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, a large-scale homogeneity optical response is needed. To address this demand we utilize molecular beam epitaxy (MBE). In our previous works, we have achieved high optical quality of MBE-grown $MoSe_2$ on exfoliated [1,2] and large-scale epitaxial [3] hexagonal boron nitride (hBN) and we have mixed $MoSe_2$ with Mn ions and showed that it can lead to the induction of 1T' phase of this material [4]. Here, we report on the WSe_2 grown on hBN by MBE, demonstrating high structural and optical quality. For the first time, multi-particle excitonic systems can be observed in WSe_2 samples fabricated in a bottom-up approach, without mechanical transfer. 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 ºC) and then annealing at a high temperature (800 ºC) 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, that covers ~50% of the substrate surface. Both techniques confirm the hexagonal structure of the material as well as high crystalline quality. Low-temperature photoluminescence, reflectivity, and PLE measurements reveal narrow and resolved spectral lines of neutral and charged exciton as well as a wide range of localized excitons present in energies lower than charged exciton. The material exhibits high homogeneity of optical properties within hBN terraces used as a substrate.

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References

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