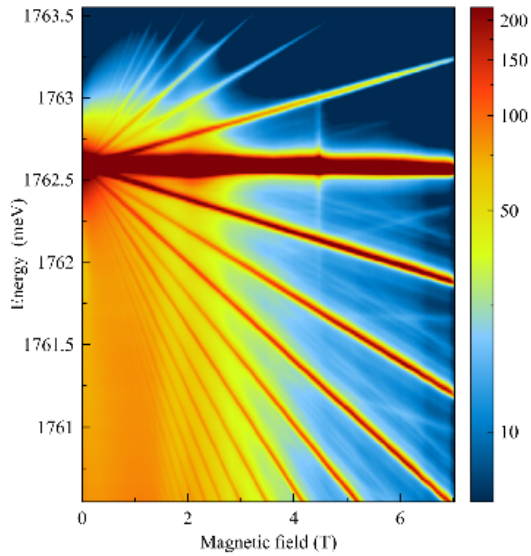
High-resolution Resonance Spin-flip Raman Spectroscopy of Pairs of Manganese Ions in CdTe:Mn

R.V. Cherbunin,[1] V.M. Litviak,[1] I.I. Ryzhov,[1] A.V. Koudinov,[1,2] S. Elsässer,[3] A. Knapp,[3] T. Kiessling,[3] J. Geurts,[3] S. Chusnutdinow,[4] T. Wojtowicz,[5] G. Karczewski[4]

[1] *SOLAB, St.-Petersburg State University, ul. Ulianovskaya, 1, 198504, St.-Petersburg, Russia*
[2] *Ioffe Institute, ul. Politekhnicheskaya, 26, 194021, St.-Petersburg, Russia*
[3] *Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany*
[4] *Institute of Physics, Polish Academy of Sciences, al. Lotników, 02668 Warsaw, Poland*
[5] *International Research Centre MagTop, Institute of Physics, 02668 Warsaw, Poland*

Exact measurement of the strength of the exchange interaction between the substitutional magnetic ions (for instance, Mn in CdTe) is, for several reasons, a principle task of the physics of diluted magnetic semiconductors (DMS). That is why this task is being readdressed time after time during the last 40 years. Exchange constants of the *d-d* interaction can be estimated by different means: magnetic susceptibility, specific heat, optics, neutron scattering, low-temperature magnetization steps. Many of the listed methods suffer from one problem: they are not really selective in respect with the local coordination of the Mn ions. As a result, even for sufficiently dilute compositions, the signals are usually dominated by contributions from single Mn's with an addition from the nearest-neighbor (NN) pairs. With rare exceptions, existing estimates of the next-NN exchange constants J_2, J_3, etc. are based on marginal discrepancies between the measured and calculated magnetization-steps curves. These results are often contradictory and model-dependent [1].

Here, we report a selective approach to this problem [2,3]. We demonstrate that high-resolution resonant spin-flip Raman spectroscopy can yield, for a model object like a (Cd,Mn)Te quantum well, separate signatures from the different types of close pairs of neighboring Mn's. We obtained up to four different characteristic energies in one measurement and with a remarkable precision of $\pm 0.05\,\mathrm{K}$: $J_1 = 5.22\,\mathrm{K}$, $J_{(2)} = 1.51\,\mathrm{K}$, $J_{(3)} = 1.16\,\mathrm{K}$, $J_{(4)} = 0.70$ K. The influence of the residual strain is, however, not quite clear for the present samples. Meanwhile, the effect inspires optimism as a basis for a prospective method of characterization applicable also to other DMS materials.



Spectral map of the radiation from the 9ML (3 nm) CdTe:Mn (x=1.7%) QW for B*-fields up to 7 T, T=1.5 K, the laser excitation energy (1762.6 meV) hits the high-energy side of the QW exciton band.*

[1] J.A. Gaj, J.Kossut. Basic consequences of the *sp-d* and *d-d* interactions in DMS. In the book: *Introduction to the Physics of Diluted Magnetic Semiconductors*, ed. by J. Gaj and J. Kossut. Springer-Verlag Berlin Heidelberg 2010, pp.31-34.
[2] A.V. Koudinov, A. Knapp, G. Karczewski and J. Geurts. *Phys. Rev. B* **96**, 241303 (2017)
[3] R.V. Cherbunin, V.M. Litviak, I.I. Ryzhov et al., arxiv:1903.01276 (2019)