Whispering gallery mode optical characterization on Si rich Si_3N_4 active microdisk resonators

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One of the major obstacles for large-scale silicon-based electronic-photonic integration is the absence of a compact and efficient silicon-based light source, due to the intrinsic inability of silicon to emit light efficiently. Various strategies for improving light emission in silicon have been demonstrated during the last decade [1], one of the most promising ones being the use of nanostructured silicon (Si-nc) in the form of clusters embedded in dielectric matrices. An intensive knowledge has been already obtained for Si rich SiO_2 materials, in which a SiO_2 medium surrounds the Si-nc. However, there are two drawbacks concerning this kind of material that should be taken into account for fabricating active photonic devices: i) the relatively low refractive index (1.5-1.6) with respect to SiO_2, which impacts on the compactness of the photonic devices; ii) this material is not ideal for the fabrication of stable and efficient electrically driven devices due to a huge barrier mismatch between Si and SiO_2. As a consequence, Si rich Si_3N_4 matrices have attracted attention since they present both a higher refractive index and a smaller band gap with respect to Si rich SiO_2. In addition, efficient light emission under optical and electrical pumping has been also reported recently [2,3].

On the other hand, monolithic circular resonators such as micro-disks, rings and toroids are triggering an intensive and rapidly evolving research due to the low fabrication complexity, which relaxes the ultrahigh resolution process needed to create photonic crystal cavities with similar properties. In circular optical microcavities electromagnetic fields at certain optical frequencies can be localized in ultra-small modal volumes by means of total internal reflection effect, leading to the so-called whispering gallery modes (WGM).

An interesting approach is to combine the light propagation and emission properties of Si rich Si_3N_4 matrices and the optical properties of microcavities. In this work we have done a simulation and experimental study of the WGM emission properties of single microdisk resonators with an optically active disk material made of luminescent Si-nc embedded in Si_3N_4 matrix deposited over a SiO_2 cladding.

By using a three-dimensional FDTD package we have done a study of the modal structure of the microresonators, i.e. the position and quality factors of the resonance peaks and electric field spatial distribution of the different modes inside the cavity, which were modified by varying the structural parameters of the optical elements.

In addition, we have produced a set of different samples where the Si_3N_4 stoichiometric material has been deposited by using the LPCVD deposition technique which has been subsequently suffered a double ion implantation of Si followed by an annealing procedure in N_2 atmosphere at 1100ºC. The photonic structures have been afterwards defined by means of standard photolithographic techniques. On figure 1 we show an AFM image of one of the microdisk structures designed, where we have achieved an average surface roughness of less than 1nm.

Room temperature micro-PL measurements have been performed in order to characterize the on-plane emission spectrum of single microdisks. The microdisks close to a cleaved sample edge were excited vertically, while the WGM emission was monitored in the plane of disks. On the main panel of figure 2 we show the actual measurement of a 3μm radius microdisk, where several resonances are observed modulating the PL emission of the active material. On panel b), a zoomed part around 715nm of the spectrum is showed in order to show clearly the width of the observed resonances. As it can be seen from the lorentzian fit of a resonance present at 719nm, sub-nanometer WGM resonances are observed, corresponding to quality factors higher than 1200. These values are among the highest previously reported values in Si-nc-based systems [4,5] and are actually limited by the resolution of our experimental setup.

In addition, an increasing of the pumping flux is not generating a spectral widening of the resonances and high pumping powers does not seem to affect the quality of both the material and the cavities. This is in contrast to what observed in other reports of Si-nc based microcavities, where significant enlargements are observed associated to carrier absorption losses [4,5].

References

[1] Silicon Photonics, edited by L. Pavesi and D. J. Lockwood Springer, Berlin, (2004)
[2] N. M. Park, C. J. Choi, T. Y. Seong, and S. J. Park, Phys. Rev. Lett. **86**, (2001) 1355
[3] K.S. Cho, N.M. Park, T.Y. Kim, K.H. Kim, G.Y. Sung and J.H. Shin, Appl. Phys. Lett. **86** (2005) 071909
[4] M. Ghulinyan, D. Navarro-Urrios, A. Pitanti, A. Lui, G. Pucker, and L. Pavesi, Opt. Express **16**, (2008), 13218
[5]R. D. Kekatpure and M. L. Brongersma, Phys. Rev. A 78, 023829 (2008)

Figures

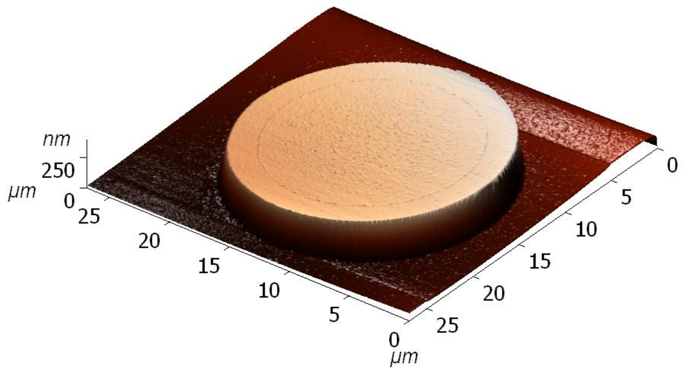

Figure 1. AFM image of a 10μm radius Si rich Si_3N_4 microdisk.

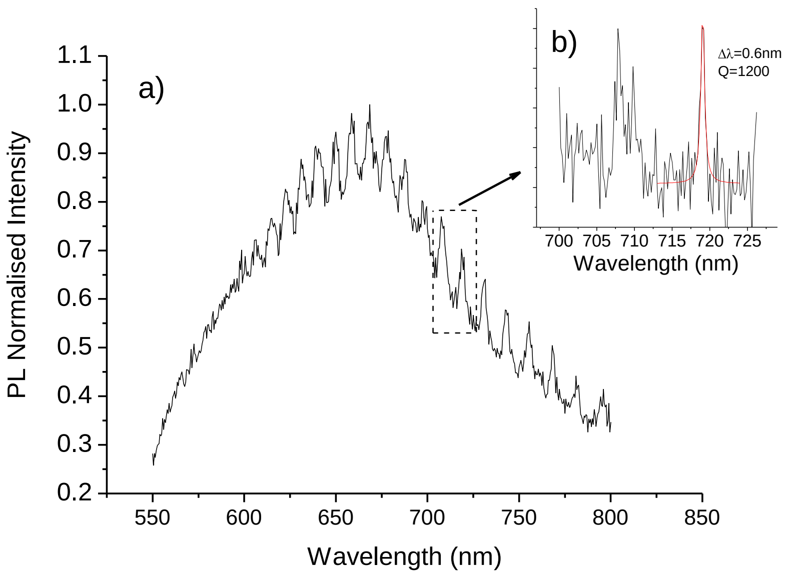

Figure 2. Panel a) Low resolution micro-PL spectrum of a 3μm radius microdisk. Panel b) High resolution spectrum of a particular part of the spectrum. The red curve shows a lorentzian fit of one of the resonances.