A New Pyramidal Quantum Dots System: achieving high optical quality in an uniform, site-controlled system

Lorenzo O. Mereni, Valeria Dimastrodonato, Robert J. Young, Emanuele Pelucchi
Tyndall National Institute, University College of Cork, Cork, Ireland
lorenzo.mereni@tyndall.ie

A reliable site controlled in a Quantum Dots (QD) system is highly desirable for many emerging technologies and has thus garnered significant effort from the scientific community. Many techniques have been proposed recently aiming to develop a method to controllably seed the nucleation of individual quantum dots[1,2]. A large number of these techniques have been successful and it is now possible to produce ordered arrays of dots with nanometer accuracy in their position. Nonetheless none of these techniques, so far, have achieved this goal while maintaining an optical quality, in terms of spectral purity and intensity, comparable to that achieved by self assembled, i.e. non site controlled, grown QDs.
Pyramidal Quantum Dots grown by MOVPE in pre-patterned tetrahedral recesses on GaAs (111)B substrates –Fig.a-, a technique that matured at the Ecole Polytechnique in Lausanne, are one of the most intriguing solutions to address the site control problem[3]. They have been used to demonstrate single photon emission with both optical or electrical excitation and are among the most uniform systems shown to date[4,5]. Conjugating the characteristics of Pyramidal QDs with the optical quality of Stranski-Krastanov grown dots is a major step which remains to be taken towards the realisation of an “ideal” QD source which is sufficiently reliable and robust for applications.

We will present a new Pyramidal QD system in which it has been possible to achieve both high uniformity and record narrowness of the linewidth from the neutral exciton emission (the best linewidth measured being just 18 μeV –Fig. d- but almost all the dots showed linewidths narrower than 30 μeV): this is an unprecedented result for any site controlled or MOVPE grown dots. Two factors have made this achievement possible: an extremely clean growth process and the replacement of AlGaAs, the traditional barrier material for this kind of dots, with GaAs. The latter not only makes the structure more simple –Fig.b-, all the vertical quantum structures that formed in previous schemes due to alloy segregation no longer exist, but it also reduces impurity incorporations associated with the presence of Aluminium, thus eliminating one of the principal causes of diminished optical quality.

Many parameters in our system are easily tuned: investigations are ongoing to understand how far the wavelength of the quantum dot emission can be pushed towards the red, but wavelengths as long as 1100 nm have been achieved by simply changing the dot size and the Indium content in the $In_xGa_{1-x}As$ alloy of the dot layer. This opens interesting possibilities keeping in mind the 1300/1500nm goal for optical communications.

The uniformity of the neutral exciton emission (Fig. c), which was identified by mean of power dependant measurements and, where possible, of fine structure splitting measurements, was probed on our best sample (the dot layer was nominally 0.5 nm of $In_{0.25}Ga_{0.75}As$). The standard deviation from the average value of 1463.5 nm was found to be just 1.2 meV, the best reported to date to our knowledge, corresponding to a FWHM of the Gaussian distribution of 2.8 meV.

The fine structure splitting of the neutral exciton was measured and found to be very small (< 7 μeV for some dots): this encourages further investigation to realise a novel highly uniform site-controlled source of both single and entangled photons[6].

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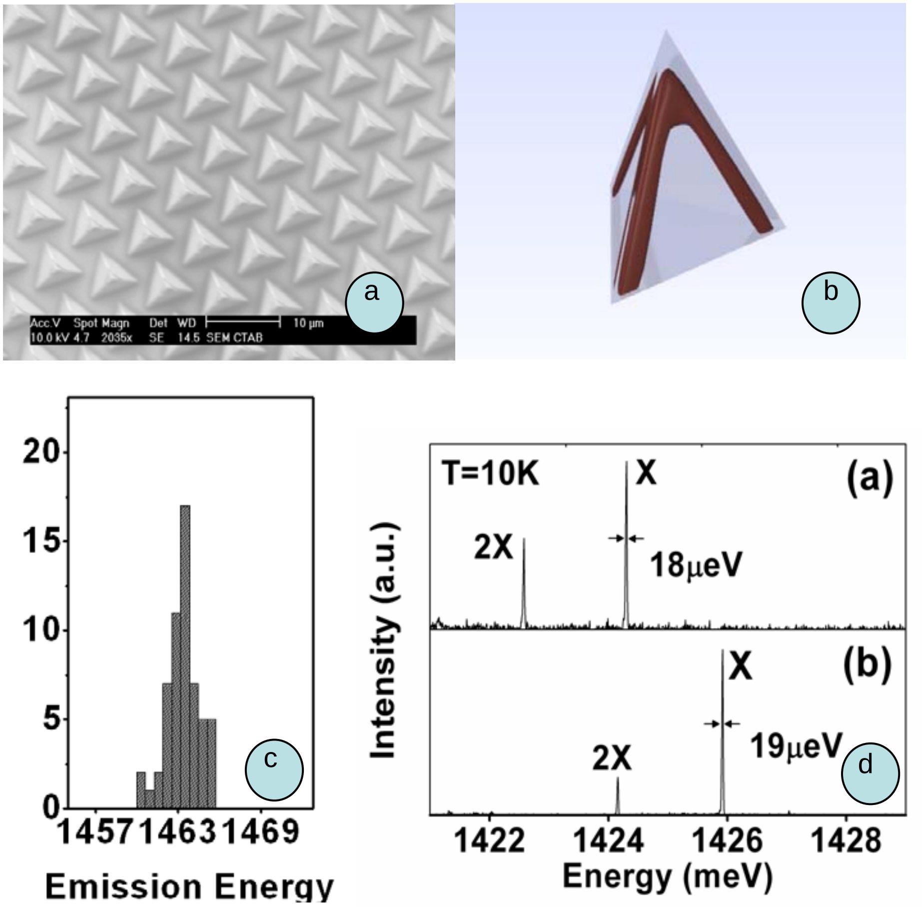

Figure: a) An SEM image of an ordered matrix of Pyramidal Quantum Dots in back etched geometry; b) A schematic drawing of the inner structure of one QD: in particular it is possible to see the lateral quantum wires. Between each couple of wires lies a lateral quantum well (not shown); c) Statistical distribution of the 60 pyramids investigated for the uniformity study. The inhomogeneous broadening due to size variations is only 2.8 meV (FWHM); d) PL spectra of two quantum dots on our best sample: the PL was made at 10K and in a very low excitation regime, the two integration times were different, but the longest (b) was 5 sec demonstrating the good quantum efficency of these dots. The neutral exciton lines were well fitted with Lorentzian lineshapes of respectively 18 and 19 μeV FWHM.