Van der Waals epitaxy of monolayer $MoSe_2$ on sapphire and on epitaxial graphene/SiC

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Abstract

Two-dimensional materials based on transition metal dichalcogenides (TMDs) have gained increasing attention because of their fascinating features in electronic and optical properties. Achievement of layered TMDs with large lateral dimensions is a pre-requisite for an easy implementation into devices and for the exploration of novel physics. Molecular beam epitaxy is a viable approach for synthetizing large-scale TMDs thin films down to one monolayer with high uniformity and purity. In addition, as TMDs bulk exhibits out-of-plane van der Waals-type interactions between sandwiched layers, a van der Waals interaction between as-grown films with substrates is expected when growing TMDs films on inert substrates. Therefore, using MBE approach allows to study impact of such short-range force on the growth dynamics of TMDs on different substrates [1].

We report the growth and characterizations of large-scale monolayer TMDs $MoSe_2$ on sapphire substrates and fashionable 2D heterostructure composed of one monolayer $MoSe_2$ on graphene/SiC substrates. The TMDs epilayers were fabricated by two-step growth process which consists of depositing TMDs layers at 500°C - 550°C followed by a post-annealing around 700°C. We point out that the growth rate and the substrate temperature of the first step play a key role in the growth dynamics of the TMDs. The post-annealing allows to improve the crystalline quality and to smooth the layers. We have performed several techniques in order to characterize the structure of TMDs layers such as RHEED, (synchrotron) X-ray diffraction, TEM, AFM. Firgures 1a, b show the in-plane scans of the monolayers $MoSe_2$ on sapphire and graphene, respectively. One can see that the $MoSe_2$ layer grows up without any preferential orientation with respect to the sapphire substrate, while it is clearly commensurately epitaxial on the graphene/SiC. Indeed, the phi-scan confirms the polycrystalline character of the layer on sapphire that means that the layer is composed of small multi-domains. For 2D heterostructure, we did not find any significant off-angle variants stemming from the free rotation of the layer regarding the graphene layer. The homogeneity over centimeter-sized surface of the $MoSe_2$ layers was confirmed by Raman spectroscopy. The XPS and TEM measurements reveal possible chemical interactions between sapphire substrate and deposited species that likely introduce random nucleation sites, thus, resulting in the polycrystalline growth. Powerful techniques such as STM–STS performed at 4K and k-resolved PEEM, a complementing ARUPS, were used to probe the atomic-scale structure and electronic properties of the heterostructure. The interplay between proximity effect and resulting electronic structure, which enables to shed light on the nature of van der Waals interaction within vertical 2D heterostructure, will be discussed in the talk.

References

[1] Koma et al., Thin Solid Films **216** (1992) 72

Figures

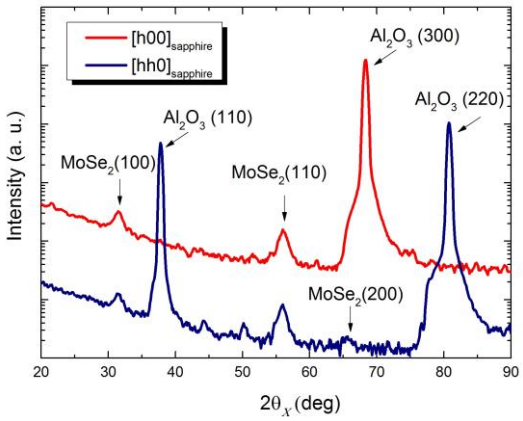
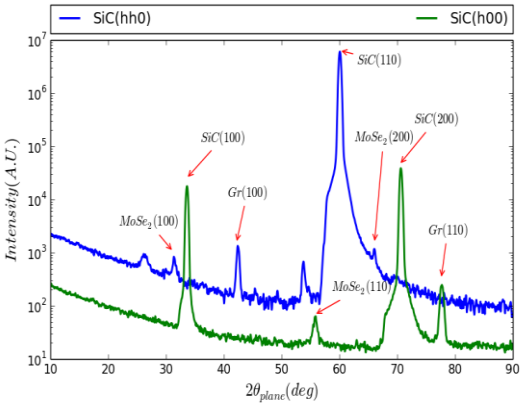


Figure 1. (a) XRD of 1ML $MoSe_2$ on sapphire



(b) XRD of 1 ML $MoSe_2$ on graphene/SiC