

Magneto-optical effects of nitrogen-vacancy centers in diamond crystals

J. Debus,¹ D. Braukmann,¹ V. P. Popov,² E. R. Glaser,³ T. A. Kennedy,³ M. Bayer^{1,4}

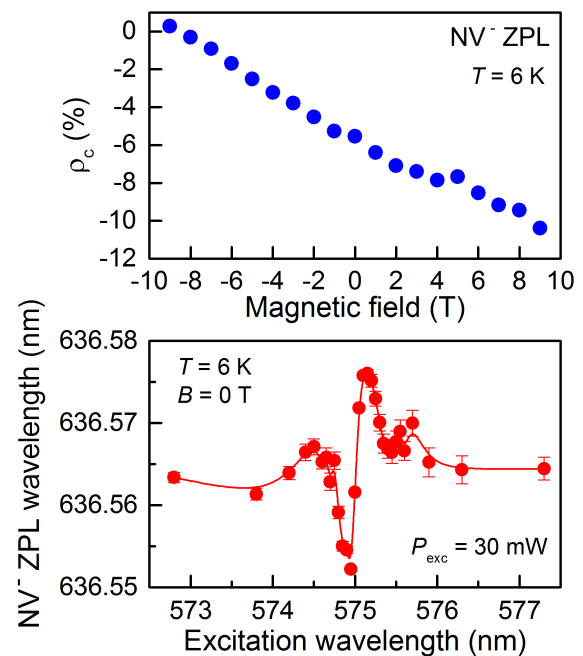
¹Experimental Physics 2, TU Dortmund University, Dortmund, Germany, ²Rzhanov Institute of Semiconductor Physics, Novosibirsk, Russia, ³Naval Research Laboratory, Washington DC, USA, ⁴Ioffe Institute, St. Petersburg, Russia

The neutral and negatively charged nitrogen-vacancy centers in diamond have been studied in recent years on account of possible applications in quantum information processing, spin-electronics, quantum sensing, and, e.g., bio-photonics. Particular focus has been drawn on their optical properties. For negatively charged nitrogen vacancies (NV^-), the triplet ground state that forms a two-level quantum system can serve as a quantum bit, whose state can be controlled coherently by electron spin resonance. The electron spin coherence time reaches 1 s at 77 K [1]; thus, many operations can be performed before dephasing occurs. The coherent manipulation of a single electron spin-qubit associated with a NV^- center could be exploited to detect very weak magnetic fields of 3 nT [2], while fluorescent nanodiamonds inside living cells could open new possibilities for quantum-based imaging in life sciences [3]. Besides considerable achievements in different fields of fundamental research and applications, several questions about magneto-optical properties of the nitrogen vacancies in diamond are still open; hence, a consistent and complete picture of the NV centers in diamond is missing.

The talk focuses on polarization-dependent optical studies of NV^- and NV^0 centers in diamond subjected to high magnetic fields B of up to 10 Tesla. We obtain thorough insight into their energy-level structure and spin-orbital properties; for instance, we observe a nonlinear Zeeman shift of the NV^- zero-phonon line (ZPL) photoluminescence (PL) only for a magnetic field direction applied along the (001) crystal direction. The magnetic-field-induced circular polarization degree ρ_c of both the NV^- and NV^0 ZPLs also depends on the B -field orientation. For $\mathbf{B} \parallel (111)$, $\rho_c^{NV^-}$ is zero at 0 T, and, for $\mathbf{B} \parallel (001)$, ρ_c differs significantly from zero at 0 T surprisingly, as shown in the figure at the top. The optical orientation degree shows a strongly nonlinear behavior as function of the magnetic field strength; however, the respective dependence is mirror-symmetric around 0 T. While the circular polarization characteristics are observable solely at cryogenic temperatures, a strong optical alignment based on linear polarization of up to 40%

is detected at room temperature. We further measure an anisotropy in the linear polarization degree as well as in the rotation of the linear polarization plane of the PL, which can be tuned even from positive to negative values. A phenomenological approach, which takes into account symmetry aspects of the diamond crystal, explains well the anisotropy observed experimentally.

A further aspect of our magneto-optical studies is related to the coupling between NV^0 and NV^- centers. For that purpose, we analyze the spectrally resolved PL excitation spectra in the energy range of the NV^0 and NV^- ZPL, for optically exciting the ensembles of either the NV^- at about 637 nm or NV^0 at 575 nm. For resonant excitation conditions, we observe both a change in the ZPL intensities and energies. The evolution of the ZPL energies, in particular of the NV^- centers, resembles a Fano resonance, see figure at the bottom; besides that, a charge-transfer model and a resonant Foerster-energy-transfer mechanism will be discussed. Hereby, we investigate the temperature and laser power dependence of the $NV^0 \Leftrightarrow NV^-$ coupling. In order to study the dynamics of the interaction between the different charged states of the NV centers, short and long-term time-resolved measurement are performed.



- [1] N. Bar-Gill et al., Nat. Commun. **4**, 1743 (2013)
- [2] J. R. Maze et al., Nature **455**, 644 (2008)
- [3] L. P. McGuinness et al., Nat. Nanotechnol. **6**, 358 (2011)