SELF-ASSEMBLED QUANTUM RINGS

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Self-assembled semiconductor quantum dots (QD), formed via lattice-mismatched heteroepitaxy, are currently being used for developing optoelectronic technologies and devices due to their high optical quality. Due to their 0D strong confinement of carriers and unique optical and electric properties2, these nanostructures rapidly became a perfect benchmark for fundamental physic research. Recently, they have been considered also as promising candidates for information storage and quantum computing applications implemented in solid state devices.

A precise control over the nanostructure height, width and shape is of crucial importance since these structural properties influence the quantum confinement of the charge carriers and therefore determine their optoelectronic properties. Unfortunately, QD do not have the flexibility of band gap engineering that quantum wells have. Commonly the size of the dots is critically determined by the optimal growing conditions employed to obtain narrow size distributions. In the particular case of InAs on GaAs(001) growth using molecular beam epitaxy (MBE), on which this work is focused, employing different growing parameters may produce variations in the sizes of the dots, but also broadens the size distribution. This is one of the major problems if we aim to employ ensembles of these nanostructures in useful devices. A possible strategy for overcoming this problem consists in growing the QD under optimal conditions and modifying its vertical size during capping. A technique which is especially useful for reducing the vertical size, i.e. for obtaining shorter wavelengths, consists in partially covering the InAs islands with a thin cap of GaAs and letting the original islands ‘melt’ and re-shape. This process can be used to reduce the original vertical size of the QD in a controlled way with atomic height accuracy. The possibility of tailoring the potential confinement in each layer of dots is also of great significance if we aim to achieve application in solar cells.

In particular, under specific growing conditions [1], a drastic change occurs, as can be seen in figure 1, which allows to obtain from each QD a self-assembled ‘nanovolcano’, or Quantum Ring (QR). Unlike mesoscopic lithography-defined rings, these QR, once embedded in a GaAs matrix, function in the true quantum limit, free of quantum de-coherence due to scattering processes, with a reduced Anisotropy Energy Splitting (AES) [2]: ideal for real quantum computing devices. A review on the structural, optical and energy level characterization will be shown. But what really differentiates these nanostructures from QD is their behavior under magnetic fields, which allows us to call them truly Quantum Rings.

As artificial atoms, the discrete energy levels of both QD and QR are affected by magnetic fields (Zeeman effect, i.e.). But only in the Quantum Rings, it is possible to observe effects associated with one of the most intriguing quantum phenomena, the Aharonov-Bohm effect (AB). Magnetization AB-related oscillations have been measured [3] at 14T in a specially designed sample with 30 stacked layers of ensembles of QR charged with one electron. The experimental data are in good agreement with theoretical calculations based on Cross section STM (X-STM) measurements which show the surviving of the AB effect even when some asymmetry in the ring shape is present.

We also will show very recent results on micro-photoluminescence measurements (μPL) under magnetic fields up to 10T. Using a confocal microscope we were able to measure the μPL signal of a single QR with a spectral resolution of 15μeV. Zeeman splitting appears at low field, which breaks the spin degeneration (fig. 2). At a certain field another splitting appears, giving rise to four circular polarized light lines coming from each individual ring. The field at which this behaviour appears is dependent on each nanostructure (for the QR under test in figure 1 this happens at 4.4T). Interestingly, the intensity ratio between the lines with the same polarization shows that this is not a heavy hole-light hole mixing behaviour. We relate this effect with a magnetically-induced decoupling of the QR into two QDs.

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Figures:

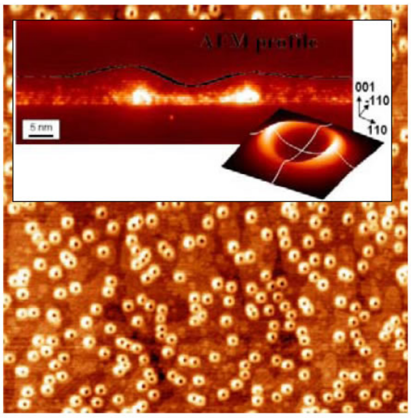

Figure 1: AFM image 2x2 micron2. Ensemble of Quantum Rings before capped. Inset shows X-STM of capped ring with a schematic view of the In profile and the measured AFM profile.

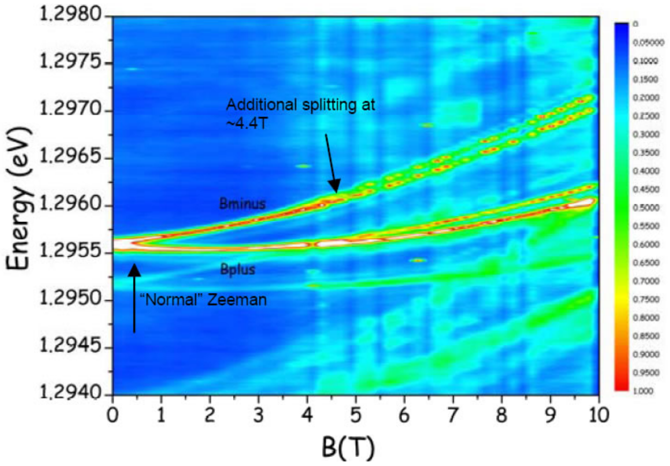

Figure 2: Micro Photoluminescence map of one single Quantum Ring. The color scale represent microPL intensity (white higher, blue lower). An anomalous splitting is observed at 4.4T, where four branches ares clearly splitted from the original two Zeeman splitting.