Optical absorption on a single semiconductor quantum dot with a magnetic field applied in Voigt geometry.

The modular design of the attoCFM III represents a highly flexible and versatile system for high resolution spectroscopy. In these experiments, the setup has been modified to accommodate an inverted geometry. A special confocal objective was designed that redirects the incoming light by 90° to impinge onto the sample perpendicular to the externally applied magnetic field, i.e. in Voigt geometry (see Fig. 1).

The measured spot diameter of ~1.5 µm is only slightly larger than that of a standard axial confocal objective. The light transmitted through the sample is measured by a photo detector directly behind the sample. All parts are made from Titanium, so that the microscope maintains its high stability during cool-down to cryogenic temperatures and exposure to magnetic fields of up to 8 T.

The optical setup allows performing high resolution laser spectroscopy on a single, self-assembled quantum dot (QD). Fig. 2(a) shows the optical spectra of a QD charged with a single electron (X^{1-}), measured with different laser polarizations at 0.7 T in Voigt geometry. According to the respective optical selection rules, the unpolarized resonance line of the X^{1-} splits into four lines (Fig. 2a-i), where two transitions are mediated by linear polarized light parallel to the external magnetic field (π_0; see Fig. 2a-ii), and two by light polarized perpendicular to the magnetic field ($\pi_{90;}$; see Fig. 2a-iii). Transmission spectroscopy allows direct probing of these optical selection rules.

In Fig. 3, the magnetic field dispersion of all four resonances is shown as a function of the applied magnetic field. The ground states (one electron in the QD; electron depicted by a filled triangle; direction indicating spin arrangement) and excited states (two electrons with anti-parallel spin and one hole; hole indicated by an open triangle) are spilt according to their Landée g-factors. Optically allowed transitions connect all four levels leading to four resonances lines with comparable oscillator strength.

The presented experimental setup allows studying the anisotropic magnetic properties of single self-assembled quantum dots with high degree of precision (Fig. 2(b)) [1]. Furthermore, the resonant optical pumping offers a spin shelving scheme for the resident electron in the QD [2,3], which was already demonstrated to be orders of magnitude more efficient if the magnetic field is applied in Voigt geometry rather than in Faraday geometry [3,4]. The equally strong coupling of the two Zeeman split ground states to either of the excited states opens the way for quantum optical coherent spin manipulation schemes as they are known from atom optics [3].

References

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[4] Xu, et al., Physical Review Letters 99, 097401 (2007).

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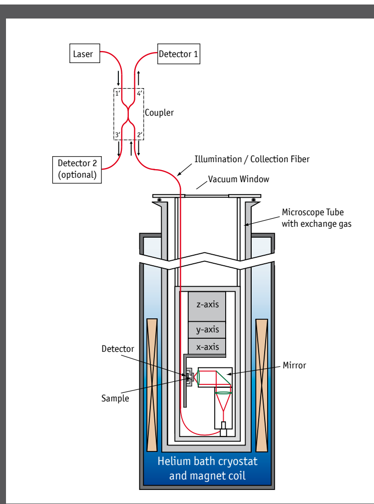

Fig. 1: Diffraction limited, fiber-based confocal microscope for high resolution spectroscopy in Voigt geometry, based on the CFM III design.

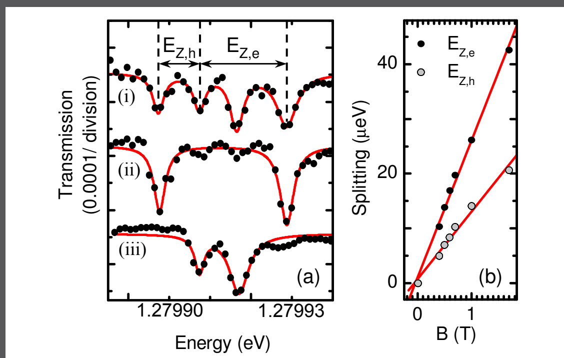

Fig. 2: (a) Transmission spectra of a single negatively charged quantum dot at a magnetic field of 0.7 T applied perpendicular to the quantum dot symmetry axis. The resonance line splits in four linear polarized lines (i). The outer resonances are resonant to light polarized parallel to the applied magnetic field direction (ii). The inner lines are polarized perpendicular (iii). (b) The Zeeman splitting of the electron ($E_{Z,e}$) and hole ($E_{Z,h}$) states of the quantum dot as a function of the magnetic field. The energies can be obtained directly from the spectra as shown in (a) (M. Kroner et al.).

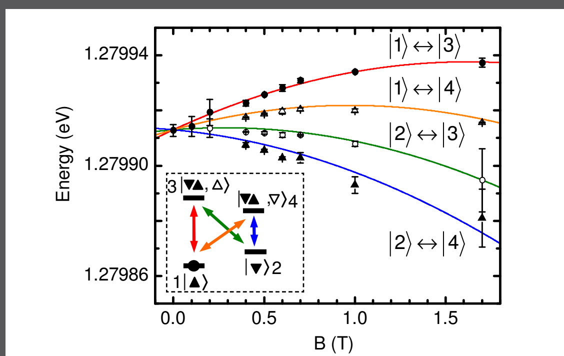

Fig. 3: Magnetic field dispersion of the X^{1-} resonance energies as a function of the magnetic field applied in Voigt geometry. The inset depicts the electronic and excitonic levels, interconnected by four optical transitions which are indicated by the arrows (M. Kroner et al.).

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