Optical properties of ReS_2 single crystals doped with Nb

J. Jadczak [1,2], Kuan-Hung Lin [2], Fei-Sheng Huang [2], Ying-Sheng Huang [2], L. Bryja [1], J. Misiewicz [1]

[1] *Institute of Physics, Wroclaw University of Technology, 50-370 Wroclaw, Poland*
[2] *Department of Electronic and Computer Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan*

Bulk rhenium disulphide is direct band gap semiconductor belonging to the family of transition-metal dichalcogenides (TMDs). Unlike other TMDs such a MoS_2, $MoSe_2$ and WSe_2, it crystallizes in distorted structure of triclinic symmetry [1]. Re atoms in each monolayer are displaced from the centre of octahedral coordination units forming zigzag chain along the b-axis. Lattice distortion leads to the anisotropy of optical and electrical properties in van der Waals plane. Furthermore, in ReS_2 the band renormalization is absent and bulk behaves as decoupled monolayers.

In this work, we focus on the optical properties of pure and Nb-doped ReS_2 single crystals. They were grown directly from the composite elements (Re: 99.99% pure; S: 99.999%) by the vapor transport method using I_2 as transport agent. To obtain nominal concentration 1-5% of Nb, the weight of doping material was determined stoichiometrically.

We performed systematic Raman scattering investigation on a series ReS_2 single crystals. In Raman spectra we observe 11 active modes in the range 100-400 cm^{-1} for all contents of Nb. These Raman peaks are caused by low symmetry of the crystal and they are mixing of in-plane and out-of-plane motion of Re and S atoms (E_g, A_g). However, certain modes have characteristic behavior. The Raman peaks at 149.4, 159.5 and 211.2 cm^{-1} have different polarization tendencies and become prominent under certain configurations: $Z(XX)\bar{Z}$ or $Z(XY)\bar{Z}$ (Fig. 1a). Furthermore, they are strongly polarized both along and perpendicular to b-axis of the crystal (Fig.1c). Additionally, we conducted polarization-resolved photoluminescence measurements for varied power excitations in the range temperatures from 10 to 160 K . At 10 K the PL spectra reveal two, well resolved peaks X_1 and X_2 at 1.556 eV and 1.585 eV as well as two additional prominent features at higher energy side X_3 and X_4, at 1.636 eV and 1.647 eV, respectively. Our results confirmed a strong, opposite polarization dependence of low energy excitons: the X_1 is not allowed for light polarized perpendicular to b axis, whereas the X_2 is not allowed for light polarized along the b-axis. In contrast, higher excitonic transition detected at 1.556 eV is only weakly polarized.

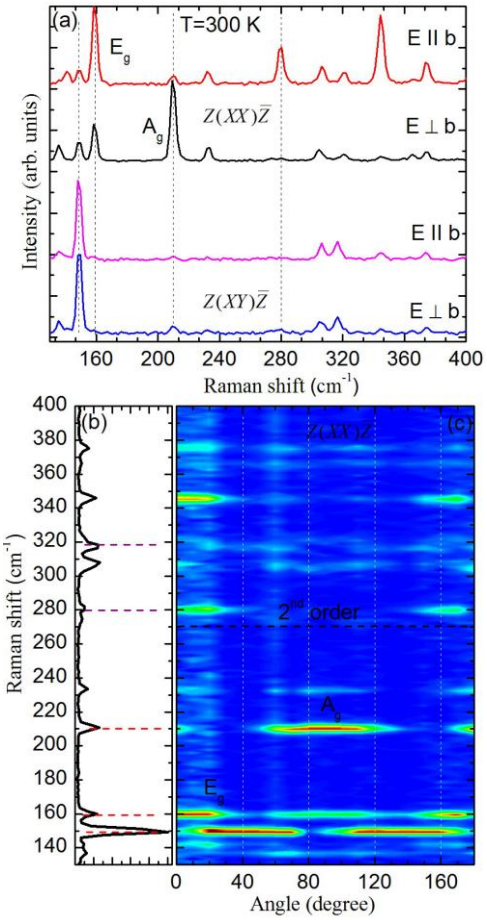

Fig.1 (a) Raman spectra measured under different configuration, (b) unpolarized Raman spectra (c) Raman spectra measured as a function of angle in relation to b-axis in $Z(XX)\bar{Z}$ configuration.

[1] Tongay S. et al, *Nature Comm.* **5**, 3252 (2014).