Optical control of charge carrier density in monolayer MoS_2 and WS_2

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Abstract

The family of the transition metal dichalcogenides (TMDs) such as MoS_2 and WS_2 have recently attracted a big attention due to two dimensional character of covalently bonded layers held together by weaker van der Waals forces. A single layer of MX_2 (M = Mo or W and X=S, Se or Te) consist of one atomic layer of metal atoms hexagonally packed between two trigonal atomic layers of chalcogenide atoms. In single-layer form the lack of inversion symmetry leads to remarkable optical and electronic properties different from those of bulk form. Unlike different 2D crystals, such as graphene and boron nitride, they are semiconductors, hence they reveal properties more attractive for specific application e.g. in optoelectronic devices.

In this work we focus on optical properties of MoS_2 and WS_2 monolayers. The studied flakes were mechanically exfoliated from bulk crystals grown by chemical vapour transport method (CVT) and transferred on Si/SiO_2 substrates. Prepared samples were identified and characterized by optical microscopy and atomic force microscopy (AFM). The power-dependent μ-Raman scattering investigations were carried out in backscattering geometry under ambient conditions at room temperature. The excitation power varied from 10 μW to 1 mW and from 12.5 μW to 1.25 mW for the laser lines λ=532 nm and λ=633 nm, respectively.

The Raman spectra of MoS_2 and WS_2 reveal two prominent first-order phonon modes: the E^1_{2g} and the A_{1g} modes. The E^1_{2g} mode is an in-plane vibration, for which the atoms are oscillating parallel to the basal plane of the van-der Waals coupled crystal layers. The A_{1g} mode is an out-of plane vibration, where the sulfur atoms are moving in opposite directions. We observe that in case of WS_2, similarly to MoS_2, the A_{1g} mode shifts towards lower energies when the power of laser beam increases, whereas E^1_{2g} phonon mode remains essentially inert. This is due to stronger coupling of A_{1g} mode with the excited d_{z2} states. Those results are consistent with previous studies of MoS_2 in FET geometry [1]. Comparison of both studied TMDs suggests that WS_2 is more sensitive to change of charge carrier density. Our results show that the charge carrier density can be effectively tunable by the light intensity.

References

[1] B. Miller, E. Parzinger, A. Vernickel, A. W. Holleitner, U. Wurstbauer, Applied Physics Letters **106** (2015) 122103.