TRANSMISSION ELECTRON MICROSCOPE IMAGES OF DOT-IN-A-WELL InAs/InGaAs/InP STRUCTURES. Sandra M. Landi(1), I. Guillermo Solórzano(2), Mauricio P. Pires(3), Patrícia Lustoza de Souza(1). (1) Laboratório de Semicondutores, CETUC, PUC-Rio, Rio de Janeiro, Brasil, (2) Departamento de Ciências de Materiais e Metalurgia, PUC-Rio, Rio de Janeiro, Brasil, (3) Instituto de Física, UFRJ, Rio de Janeiro, Brasil.

InAs quantum dots (QD) grown on InP substrates are expected to be useful in applications such as integrated optoelectronic devices for optical fiber communication and room temperature operating infrared photodetectors. In particular, there is growing interest in developing mid-infrared (2–20 μm) photodetectors for night vision, environmental monitoring, toxic gas detection and free space communication. For these purposes, the growth of high quality stacked self-assembled QDs becomes fundamental. As the optical and electronic properties of such structures depend on the size and shape of the QDs [1], accurate techniques for verifying their density, shape, and distribution are required. This work presents a characterization study by cross-sectional transmission electron microscopy (TEM) of multilayer InAs/InGaAs/InP structures.

The samples investigated are the so-called "dot-in-well" (DWELL) structures, which are attractive for infrared photodetection because they allow tuning the transition energy by changing the quantum well thickness and/or composition [2]. The samples were grown on semi-insulating InP (001) substrate in a low-pressure metal-organic chemical vapor deposition reactor. They consist of 10 layers of InAs QDs, each one grown on a nominally 8.5 nm thick InGaAs layer lattice-matched with the InP substrate and capped by an 18 nm thick InP layer. The multi-layer structure was sandwiched between 0.4 μm InP contact layers doped with Si to reach $n = 4 \times 10^{18}$ cm^{-3}. The thicknesses of the different layers and the composition of the ternary layer were obtained by X-ray diffraction measurements.

The sample cross section was polished with a Minimet® 1000, Buehler Ltd. polisher. Silicon carbide papers with grit sizes of 600, 1200, 2000 and 4000 were used for polishing until the sample was reduced to 100 μm in thickness. Then a dimple polish using a Gatan Dimple Grinder model 656 was performed. Since InP is a delicate material and is easily damaged mechanically, the polishing pressure was reduced to its minimum value. The final polishing step was performed with 0.05 μm colloidal silica. After thoroughly rinsed with water, the sample was mounted on a standard copper grid and was ion-milled at 12° with 4 keV Argon ions using a DuoMill ™ Gatan system. TEM studies were conducted with a Jeol 2010 instrument operating under 200 kV accelerating potential. Conventional diffraction contrast and phase contrast imaging techniques were applied. The first sets conditions for observing nano-scale crystalline defects under bright field (BF) and dark field (DF) imaging conditions. The second allows lattice imaging when the sample is properly oriented with respect to the incident electron beam. The images were recorded using a Gatan CCD camera and the diffraction patterns were taken directly on the negative plate.

A low magnification BF TEM image of the multi-layer structure (see Fig. 1) shows that the layers are well defined and the QDs in adjacent layers are aligned, as expected. Figures 2 and 3 are two BF / DF pairs at two different magnifications. The measured thickness of the InGaAs well and the InP barrier are 12 nm and 16 nm, respectively. The dots appear to be lens-shaped, with a base diameter of around 30 nm. Figure 4 is a high-resolution (HREM) image where the projection of the lattice planes can be resolved. It is also possible to identify the fully coherent structure of the InAs/ InGaAs/ InP interfaces. Figure 5 is a HREM image before (Fig.5a) and after (Fig.5b) applying FFT filtering, where the atoms are resolved. The corresponding diffraction pattern is shown in Fig.5c.

