Multi-particle Excitonic Systems in WSe_2 Grown on hBN by Molecular Beam Epitaxy

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Monolayer transition-metal dichalcogenides (TMDs) exhibit exceptional optical properties useful for optoelectronic applications. However, for industrial use, large-scale homogeneity optical response is needed. To address this demand we utilize molecular beam epitaxy (MBE), which is a crystal growth technique offering the best structural, electronic, and optical parameters for many semiconducting materials. Here, we report on the WSe_2 grown on hexagonal boron nitride (hBN) by MBE, demonstrating high structural and optical quality on a large-scale. For the first time, multi-particle excitonic systems can be observed in WSe_2 samples fabricated in a bottom-up approach.

Monolayers of WSe_2 were grown by MBE on exfoliated hBN flakes that are the best substrate known for TMDs growth. Because of its atomically smooth surface, lack of dangling bonds and uncompensated charges, hBN substrates allows to grow the highest quality monolayers both in terms of optical and structural properties. Before TMD growth, hBN flakes were exfoliated from bulk and deposited on a Si substrate with polycrystalline SiO_2 buffer. Growth has been realised in two step process: first deposition at relatively low temperature (300 °C) and then annealing at a high temperature (800 °C) under a high Se flux.

WSe_2 was investigated by atomic force microscopy and transmission electron microscopy in cross-section to verify their structural properties. Both techniques confirm that most of the TMD material is observed in the form of one monolayer thin flakes, with only a small admixture of bilayer areas. Both techniques confirm hexagonal structure of the material as well as high crystalline quality and very low amount of defects. We have used room and low temperature photoluminescence measurements to study optical properties of monolayers. WSe_2 features narrow and resolved spectral lines of neutral and charged exciton and other excitonic systems characteristic for WSe_2 monolayer. Material exhibits high homogeneity of optical properties within micrometres squared.

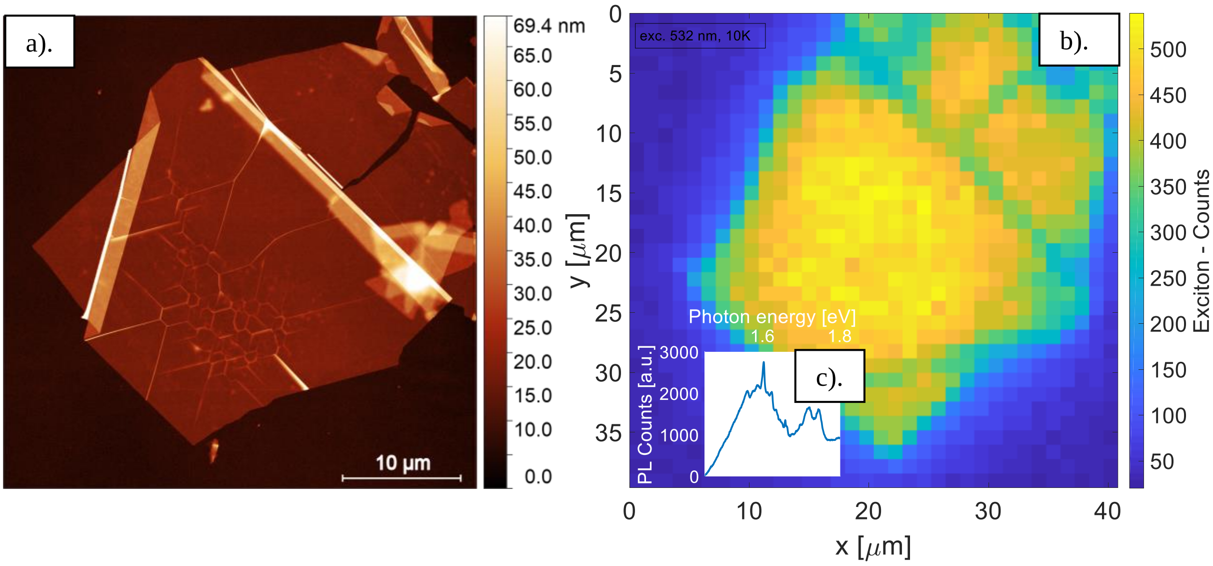

Fig. 1. a). AFM photo of an hBN flake. b). PL map presenting exciton intensity and c). an exemplary spectrum taken on the flake from a).