Dynamics of Indirect Excitons in Few-Layer Tungsten Disulfide

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Two-dimensional semiconducting transition metal dichalcogenides (s-TMDs) attract much attention due to their robust optical properties and energy gap in a visible or near infrared range. Particularly strong photoluminescence (PL) is observed for the monolayers of such materials due to their direct bandgap. In the case of thicker layers the bandgap becomes indirect, which hinders the photoluminescence.

Here we present a study of the photoluminescence decay times measured for WS_2 flakes of different thickness varying from 2 to 8 layers. The experiments were conducted with the use of a femtosecond laser and a streak camera providing temporal resolution of a few picoseconds. The investigated samples were kept in a helium cryostat at temperature down to 10 K.

The samples were prepared by mechanical exfoliation and deposited on a Si/SiO_2 substrate. Thickness of the flakes was determined based on their optical contrast and crosschecked with PL measurements performed under continuous-wave (CW) excitation. Our results stays in agreement with recent measurements by Molas et al.[1] who established a monotonic relationship between the number of monolayers and the energy of the PL signal in few-layer WS_2 (from 1 to 8 layers).

We have found a significant increase of the PL lifetime from 10 ps to 60 ps when increasing the layer thickness. This trend is followed by a strong decrease of the PL signal. Our results clearly illustrate a gradual nature of transformation of the exciton state from a fully bright (in the monolayer) to a fully dark (in the bulk).

The observed dependence is interpreted as an intrinsic phenomenon rather than an effect of competing non-radiative decay channels. This conjecture is supported by additional measurements of the decay time in a tetralayer as a function of temperature. The experiment evidenced that the decay time is constant in the whole studied range of 10 K–250 K, as expected for a truly intrinsic mechanism.

[1] Maciej R. Molas, Karol Nogajewski, Artur O. Slobodeniuk, Johannes Binder, Miroslav Bartos, and Marek Potemski, *Nanoscale*, 2017, 9.35: 13128-13141.