MBE grown $MoSe_2$ heterostructures with selenium compounds: Se, MgSe, ZnSe, InSe

A. K. Szczerba [1,*], B. Tronowicz [1], J. Kucharek [1], R. Bożek[1], T. Taniguchi [2], K. Watanabe [3], P. Wojnar[4] and W. Pacuski [1]

[1] *Faculty of Physics, University of Warsaw, Pasteura St. 5, 02-093 Warsaw, Poland*
[2] *Research Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan*
[3] *Research Center for Electronic and Optical Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan*
[4] *Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland*

The optimal optical properties of transition metal dichalcogenides (TMDs) are achieved when monolayers are encapsulated between hBN layers. While this can be accomplished on a small scale using exfoliated materials, replicating such a structure epitaxially on a large scale remains a significant challenge. Although epitaxial TMDs can be effectively grown on hBN [1], the high growth temperature of hBN prevents covering TMDs without altering their properties. Consequently, there is an ongoing search for materials that can protect TMDs while preserving their properties and potentially serving as barrier materials. This study focuses on the interactions between $MoSe_2$ and various selenides (MgSe, ZnSe, InSe) and investigates the optical properties of structures containing these materials. InSe cap is particularly promising, because it is van der Waals material, and heterostructures of InSe with exfoliated TMDs has been just reported [2]. Moreover, the band gap of InSe differs from the $MoSe_2$, which gives the opportunity to study the emission from both materials simultaneously.

The growth of heterostructures was realized by Molecular Beam Epitaxy on exfoliated hexagonal boron nitride deposited on the p-doped silicon (100) wafer covered by 90 nm of silicon dioxide. Growing on a conductive substrate provides the opportunity to apply voltage to the structure. In these studies the $MoSe_2$ monolayer was grown first, to verify its quality, and then it was covered with various selenides. The samples were examined with Atomic Force Microscopy (AFM). Exciton energies were investigated using low-temperature photoluminescence (PL).

The PL signal of the uncovered $MoSe_2$ shows strong, narrow excitonic lines with the full width at half maximum (FWHM) of about 7-8 meV. Such a signal was visible almost everywhere on the hBN surface, which is a sign of a dense arrangement of $MoSe_2$ flakes. However, after the growth of selenide cap, for example ZnSe, photoluminescence peaks intensities quench and the lines are wider. Moreover, different samples exhibits various energy shifts of PL signal, both to lower and higher energies. These shifts were investigated considering strain in heterostructure, change of dielectric function and interaction between band structures of $MoSe_2$ and the capping material. The comparison of various II-VI materials grown on 2D substrates [3] provides a better understanding of 2D/3D heterostructures.

Acknowledgements

We acknowledge the financial support from National Science Centre Poland, project no. 2021/41/B/ST3/04183

References

[1] W. Pacuski, et.al., *Nano Letters* **20**, 3058 (2020).
[2] E. Blundo, et. al., *Nano Letters* **Article ASAP**
[3] A. K. Szczerba et al., *ACS Omega* **8**, 44745 (2023)