Research Matters SUMMER 2002

Magneto μ-photoluminescence of Single self-assembled InGaAs Quantum Dots

Progress in semiconductor growth and fabrication has been accompanied by a steady shift of interest towards nanostructures with progressively reduced dimensionality. The fundamental limit of this progression has been reached with the development of fabrication techniques for zero-dimensional (0D) semiconductor heterostructures. These have unique optical and electronic properties, arising from the *complete* quantum mechanical confinement of the motion of the charge carriers (electrons - e and holes - h). Such 0D nanostructures termed quantum dots (QDs) can be considered the man-made analogue of atoms in the solid state. Their unique properties may enable a new generation of optoelectronic devices.

We are investigating the fundamental optoelectronic properties of self-assembled In(Ga)As-(Al)GaAs QDs using photoluminescence spectroscopy (PL). This technique is powerful when applied to the study of higher dimensional nanostructures such as quantum wells. However, as a consequence of their formation process, self-assembled quantum dots suffer from weak dot-dot fluctuations in size and composition that result in each dot absorbing and emitting light at a slightly different energy. This property complicates interpretation of conventional optical measurements since hundreds of thousands of QDs are probed simultaneously masking their true “atom-like” properties. This problem can be completely circumvented by investigating *single* quantum dots; a task that is complicated by the high areal density of QDs (~5.10^{-10}cm^{-2}). Single dot spectroscopy requires the development of sophisticated spectroscopic techniques that have extremely high spatial and spectral resolution. We have developed a low temperature microscope facilitating the study of individual QDs and allows access to a rich spectrum of the novel physical phenomena that occurs in these incredible systems.

One example concerns the fine structure of the exciton, a correlated state consisting of a single electron (e) and hole (h). Normally, two flavours of exciton are possible: one comprising a spin up-electron and spin-down hole (↑ e+ ↓ h) and the second in which the spins of the electron and hole are Inverted (↑ e+ ↓ h) . In systems that possess cylindrical symmetry (i.e. when the shape of the QD is like a disc), these two excitons have exactly the same energy, i.e. are degenerate. When the shape of the QD becomes asymmetric, this degeneracy is removed due to the spinspin exchange interaction between the electron and hole. In this case, the PL spectrum of a single exciton is expected to consist of *two* linearly polarised lines.

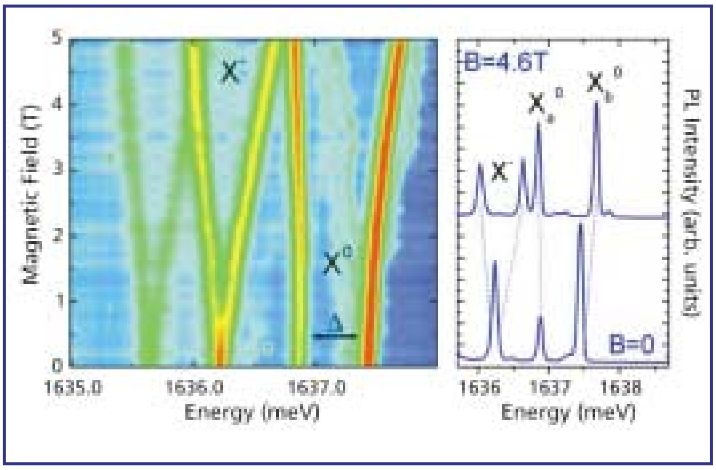

Figure 1 – Left: False colour image depicting magnetic field dependence of the photoluminescence spectrum from charge neutral (X^0) and negatively charged exciton (X^-) in a single asymmetric InAs-AlGaAs quantum dot. Right: PL spectra showing charge neutral and negatively charged exciton.

Figure 1 shows such a spectrum consisting of a linearly polarised doublet (X^0) as a function of magnetic field B=0-5T. At B=0, the two linearly polarised lines (X_a and X_b) are split by △ ~0.8meV, reflecting the extremely strong electron-hole exchange interaction strength in these QDs and the splitting increases with B due to the interaction of the spins with the magnetic field (Zeeman effect). Also evident is the negatively charged exciton (X-=2e+1h) in which the doublet fine structure at B=0 has vanished. This occurs since X- has two electrons, and in the ground state the electron spins “pair-up” forming a zero net electron spin state (e.g. ↑ e ↓ e+ ↑ h) .The e-h exchange interaction vanishes completely and the two distinct (X^-) states are only revealed by the magnetic field (X_a^-, X_b^-).

Experiments are underway to investigate the possibilities to coherently control the spin and carrier population of the QD over a ps timescale. Such experiments are aimed at using the QD as a QBIT, the basic element in a quantum computer. When achieved, such complete coherent control of the QD quantum state using fast optical pulses may open up new possibilities to create optoelectronic devices that have true quantum functionality.

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