Application Note CI07

3D g-factor mapping of single quantum dots utilizing an attocube ANPxyz50 positioner stack

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In this application, we report on a novel fibre-based confocal microscope [1] to investigate the properties of nanostructures such as InGaAs quantum dots (QDs) via magneto-photoluminescence (PL). The design allows them to turn the samples to arbitrary angles of tilt and rotation with respect to a magnetic field of up to 10 T at low temperatures, while maintaining focus on a single QD. Modelling the exciton emission [2] they can extract the full 3-dimensional g-factor tensors for the electrons and holes and their exchange parameters. The new method improves upon the first studies of this type [3,4] by allowing dots to be selected in the microscope using the positioning capability.

An integral part of this setup is a stack of four attocube nanopositioners consisting of an ANPz50, an ANR50 and two ANPx50's; this stack is fixed to a rotatable mount by a gear mechanism (see Figure 1). The ANR50 and the mount provide the two axes required to allow exploration of all orientations with respect to an applied magnetic field. Ediger & Phillips are able to make full use of the high spatial resolution of the positioners at any angle, which allows them to correct efficiently for the effects of gravity or diamagnetic shifts during parameter change in the experiments. On the other hand, the high stability of the motors is demonstrated by the ability to study the same structure at any angle over extended periods of time without loss of focus. The only effect of tilt on the operation of the motors is the transfer of the slight preferential down movement of the ANPz50 due to gravitation to one of the ANPx50.

The example data in Figure 2 shows the emission of the neutral exciton of a single InGaAs quantum dot tilted to 45° with respect to a magnetic field of 0 to 10 T at a temperature of 4 K. The intense upper doublet belongs to the bright exciton states, while the faint lines emerging at about 2 T stem from predominantly dark transitions that only become visible due to a field-induced mixing with the bright states. For standard magneto-PL in Faraday geometry (0° tilt) this mixing would not appear for rotationally symmetric dots.

An obvious feature for tilt angles around 45° is the anti-crossing of the dark and bright states, which in this case happens at about 5 T. The size of this splitting, as obtained from precise modelling shown in the Figure 3, is dominated by and gives direct access to the in-plane hole g-factor [5], an important parameter for the emerging idea of quantum information processing using long-lived hole spins. This effect is again typically not visible in standard magneto-PL setups in either Faraday or Voigt (90° tilt) geometry, respectively.

This technique is adaptable to a host of different nanostructures giving access to wealth of detailed information about the wave functions, the bright and dark spin states, as well as structural information by probing the 3D confinement properties of the respective nanostructure.

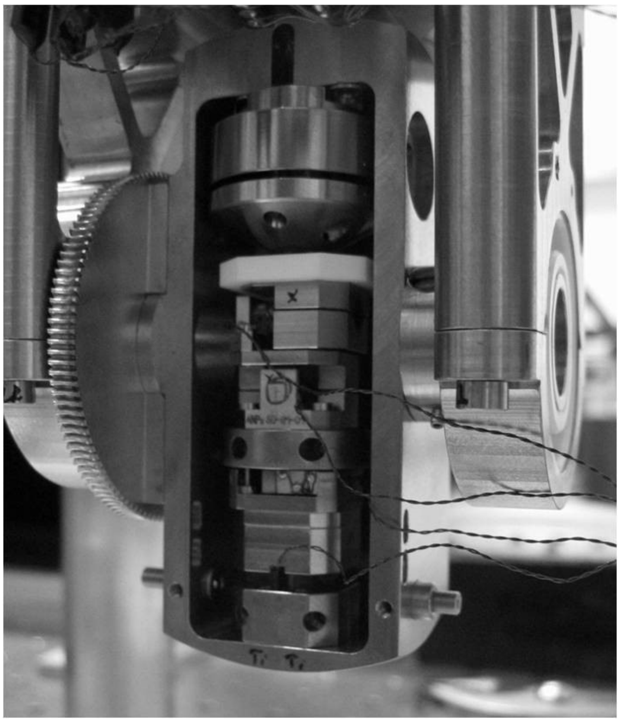

Figure 1: Photo of the experimental setup. The positioner stack is mounted in a rotatable cage. The rotator ANR50 is mounted onto the ANPz50.

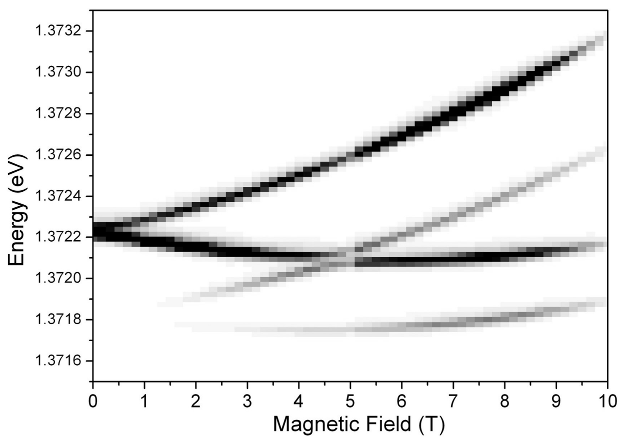

Figure 2: Photoluminescence data from a single quantum dot in a magnetic field at 45° inclination to the surface.

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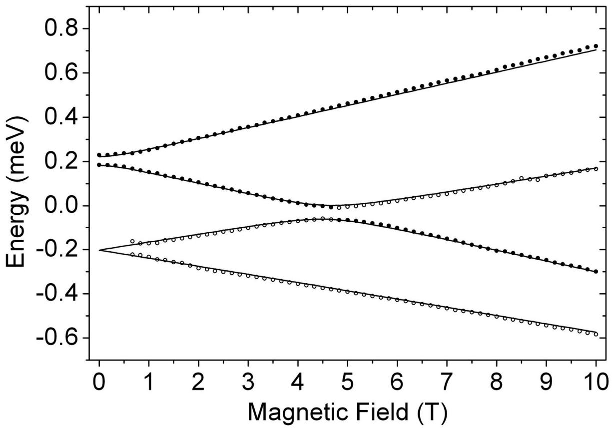

Figure 3: *Model of the anti-crossing data shown in Figure 2. Emission energy and diamagnetic shift have been subtracted in this model.*

Figure 1-3 *courtesy of M. Ediger and R. T. Phillips, University of Cambridge.*

References

[1] T. Kehoe, M. Ediger, R. T. Phillips, and M. Hopkinson, Rev. Sci. Instrum. **81** 013906 (2010).

[2] H. W. Van Kesteren, E. C. Cosman, W. A. J. A. Van der Poel, and C. T. Foxon Phys. Rev. B **41** 5283 (1990).

[3] A. G. Steffan and R. T. Phillips, physica status solidi a 190 541-545 (2002); Physica E **17** 15-18 (2003).

[4] R. T. Phillips, A. G. Steffan, S. R. Newton, T. L. Reinecke and R. Kotlyar physica status solidi b **238** 601-606 (2003).

[5] I. Toft and R. T. Phillips, Physical Review B **76** 033301 (2007).