

Low-dimensional In-based semiconductor systems

Recent advances in the epitaxial growth of low-dimensional semiconductor systems with techniques such as molecular beam epitaxy (MBE) make it possible to form structures of various geometries. The composition profile and the vertical transport properties of self-assembled InAs/GaAs quantum dots (QDs) and quantum rings (QRs) are investigated by X-ray photoemission electron microscopy and conductive atomic force microscopy [1-3]. The resulting measurements give information on the mechanisms driving the formation of such low-dimensional structures. Furthermore, we have investigated the transport properties of two dimensional electron gases (2DEGs) in $\text{In}_{0.75}\text{Ga}_{0.25}\text{As}$ quantum wells and found a correlation between the local indium concentration modulation, measured with X-ray photoemission electron microscopy, and the pronounced anisotropy observed in the low-temperature mobility of the 2DEG [4-5].

The self-organization of nanostructures represents a phenomenon of fundamental interest in material science, with great potential in various fields of technology. However, size, shape, and compositional distribution in strain-driven self-assembled nanostructures can be significantly modified by deposition of a capping layer. A striking example is the transformation of self-assembled QDs into QRs when a thin (few nm-thick) layer of barrier material is overgrown on the original islands under appropriate conditions.

QR samples were prepared in the high mobility MBE facility at the TASC laboratory in Trieste [2]. Topography and current maps of a QR sample were measured simultaneously by conductive atomic force microscopy (C-AFM) as shown in Fig. 1. The most significant feature exhibited in the current map is the lower conductivity (dark region) of the central QR hole compared to rim and wetting layer. Considering the presence of a surface oxide in the case of the C-AFM measurements, these results are consistent with data on the QR composition acquired with X-ray photoemission electron microscopy (XPEEM) [6]. For the topmost layer of the QR sample consisting of $\text{In}_x\text{Ga}_{1-x}\text{As}$ with varying In content x , the XPEEM measurements show that the average In content is lowest in the capping layer ($x = 0.53$) and gradually rises towards the central QR hole, where it reaches its maximum ($x = 0.67$).

Two-dimensional electron gases (2DEGs)

based on $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{In}_x\text{Al}_{1-x}\text{As}$ quantum wells (QWs) with high In concentration offer potential advantages over GaAs/ $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ones, both for studies in fundamental physics and for device applications, due to their peculiar properties such as low effective electron mass, large bare g-factor, large Rashba coupling, and highly transmissive metal-semiconductor interfaces for $x \geq 0.75$. The low temperature transport properties of $\text{In}_{0.75}\text{Ga}_{0.25}\text{As}$ QWs manifest a strong mobility anisotropy that cannot be explained in terms of interface roughness scattering [4]. The identification of the mechanism limiting the mobility

