

3D g-factor mapping of single quantum dots at high magnetic fields

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Application Note

Confocal microscopy at cryogenic temperatures has become an essential tool for the study of semiconductor quantum dots. Furthermore if a high magnetic field can be applied to the sample and the sample rotated within the field then even greater information can be obtained from magneto-optical spectroscopy.

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



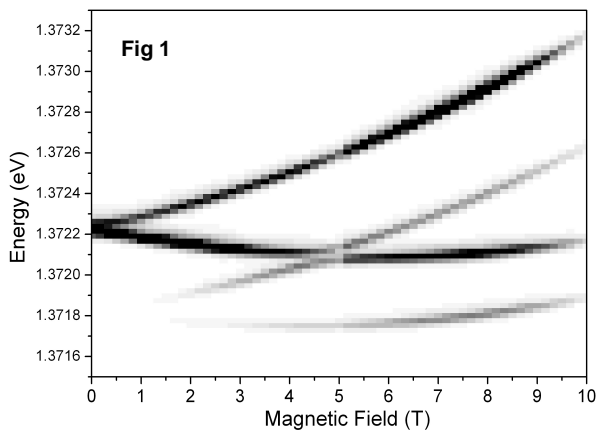
Experimental set-up

Our set-up includes two custom-built Oxford Instruments units:

- a 10 T cryogen-free superconducting magnet with a 110 mm room-temperature bore
- a helium bath cryostat with dynamic exchange gas and a 85 mm sample space to accommodate the rotating parts of the confocal microscope .

The microscope cryostat is mounted on a vibration-isolated optical table. The cryostat tail is inserted into the magnet bore with a clearance of about 1mm. The vacuum can of the magnet system rests on the laboratory floor, so there is no direct coupling between the two cryostat systems.

We found that, even without floating the optical table, the vibration isolation between the closed-cycle cold head of the magnet and the confocal microscope was so good that we were able to study the same single nanostructure over days and weeks. The Cryofree® magnet is ready for use after about 48 hours of cooling from room temperature, and can be left cold for months. The hold-time of the microscope's cryostat is about 4 days under normal operation and the helium reservoir can be refilled during experiments without disturbing the optical alignment in the sample space. In the event of a quench, recovery to normal operating temperature is very quick as there is no liquid helium to boil off in the magnet cryostat. The confocal microscope has been designed to minimise the effects of forces related to eddy currents when sweeping the magnetic field and in fact, we have found that the system remains aligned on the same optical feature with displacement of less than a micron after a quench.



Experimental results

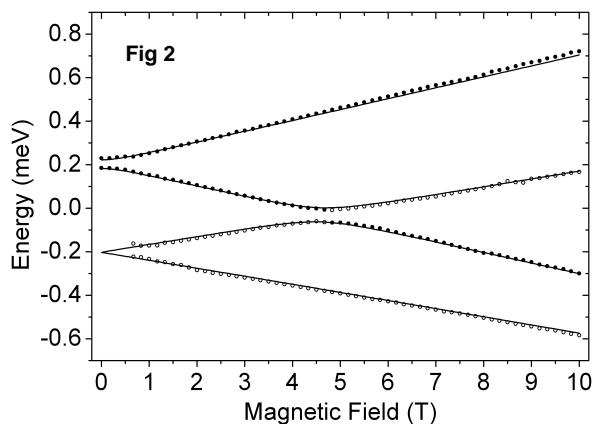
Figure 1 shows the emission of a neutral exciton of a single InGaAs quantum dot tilted to 45° with respect to a magnetic field of 0 to 10 T at a temperature of 4 K.

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. If a standard magneto-PL set-up would have been used in Faraday geometry (0° tilt), this mixing would not appear for rotationally symmetric dots. An other

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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 the splitting, as shown in figure 2, obtained from the precise modelling, is dominated by and gives direct access to the in-plane hole g-factor[5]. This is an important parameter for the emerging idea of quantum information processing using long-lived hole spins.

Conclusion

We have developed a technique which is adaptable to a range of different nanostructures, and gives detailed information about the shape of wave functions (deduced from diamagnetic shifts), the bright and dark spin states, as well as structural information by probing the 3D confinement properties of the respective nanostructure.

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