References

[1] see for example: J. P. McCaffrey, et al., J. Appl. Phys. 90 (2001) 1784-1787
[2] M. P. Pires, et al., J. Crystal Growth 272 (2004) 192-197

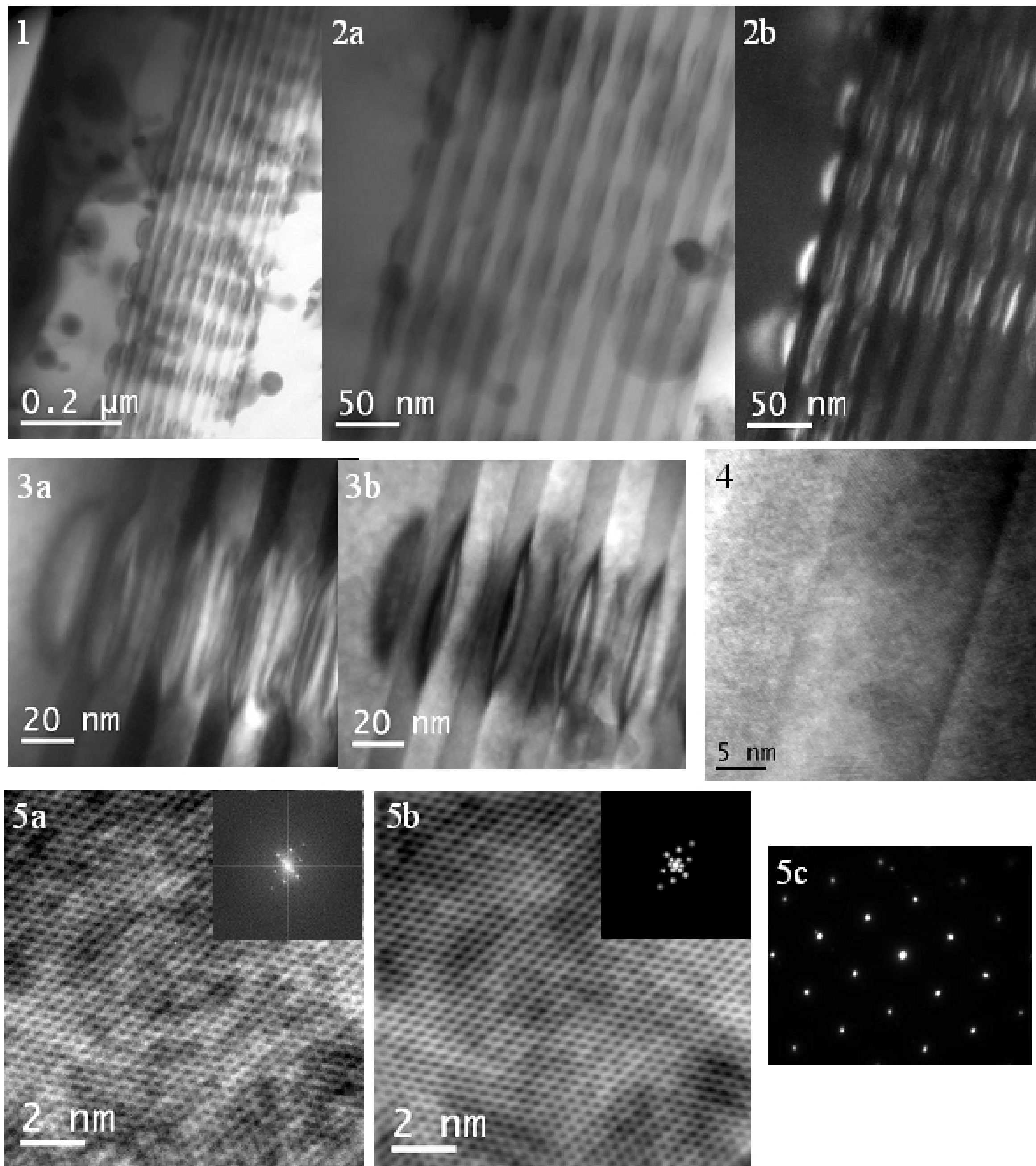

Figure 1 – Low-magnification TEM image of the multi-layer structure of QDs.
Figure 2 – BF/DF pair showing the alignment of QDs.
Figure 3 – BF/DF pair of outermost layers of the sample.
Figure 4 – HREM image showing coherent interfaces.
Figure 5 –HREM images with their corresponding FFT (a) before and (b) after applying image processing. (c) The corresponding diffraction pattern.