Anti-Stokes luminescence of transferred tungsten disulfide monolayer

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Semiconductor transition metal dichalcogenides (TMDs) have been subject of increasing interest over the last years. In particular single layers of molybdenum (or tungsten) disulfide (or diselenide) show strong photoluminescence (PL) associated with a direct-gap transition, in contrast to bulk. Monolayer luminescence is composed of the emission from the A exciton and the trion at room temperature, plus localized states at low temperature [1]. Our samples were fabricated by a dry transfer method of exfoliated flakes [2].

First we studied the influence of the transfer process on the optical properties by Raman and PL spectroscopy. By carefully looking at the flake surface by AFM (atomic force microscopy), we observe polymer residues that we manage to remove by contact mode AFM, leading to enhanced optical properties.

Second, anti-Stokes PL (ASPL) has been investigated on these flakes. ASPL refers to a process, where photons of higher energies than the incident ones are emitted, in opposition to the usual Stokes luminescence. This up-conversion process has intrinsically a low efficiency, but several reports on semiconductors already show its occurrence at low excitation intensity [3]. In these classes of materials, in-gap intermediate states involving defects are needed. Phonons are often taken into account to bridge the remaining energy gap [3].

We report high-efficiency anti-Stokes luminescence at room and low temperature on WS_2 monolayer. As opposed to recently reported results on WSe_2 monolayer [4], we observe ASPL not just of the exciton but also of the trion and the localized states. Based on anti-Stokes photoluminescence excitation (PLE), power- and temperature-dependent ASPL measurements, we will discuss the origin of this observation.

This work was supported by the European Research Council (ERC) under grant number 259286.

References

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Figures

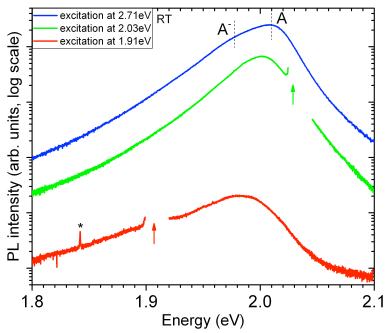

Figure 1: Stokes, resonant and anti-Stokes luminescence of WS_2 monolayer