Different strategies towards the deterministic coupling of a Single QD to a Photonic Crystal Cavity Mode

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A single Quantum Dot (QD) coupled to a photonic cavity mode is the fundamental system for the study of Cavity Quantum Electrodynamics (CQED) phenomena in the solid state approximation**[1]**. These studies are essential for the development of devices such as single photon emitters and entangled photon pair sources, key elements for quantum information technologies. The successful fabrication of this kind of systems is very challenging due to the simultaneous requirements of spatial matching (the QD has to be placed at the maximum of the photonic cavity mode field) and spectral matching (both the wavelength of the QD emission and of the photonic cavity mode have to be the same) between the QD and the photonic cavity mode. Although coupling of single self-assembled QD to a photonic crystal (PC) cavity mode has already been demonstrated **[2, 3]**, the technology is far from being mature. In this sense, the use of high spatial resolution lithographic techniques for site controlled QD formation**[4, 5]** is crucial in order to improve the yield of deterministic integration of a coupled QD – cavity mode**[6,7].**

In this work we present two strategies for coupling of InAs site-controlled QD with the mode of GaAs-based PC nanocavities. In both approaches InAs QD are formed at specific sites of the GaAs surface defined by the presence of nanoholes formed after desorption of the GaAs oxide points obtained by AFM local oxidation lithography. These site-controlled nanostructures show good optical emission properties and are efficient quantum emitters operating as single photon sources **[5]**. In both approaches the photonic crystal nanocavities are fabricated by *e*-beam lithography and dry etching (RIE) on GaAs epitaxial layers grown on 1 micron thick $Al_{0.75}Ga_{0.25}As$ sacrificial layer by molecular beam epitaxy (MBE).

The first approach (Fig. 1) consists of the fabrication of photonic crystal nanocavities on a 105 nm thick GaAs slabs. We have fabricated L*n*-type (L3 tuned, L7, L9) and H1 modified cavities. The slab thickness is smaller than the target (140 nm) for the final structure. On top of the microcavities, AFM local oxidation lithography is performed to define the nucleation site of a single QD at the the electric field maximum within the cavity. Then, a MBE re-growth process is developed for InAs QD formation and the increase (35 nm) of the thickness of the GaAs slab. This way, the final structure consists of a InAs single QD spatially located at the predefined position by AFM local oxidation lithography embedded in a photonic cavity slab with the appropriate thickness for optical coupling to the photonic cavity. Our results show that this process leads to a strong evolution of the round shape of the PC holes that degrades the quality factor (Q) of the cavity mode. Some attempts for minimizing the shape evolution of the round holes by changing the crystallographic direction along which the PC round holes are fabricated will be shown. Optical micro-PL emission carried out by confocal microscopy at 77K of the re-grown nanostructures will be shown.

In the second approach an etched ruler is fabricated by using *e*-beam lithography and dry etching (RIE) on a 65nm-thick GaAs epitaxial layer. Then, AFM local oxidation lithography is performed to define the nucleation sites of InAs QDs and their position coordinates are recorded with respect to the fabricated ruler (Fig 2). The formation of InAs QD and the target thickness of the slab with the embedded site controlled InAs single QD is later completed by the developed MBE re-growth process. Micro-photoluminescence characterization of these site controlled QDs will be made in order to know their actual emission wavelengths. This way, we could access to know both the spatial coordinates and the emission wavelength of every QD. In this situation, a PC cavity can be designed for matching the emission wavelength of the embedded QD and later fabricate around the previously recorded position coordinates of the QD with respect to the ruler.

References

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Figures

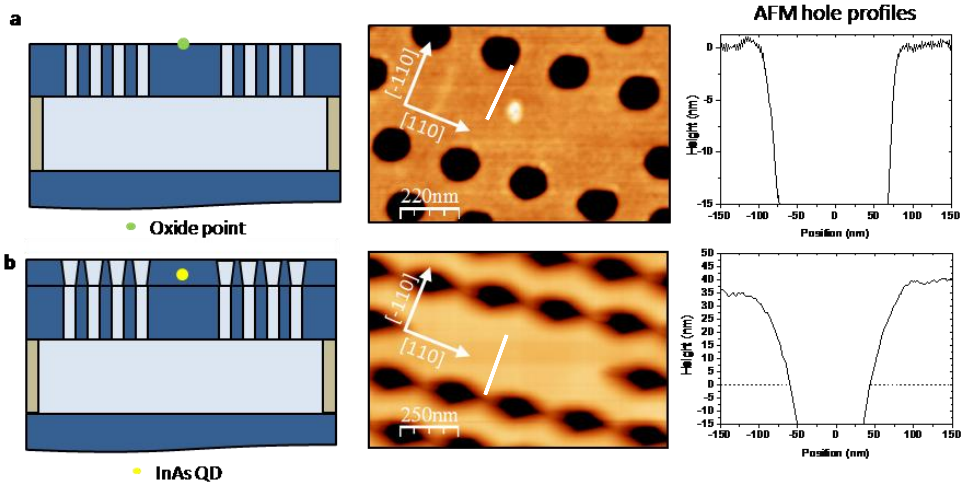

Figure 1. First approximation: Site controlled InAs QD fabrication at the maximum of the electric field of a pre-patterned photonic crystal cavity. Different process steps and the corresponding AFM images: (a) Fabrication of the photonic crystal structure (SEM-RIE) and GaAs oxide dot (AFM local oxidation) on a GaAs 105 nm thick slab; (b) The structure is completed by a MBE regrowth process up to 140nm thickness with an embedded site-controlled InAs QD placed 20nm below the surface. AFM profiles show the change on the hole shape due to the regrowth step.

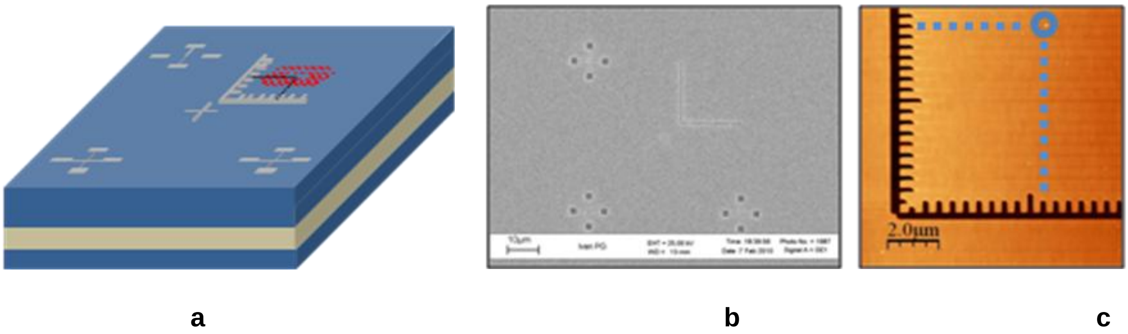

Figure 2. Second approximation: Deterministic cavity fabrication around site controlled InAs QD positioned respect to a pre-patterned etched ruler. (a) Sketch of the final structure with a photonic cavity fabricated at the position of a site-controlled InAs QD, with coordinates set by the etched ruler. (b) SEM image of the fabricated etched ruler with the alignment marks. (c) AFM image of an actual GaAs oxide dot obtained by AFM local oxidation with known coordinates respect to the ruler.