Molecular Beam Epitaxy (MBE), a versatile tool to integrate model semiconductor nanostructures into advanced solar cell concepts

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Semiconductor quantum nanostructures are at the base of advanced designs for high efficiency photovoltaic solar cells. MBE technology is an advanced and versatile technique to create highly perfect single-crystalline semiconductor heterostructures with superb control of dimensions, composition and doping in the nanoscale. In particular, this technique is perfectly adequate to epitaxialy grow complete device structures containing tailor designed nanostructures, due to its compatibility with a variety of in-situ control and characterization techniques. We will describe how MBE is applied at IMM to create model solar cell structures incorporating self-assembled Quantum Dots stacks and Quantum Posts in the InAs/GaAs or InAs/InP systems, together with sharp tunnel junctions, that should allow to test ideas, to study physics of novel structures and to obtain realistic estimations on the feasibility of advanced designs for high efficiency solar cells as the IB concept (1)
After a brief introduction on the peculiarities and applications of MBE, a more detailed description will be given of the principles and techniques used to design, monitor and control the strain distribution, accumulation and compensation. Examples will be presented of cells containing heterostructures and materials with large lattice parameter mismatch and corresponding large local strains. The incorporation of Phosphorus or Antimony as strain creating or compensating elements results in interesting device properties (2). As a particular case of extreme difficulty, the fabrication of GaAs solar cells, with a large number of stacked QDs layers in the intrinsic zone to enhance QD absorption characteristics without generating dislocations, will be considered. (3)

As a further example, the techniques to grow a new type of nanostructures, Quantum Posts, will be considered. Main interest of using quantum posts instead of quantum dots to form the intermediate band is intimately related with their elongated shape, and hence their potential to tailor the absorption of the photons that cause transitions from the IB to the CB. Typical QDs grown in the Stranski-Krastanov mode have a flat shape with the vertical dimension shorter than the lateral ones. Producing QDs with increased vertical dimension can increase the transition element related to IB to CB transitions and therefore increase the absorption associated to this transition. Stacking several QDs (that is, creating a QP) can be a way to produce the desired aspect ratio. On the other hand, it is of interest to research on the non delta-like density of states introduced by the QPs to investigate the limits in which the extra density of states introduced does not jeopardize the voltage preservation predicted for the IBSC.
Quantum posts are assembled by epitaxial growth of closely spaced quantum dot layers, modulating the composition of a semiconductor alloy, typically InGaAs. In contrast with most self-assembled nanostructures, the height of quantum posts can be controlled with nanometer precision, up to a maximum value limited by the accumulated stress due to the lattice mismatch. Here we present a strain compensation technique based on the controlled incorporation of phosphorous, which substantially increases the maximum attainable quantum post height. The luminescence from the resulting nanostructures presents giant linear polarization anisotropy.
Finally, novel process techniques, derived from the understanding of MBE growth kinetics in the research environment, but applicable to other materials and polycrystalline thin film structures, will be discussed in view of their application to solar cell commercial fabrication.
We conclude that in the next future, similarly to what has been happening in the microelectronics field, a remarkable photovoltaic cell sophistication and efficiency will be compatible with a large scale, low cost industrial scenario.

References

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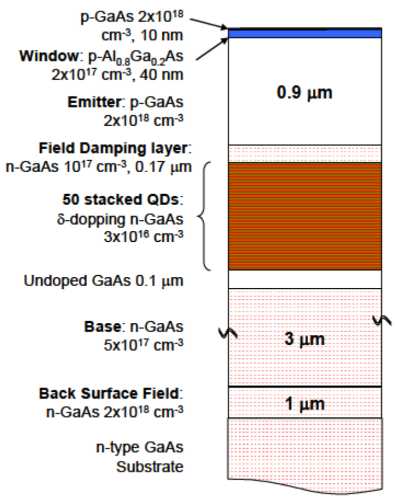
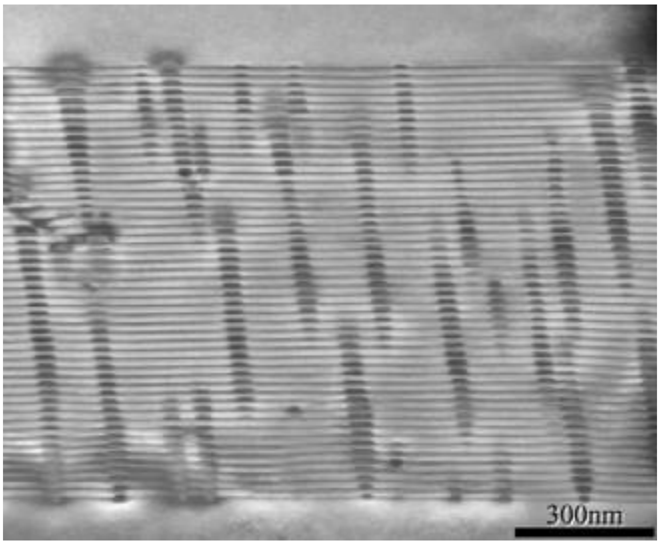
Figures



Solar Cell structure



TEM image (<1-10> plane) of the 50 stacked QDs solar cell with SC

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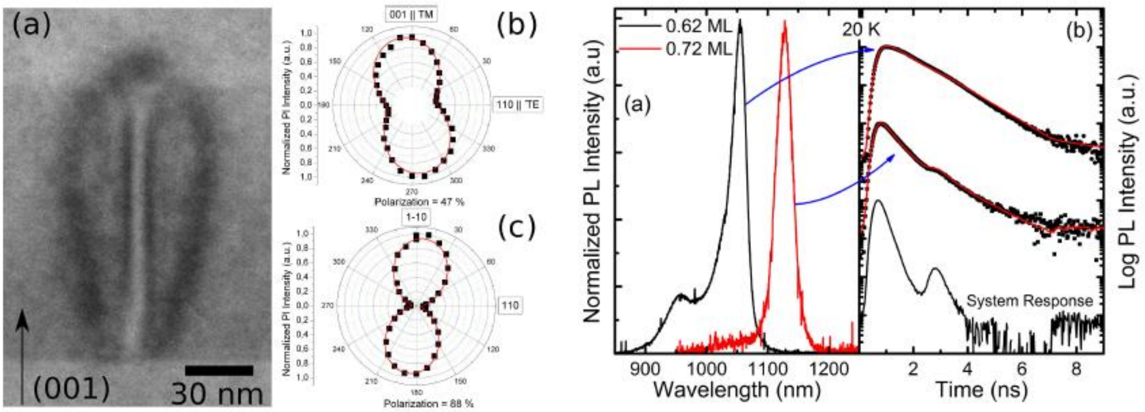

Left : (a) TEM detail of a QP. Middle: Linear polarization of light emitted along the (b) cleaved edge and (c) growth direction. Right : (a) PL of QPs with different In content and (b) their corresponding time resolved PL decay curves.