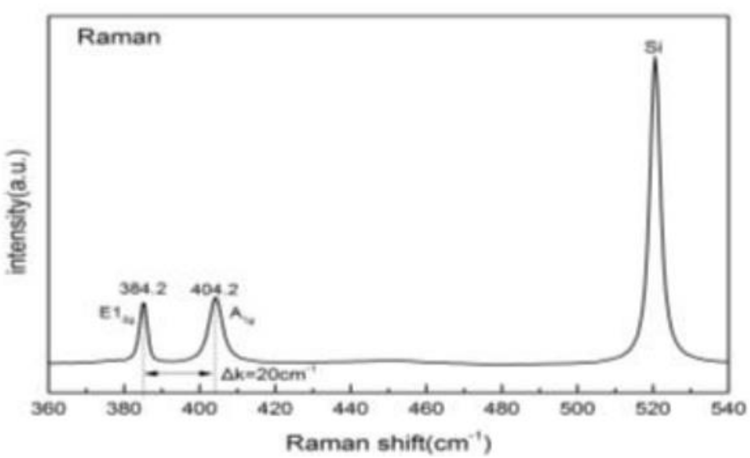


Fig. 3 Raman spectrum of MoS2 film

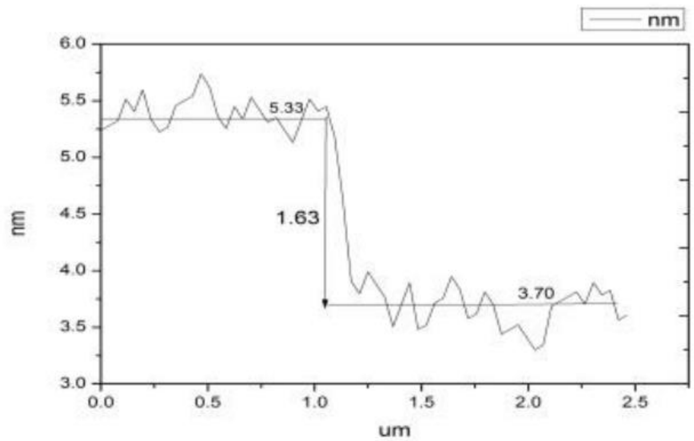


Fig. 4 AFM image and height profile for MoS2 domains

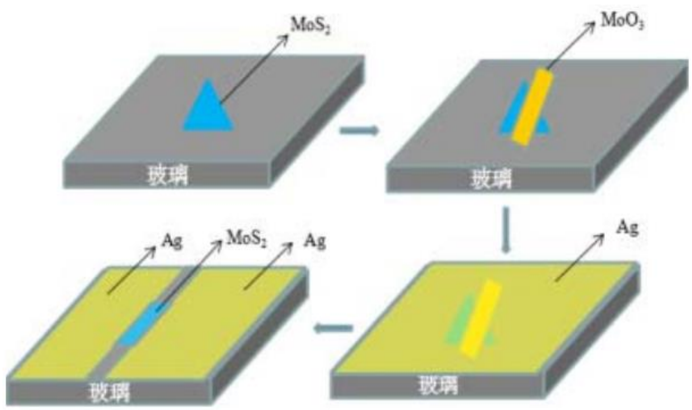


Fig. 5 The schematic diagram of the preparation of MoS2

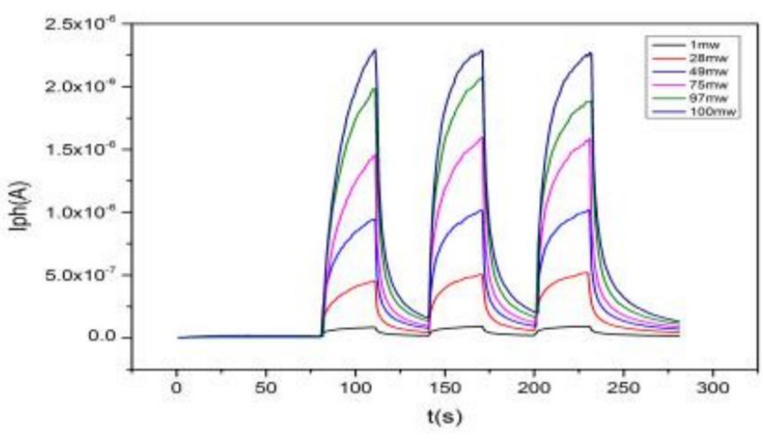


Fig. 6 The photocurrent response of the single wavelength.

References

[1] Lembke D, Bertolazzi S, Kis A. Single-layer MoS2 electronics[J]. Accounts of Chemical Research, 2015, 48(1):100.

[2] Null N. Two-Dimensional Material Nanophot- onics[J]. 2014.

[3] Bonaccorso F, Colombo L, Yu G, et al. 2D materials. Graphene, related two-dimensional crystals, and hybrid systems for energy conversion and storage[J]. Science, 2015, 347(6217):1246501.

[4] Wang Q H, Kalantarzadeh K, Kis A, et al. Electronics and optoelectronics of two-dimensional transition metal dichalcogenides[J]. Nature Nanotech- nology, 2012, 7(11):699-712.

[5] Jeon J, Jang S K, Jeon S M, et al. Layer-controlled CVD growth of large-area two-dimensional MoS 2 films[J]. Nanoscale, 2015, 7(5): 1688-1695.

[6] Van Der Zande A M, Huang P Y, Chenet D A, et al. Grains and grain boundaries in highly crystalline monolayer molybdenum disulphide[J]. Nature materials, 2013, 12(6): 554-561.

[7] Tonndorf P, Schmidt R, Böttger P, et al. Photoluminescence emission and Raman response of monolayer MoS 2, MoSe 2, and WSe 2[J]. Optics express, 2013, 21(4): 4908-4916.