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Mini Review

Two-Dimensional MoS_2 and Heterostructure Growth by Pulsed Laser Deposition

Rajib Sahu*

Max Planck Institute for Iron Research, Germany

***Corresponding author:** Rajib Sahu, Max Planck Institute for Iron Research, Düsseldorf 40237, Germany.

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Abstract

MoS_2, a two-dimensional (2D) transition metal dichalcogenides (TMDCs), have attracted significant progress in optoelectronics in recent times. Scalable, low-cost growth techniques are not still wholly optimized. This article reviews the growth method to obtain a simple, safe, cost-effective and layered controlled crystalline MoS_2. Furthermore, we will describe MoS2 based heterostructure synthesis using pulsed laser deposition (PLD).

Keywords: 2D TMDCs; MoS_2; Heterostructure; PLD

Introduction

Due to having zero band gap in two-dimensional graphene shifted the attention towards MoS_2, WS_2, and similar inorganic transition metal-based dichalcogenides. Most of them perform indirect to direct band gap crossover form bulk to monolayer make them a potential candidate for optoelectronic device applications [1-4]. MoS_2 is stabilized in 2H semiconducting state, having a band gap of 1.9 eV for monolayer and 1.28 eV for bulk [5-6]. Thinnest transistor based on MoS_2 have been already reported [2]. Based on unique excitons, spin and valley properties, MoS_2 is considered for the next-generation platform for future electronics [7-9]. The metastable 1T phase is demanding due to metallicity and shows excellent hydrogen evolution activity [10-12]. This qualitative metal-semiconducting state in 1T-2H phase transition is promising for switchable device applications [13-14].

Mechanically exfoliated and chemically synthesized TMDCs are investigated primarily for fundamental properties are not suitable for large area practical devices [15-16]. Bottom-up synthesis, namely chemical vapor synthesis (CVD), molecular beam epitaxy (MBE), metal-organic chemical vapor deposition (MOCVD), and magnetron sputtering (MS), pulsed laser deposition (PLD) are significantly successful producing scalable high quality MoS_2 thin film. However, the challenges for researchers in theses growth methods include contaminations, choice of precursor, proper precursor transport and controlled chemical reactions, formation of byproducts, growth kinetics for layered control synthesis, time, and cost. For instant MoS_2 growth in CVD has proven to be a versatile method. Still, the yield is low, and contamination is moderate due to sluggish thermal evaporation and chemical reactions of desired precursors [17]. The restriction of the choice of growth substrate is limited due to high substrate temperature [18]. Similarly, MOCVD uses metal organic gasses like $(C_2H_5)_2S$ and Mo $(CO)_6$ for chemical reactions and forms high chemical contaminations level [19]. MBE method is highly cost-effective for ultra-high vacuum and finds time consuming [20-21]. The most challenging issue is the limitation of substrate choice due to lattice miss-match between film and substrates. We find magnetron sputtering is simple, clean, scalable, low time consuming and low-cost effective but suffer from poor crystal quality, rough surface, high energy consumption [22-23]. Therefore, we look forward for a simple, fast, low cost, highly controllable, scalable, and less contaminated universal growth solution (Figure 1).

PLD has several advantages over other growth techniques and potentially competent to address all the issues as mentioned earlier. PLD is simple, highly manageable, clean, safe, highly efficient, easily controllable, scalable and versatile method. Generally, the method includes a high vacuum growth chamber, gas flow, optical path and a high energy excimer laser. In first step, pulsed laser is focused on the target and starts bombarding the surface. Then, the generating plasma plume is deposited on a substrate placed on the heater

inside the chamber. One can easily optimize the growth kinetics controlling mentioned parameters; laser energy, laser pulse rate, laser pulse width, substrate temperature, gas flow, pressure, target-substrate distance, target composition and thickness. Therefore, two-dimensional (2D) graphene, MoS_2 and other inorganic TMDCs are successfully synthesized using PLD.

