Nanofabrication of silicon nitride photonic crystals membranes

Valentim, P. T.,[1, 2, 3] Vasco, J. P.,[2, 3] Fonseca, H.,[1] Borme, J.,[1] Assis, P.-L.,[2, 3] Rodrigues, W. N.,[2, 3] Quivy, A. A.,[3, 4] Guimarães, P. S. S.,[2, 3] Gaspar, J.[1]

[1]INL- International Iberian Nanotechnology Laboratory, Braga, Portugal
[2]Departamento de Física, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil
[3]DISSE-INCT de Nanodispositivos Semicondutores, Brazil
[4]Instituto de Física da Universidade de São Paulo, CP 66318, 05314-970 São Paulo, SP, Brazil
pablo.valentim@visitor.inl.int

We report on the nanofabrication of silicon nitride (SiN_x) L3 photonic crystals nanocavities with high geometrical quality. Lately, these kind of devices have attracted much attention due to their capability for confining, guiding and modifying the light transportation within the matter. These can also interact with novel materials such as transition metal dichalcogenides (TMDC) and antibodies within the visible range of the electromagnetic spectrum [1]. The aim of this work is to develop an efficient fabrication process and study the emission properties of such cavities both with photoluminescence and reflectivity experiments at room temperature. Theoretical calculations were carried out using guided mode expansion approach to help us establish the optimal geometrical parameters of our structures, such as lattice parameter (a), radius (r) and thickness (t), which in our case, were chosen to be a = 270 nm, r = 83.7 nm and t = 270 nm, respectively. Taking into account the refractive index for SiN_x (n = 2.01), the theoretical fundamental L3 photonic mode is expected to be around 672 nm and has a theoretical quality factor (Q) of 4300. Figure 1 bellow shows the schematics of our structure.

It is known from literature that fabrication imperfections are the major causes for cavities low quality factors [2]. To overcome these challenges, we have developed a method for producing high quality factor cavities using MEMS/NEMS fabrication based technologies. Firstly, using a plasma enhanced chemical vapor deposition (PECVD) system, we deposit a 270-nm-thick layer of SiN_x on the front side of a 725 µm-thick double side polished (DSP) silicon wafer. A 3500-nm-thick layer of silicon dioxide (SiO_2) is then deposited on the backside. The photonic crystal cavity (PHC) pattern is produced on the front side of the wafer by the means of a negative tone resist E-beam lithography, development and deposition 25 nm-thick layer of Al followed by lift-off in a Microstrip solution at 60°C under ultrasonic agitation. By the end of this step we have fabricated a metallic aluminum hard mask that will be used to transfer the PHC pattern into the SiN_x layer. After that, the sample is etched in a fluorine based reactive ion etch (RIE) process to remove only the areas on the SiN_x layer that are not protected by the Al mask. Then, on the back side of the wafer, a conventional optical lithography is combined with a RIE plasma to make small apertures on the SiO_2 layer that will serve as a hard mask for deep reactive ion etch (DRIE) of silicon. During this process most of Si is removed, leaving just a 100 µm-thick layer left. The last step is an anisotropic Tetramethylammonium hydroxide (TMAH) wet etch. Along this part, the last 100 µm of Si are slowly etched, in a rate of 45 µm/h, enabling the gentle releasing of the patterned SiN_x suspended membranes. The outcome are free-standing silicon nitride layers exhibiting very good holes circularity and very straight side walls, both desirable features of high quality structures necessary to study cavity quantum electrodynamic (cQED) phenomena.

We are currently implementing a cross-polarization measurement system that will allow us to perform microphotoluminescence and reflectivity (transmission) experiments at room temperature on the samples. The first objective is to study how the quality factor of these cavities changes with respect to the lattice parameter, hole size and membrane thickness. Afterwards, we intend to investigate the coupling behavior between the cavity mode and external light sources, as well as, the coupling between two photonic cavities containing external light emitters.

[1] Gan, X. *et al.*, App. Phys. Letters **103**, 181119 (2013);
[2] Lim, K-m., *et al.* Microelectronic Engineering **88**, 994-998 (2011).

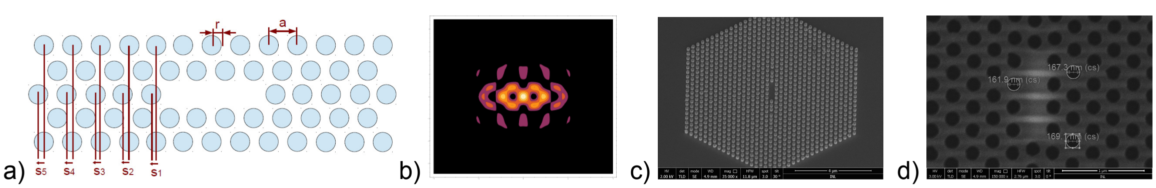

Figure 1: a) Schematic of PHC showing the parameters used in our calculations. To further increase the quality factor five holes on both sides of the cavity, S1, S2, S3, S4 and S5, are displaced outwards by 91 nm, 72.9nm, 23.76 nm, 87.21 nm and 46.71 nm, respectively. b) Theoretical calculation of the fundamental mode electric field distribution. c) PHC pattern after Al deposition. d) PHC structure obtained using the fabrication process described above.