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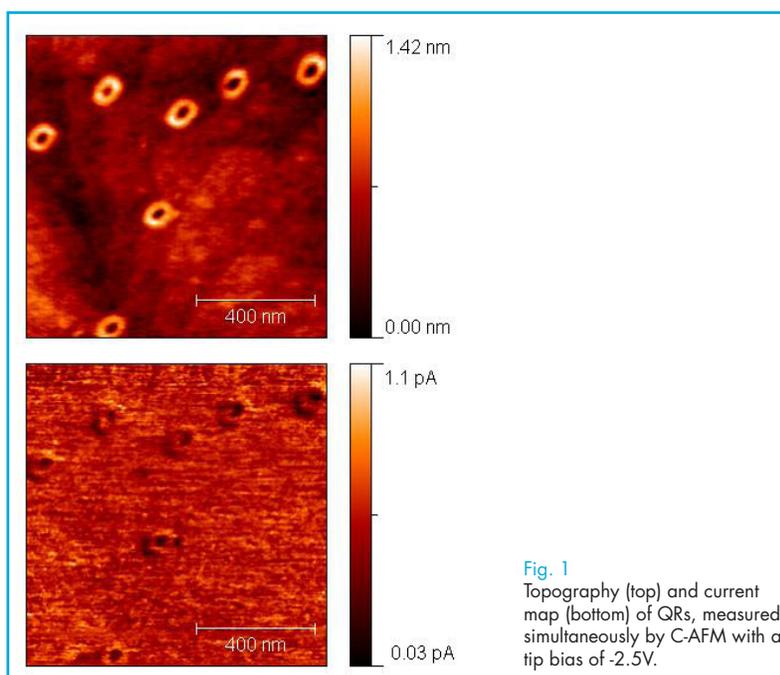
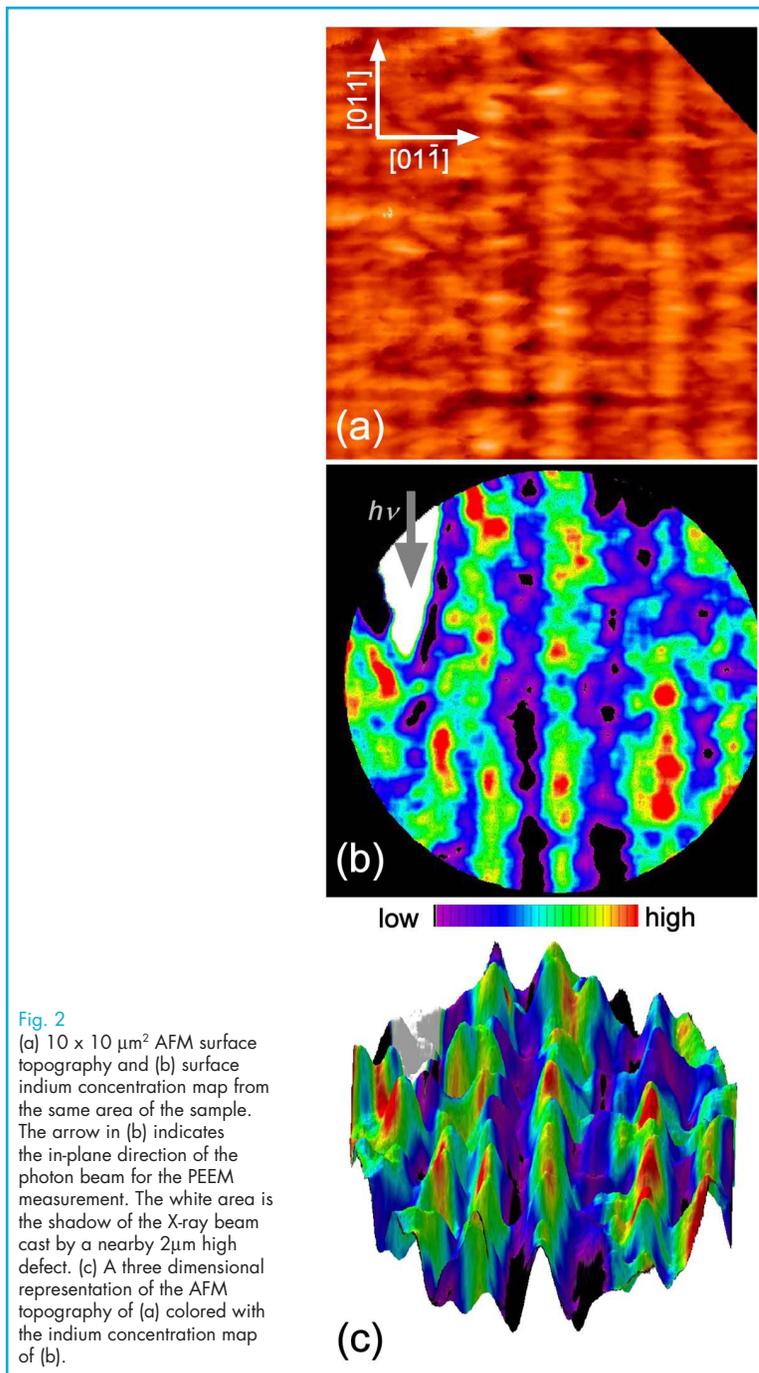


Fig. 1
Topography (top) and current map (bottom) of QRs, measured simultaneously by C-AFM with a tip bias of -2.5V.

allows to design and grow higher quality 2DEGs, needed for high indium content InGaAs device fabrication. The surface concentration map obtained with XPEEM has allowed us to correlate, for the first time, the morphological properties of the sample surface measured by AFM shown in Fig. 2a with local variations in the indium concentration of the alloy (see Fig. 2b). In order to evaluate the

contribution of the local In fluctuations on the mobility, simulations were performed in collaboration with the University of Modena and Reggio Emilia [4] to verify if the transport asymmetry can be explained by a conduction band energy modulation correlated with the indium concentration. Good agreement was reached between the simulated and measured transport asymmetry. We have thus identified the main origin of the transport asymmetry to be a spatial modulation of the indium concentration in the QW.

These conclusions are confirmed by the increased mobility (in excess of 50 m²/V·s) and reduced anisotropy of a QW sample containing a pure InAs layer.



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