Optical properties of $MoSe_2$ grown on various substrates using MBE

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We report on the growth details and characterization of thin $MoSe_2$ layers. Growth has been realized in molecular beam epitaxy (MBE) chamber optimized for II-VI semiconductor compounds, equipped with standard effusion cell working as a source of selenium, and e-beam evaporator, working as a source of molybdenum. Deposition rate of Mo (0.5-25 nm/h), which governs also the growth rate of $MoSe_2$, was calibrated by deposition of thin metal layers on glass and subsequent study with XPS, AFM and optical transmission.

Using various substrates: GaAs, SiO_2, Mo, BN, and graphene, we have found wide range of growth conditions enabling deposition of 1-3 monolayer thick $MoSe_2$ exhibiting characteristic Raman line close to 240 cm^{-1}. We found that excitonic photoluminescence (PL) (measured mostly at room temperature) is much more sensitive to $MoSe_2$ growth conditions than Raman scattering. In particular, only well-defined amount of $MoSe_2$ leads to observable PL peak. The best optical properties: sharp Raman lines, reasonably strong excitonic PL, and several excitonic peaks in reflectivity spectrum (Fig. 1), were obtained for $MoSe_2$ layers grown on two kinds of substrates: amorphous SiO_2 and graphene.

Optical properties of MBE grown $MoSe_2$ still cannot compete with those of mechanically exfoliated $MoSe_2$ in terms of e.g. PL intensity. There is however a great advantage of the MBE samples which is their homogeneity. We have found that the optical properties of MBE $MoSe_2$ do not change significantly over large distances on the substrates. We believe that further optimization of the growth conditions will result in large area layers of technological relevance.

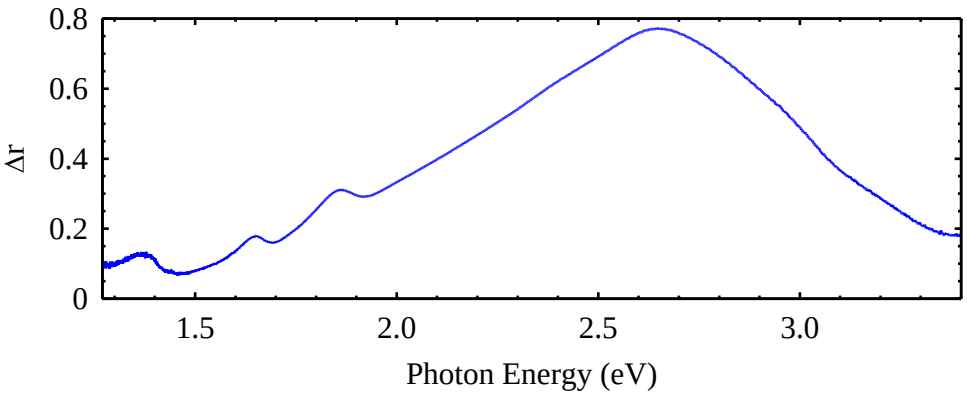

Fig. 1. Low temperature (T = 7 K) differential reflection of $MoSe_2$ grown on SiO_2 buffer, on Si substrate. Series of excitonic peaks is well visible, in agreement with literature data for $MoSe_2$ grown using other methods [1].

[1] Han Gyeol Park et al., *Scientific Reports* **8**, 3173 (2018).