Optical Manipulation of the Exciton Charge State in Single Layer Tungsten Disulfide

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Layered compounds involving transition metals from group VI and chalcogens (the so-called dichalcogenides) are promising candidates for exploring atomically thin structures. Bulk crystals are semiconductors with an indirect gap in the near infrared spectral range. In contrast, single layer transition metal dichalcogenides such as molybdenum disulfide (MoS_2), tungsten disulfide (WS_2) or tungsten diselenide (WSe_2) are two dimensional (2D) semiconductors with a direct gap in the visible spectral range. The optical response of a single layer of these materials is dominated by excitonic effects; the optical spectrum is characterized by the presence of two low-energy exciton peaks (*A* and *B* excitons) that arise from vertical transitions from a spin-orbit-split valence band to a doubly degenerate conduction band at the **K** point of the Brillouin zone. Moreover, electronic levels are four times degenerated (2 times valley and 2 times spin). Population of each valley can be controlled by circular polarization of light. Hence the dichalcogenides have been proposed as a good candidate for "valley-tronics" [1]. Recently a single layer of the molybdenum disulfide was isolated. However, as isolation of single layer of different dichalcogenides is recent, many electronic properties are still not known.

Here we show that in a single layer of tungsten disulfide (WS_2) obtained by the exfoliation of *n*-type bulk crystals, we observe both charged and neutral exciton recombination in the photoluminescence (PL) emission spectra [2]. Additionally, by simply changing the intensity of the laser excitation, we can tune the ratio between the trion and exciton emission which demonstrates our ability to tune the density of 2D carriers with light (Fig. 1). Moreover, using additional sub band gap laser excitation, the trion emission intensity can be independently tuned.

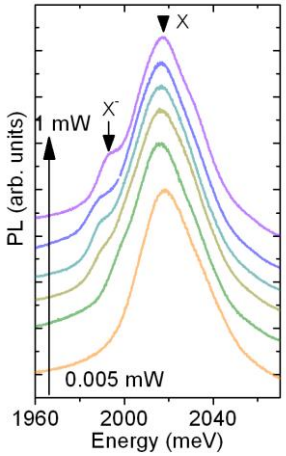

Fig. 1 Typical µPL spectra on a monolayer region of a WS_2 flake showing exciton (X) and charged exciton (X^-) emission measured as a function of the excitation power at T=4K

[1] R. Ganatra and Q. Zhang, *ACS Nano*, Just Accepted Manuscript (2014).
[2] A. A. Mitioglu, P. Plochocka, J. N. Jadczak, W. Escoffier, G. L. J. A. Rikken, L. Kulyuk, and D. K. Maude, *Phys. Rev. B* **88**, 245403 (2013).