High optical quality of $MoSe_2$ monolayers grown on two inch wafers of epitaxial hBN: a combined MBE/MOVPE approach

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Ultrathin transition metal dichalcogenides (TMD) are two-dimensional semiconductors exhibiting exceptional optical, mechanical and chemical properties. Hence, they can complement other layered materials like graphene in various next-generation nanodevices.

High-quality TMD monolayers can be obtained by mechanical exfoliation - a process that is extremely time-consuming, non-deterministic and provides flakes of only a few-micrometers in size. Here, we present a heteroepitaxial method to grow single layer $MoSe_2$ directly on hBN, allowing to overcome the before mentioned problems.

In our approach, we use Metalorganic Vapour Phase Epitaxy (MOVPE) to grow few-nanometres thick layers of hexagonal boron nitride (h-BN) on two-inch sapphire substrates [1,2]. We present thorough optical and structural studies demonstrating a high structural quality of the samples. h-BN possesses a wide bandgap (~6 eV) that makes it a perfect insulating barrier in heterostructures and is also known to improve optical properties of other layered materials due to the lack of dangling bonds on its surface [3]. Therefore, we use the epitaxial h-BN as a substrate for a subsequent growth of a monolayer of molybdenum diselenide ($MoSe_2$) using Molecular Beam Epitaxy (MBE) [4] (Figure 1a).

We studied the optical quality of the obtained TMD layers as a function of h-BN substrate thickness by performing Raman scattering and photoluminescence measurements. For the samples from well-optimized processes, we observe excitonic lines that can be resolved into two peaks corresponding to the neutral exciton A and trion at low temperatures (4 K), indicating that the material is of excellent optical quality.

Further characterization includes optical mapping of the whole two-inch samples, which proves a high homogeneity of the material (Figure 1b). Such measurements additionally demonstrate the formation of a single atomic layer of $MoSe_2$.

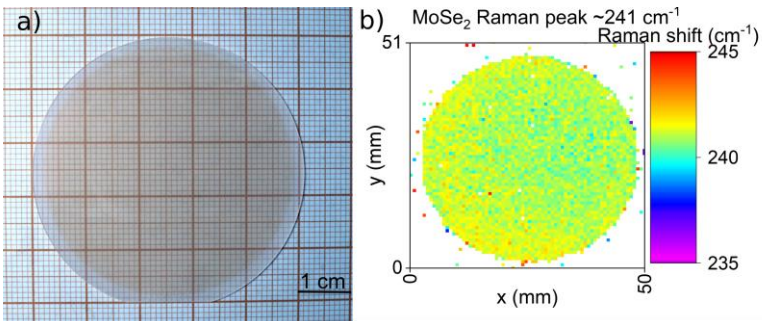

Figure 1. a) Photo of a 2" wafer. The darker, brownish area corresponds to the $MoSe_2$ monolayer. b) Results of Raman mapping of the whole sample indicating homogeneous growth of a monolayer on the whole sample.

Our results constitute a large step towards the wafer-scale growth of van der Waals heterostructures, which is of crucial importance for future applications. Our work also demonstrates for the first time, that using epitaxial h-BN, $MoSe_2$ of excellent optical quality can be scaled up to the size of 2 inch wafers. Moreover, the presented method can be easily applied to grow other TMD which can be used to construct optoelectronic devices such as photodetectors, LEDs and phototransistors.

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[3] F. Cadiz et al., Phys. Rev. X 7, 021026 [4] W. Pacuski et al., Nano Lett. 20, 3058–3066 (2020)