Emission properties of near band-gap excitons and exciton kinetics in Niobium-doped Rhenium Disulphide (ReS_2:Nb)

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Atomically thin Transition Metal Dichalcogenides (TMDs) are a new class of materials which exhibit variety of physical properties.[1] Some of these properties are quite similar to the bulk-like materials, however, other rely strongly on quantum confinement effects. Among TMDs one can find well known semiconductors like MoS_2, WSe_2, superconductors like $NbSe_2$, $PdTe_2$, or semimetals e.g. WTe_2, $TiSe_2$, however, there are still some TMD chemical compounds for which their basic physical parameters are unknown. The ReS_2 is one of those. In this work we examine emission properties of near band-gap excitons and exciton kinetics in the ReS_2:Nb.

We utilize a polarization-resolved, high spectral resolution photoluminescence experiment at T=10 K in order to obtain emission properties of a ReS_2:Nb thin layer. The PL spectrum of the ReS_2:Nb shows a doublet of linearly-polarized emission bands E_1, and E_2 centered at 1.553 eV and 1.585 eV, respectively. According to the latest theoretical studies [2] these bands can be formed due to radiative recombination process of excitons near the fundamental gap of rhenium disulphide at the Γ point of the Brillouin zone (direct gap). Both PL lines are orthogonally polarized. Although the physical picture lying behind this observation remains still unclear, it can be attributed to the existence of zigzag Re chains along one of the lattice vectors in the plane of a ReS_2:Nb layer. At the high energy range of the PL spectrum another two emission bands are observed: the E_3 band located at 1.644 eV, and E_4 one centered at ~1.67 eV, both being polarization insensitive. In contrast to previous observations existing in the literature the E_4 band reveals its fine structure. It consists of four equidistant PL peaks separated by ~5 meV each. The E_3 and E_4 bands are attributed to the recombination of excitons at higher energy states within the ReS2 band structure, however exact origin of those states is ambiguous.

Exciton kinetics on the E_1 and E_2 energy levels is examined in a time-resolved, pump-probe differential reflection experiment at T=10 K. Decay traces of the differential reflection signal are typically composed of two components. The fast component of ~0.2 ps decay time, which is close to the setup resolution, is attributed to radiative decay of a free exciton within the fundamental gap of ReS_2. The slow component of ~1.2 ns decay time constant is associated to the recombination process of bound exciton states near the fundamental gap of the ReS_2. These time constant parameters where unavailable in the literature, up to now.

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