Capacitance Spectroscopy of Self-Assembled InGaAs Quantum Rings

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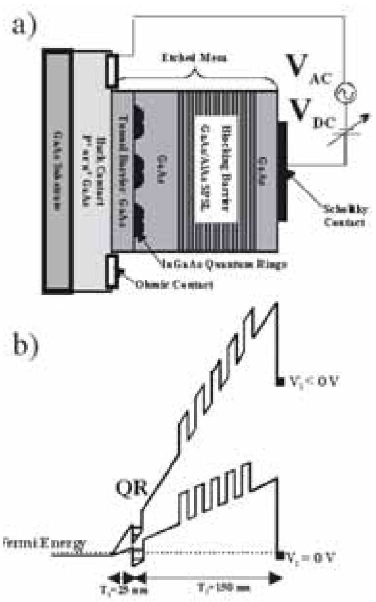
Self-assembled semiconductor nanostructures formed by lattice-mismatched heteroepitaxy are defect free islands with high optical quality and suitable confinement properties for the development of optoelectronic devices. Recently, they have been considered also as promising candidates for information storage and quantum computing applications. Many authors have reported experimental and theoretical detailed work on the growth mechanics, morphology and optical properties of these nanostructures, though less work has been reported on their transport characteristics. The electron and hole energy levels and confining potentials depend strongly on the shape, composition and surrounding material of the nanostructures, which makes theoretical predictions complex. On the other hand, optical characterization gives information on the recombination of excitons between the valance band and the conduction band. Several authors [1, 2, 3, 4] have reported measurements on the transport characteristics of InAs on GaAs nanostructures, and have emphasized the importance of a precise knowledge of the electron and hole system independently.

Figure 1



In this work we study the electron and hole systems of self-assembled InGaAs on GaAs (001) quantum rings (QR) by combining photoluminescence and capacitance-voltage measurements (CV) which provides characterization of the QR electrons (and holes) energy levels position. The band offsets [4] between the nanostructures confined states and the surrounding material (GaAs) can also be obtained.

The samples are grown by molecular beam epitaxy (MBE), details on the growth of the samples and the QR can be obtained elsewhere [4,5]. To study the transport properties of electrons (holes) a metal-insulator-semiconductor schottky diode (MISSD), described in Figure 1(a), is developed. A highly doped ($2x10^{18}$ cm^{-3}) GaAs:Si buffer to study the conduction band properties (or a GaAs:Be for the valence band), acts as back contact to inject carriers. The QR are embedded between a GaAs tunnel barrier 25 nm thick (t_1); and a GaAs layer followed by an AlAs/GaAs short period super lattice (SPSL) which acts as blocking barrier to forbid current, the thickness of this barrier is 150nm (t_2). 5nm of GaAs on the top prevents surface oxidation. A schottky contact gate is deposited on top of the structure. When an AC signal imposed upon a large negative DC voltage is applied between the gate and the back contact (V_1 in Figure1(b)) at low temperature, the QR energy levels lie above the fermi energy level and are unoccupied. For more positive DC voltages (V_2 in figure 1(b)) it is possible to align the fermi energy level with the QR lowest energy level, resonantly [3]. When this occurs, electrons tunnel in and out of the QR. This tunnel can be monitorized by measuring the capacitance between back contact and gate with a lock-in technique. By applying more positive voltages, it is possible to monitor the energy levels of the QR.

Figure 2:

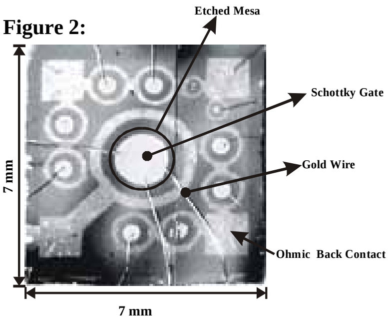
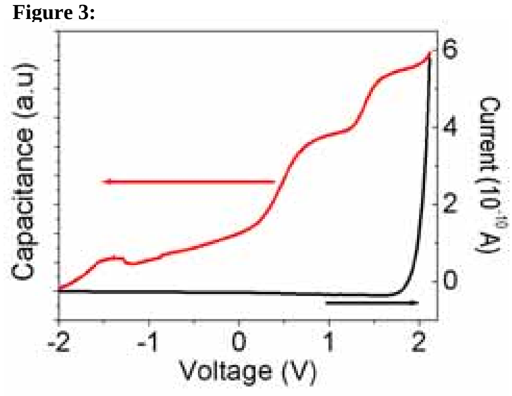


Figure 2 shows a photograph of a sample with eleven processed devices with different gate areas. The processing of the devices requires several steps involving mask design, wet chemical etching, ultraviolet lithography, and metallization. Several mesas are defined by wet chemical etching from the surface to the doped GaAs layer to prevent possible leakage. Ohmic contacts are prepared depositing and alloying Au/Ge for n^+ samples and Au/Zn for p^+ samples, on the top of the GaAs doped layer. This contacts are ring shaped and surround the mesas to reduce signal noise. The schottky contact gate is formed by a Cr/Ni/Au layer.

Figure 3:



Several n^+ and p^+ sample have been grown with different t_1, t_2 ratios and are being processed and are characterized. The samples are measured in a closed circuit He cryostat with a window, this allows the simultaneous measurement of CV and photoluminescence (PL) spectra. Capacitance-voltage spectra is shown in figure 3. The quality of the diode is very good. The capacitance spectra shows two remarkable step like features in the positive voltage range which are attributed to loading of the charge into 2D electron systems, i.e. the wetting layer and the accumulation of free electron on the SPS barrier. Although the broad peak at –1.5 V can be related to the nanostructures, with a clear delta like characteristic, it is not clear that are associated with the QR layer. Further work is in progress.

This work has been supported by the European Commission Growth program NANOMAT project, contract no. G5RD-CT-2001-00545 and by Spanish MCYT under NANOSELF project TIC2002-04096-C03-03

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Figure 1: a) Schematic description of the MISSD used to measure the transport properties of electrons and holes in QR. b) Valence band diagram of a n+ doped device under two different gate voltages.

Figure 2: Photograph of MISSD device with eleven processed devices with different gate areas

Figure 3: Capacitance signal (left axis) and currents vs. the applied voltage to the schottky diode of a sample with a n+ doped back contact and with a layer of quantum rings.