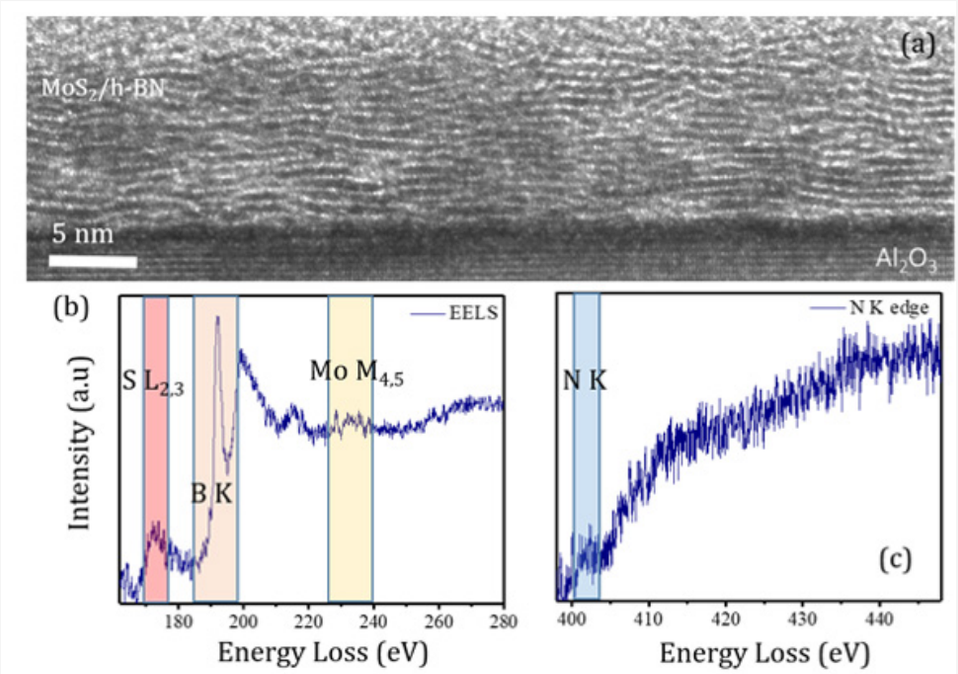

Figure 1: (a) High resolution transmission electron microscopy image (HRTEM) of MoS2/h-BN heterostructure and (b) and (c) represent electron energy loss (EEL) spectra of Mo M4,5, S L2,3, B K and N K edge respectively.

In 2015, Serrao et al. reported MoS_2 deposition on several substrates; Al_2O_3 (0001), GaN (0001) and SiC-6H (0001) by PLD [24]. Serna et al. successfully deposited stoichiometric scalable MoS_2 films without additional surface preparation of the substrate [25]. Our findings show under slow kinetics provide precise control on the thickness of MoS_2 down to 1ML [26]. Challenges are initially to optimize growth conditions result buckling of MoS_2 layers and form a polycrystalline film. We solved this issue keeping the nucleation temperature at 400°C with laser ablation frequency of 1 Hz. We observe only nucleation temperature are different for other TMDCs, but slow kinetics works well to keep Van der waal layers intact with underlying substrate forms crystalline film. Now, one could think one step further growing heterostructure in PLD. MoS_2 based multilayered heterostructures have been reported for optical and magnetic applications [27-28]. Our HRTEM image shows scalable MoS_2/h-BN heterostructure on *c*-plane sapphire in Figure 1(a). High resolution electron energy loss spectra confirm chemical identification of the heterostructure (Figure 1(b) & (c)).

Conclusion

In summary, we briefly review the growth method of MoS_2 and MoS_2 based heterostructures. PLD is much effective and significant among all simple and fast TMDCs based growth techniques. PLD is a promising method to transfer stoichiometric transfer of starting materials to substrate. Improvement of PLD day by day makes it versatile method. Now challenges one can think further to grow horizontal heterostructures inside PLD chamber.

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

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