Photoluminescence of silicon nanocrystals

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Since the discovery of luminescent properties of porous silicon [1 - 3], many research efforts were dedicated to the light emitting properties of nanometric sized silicon. Light emitting Si based materials promise to allow merging of electronics and photonics in a single chip, thus overcoming the restrictions settled by the power dissipation bottleneck on the short/medium distance interconnects [4, 5]. Room temperature luminescence emission in silicon nanocrystals (Si-nc) is routinely observed independently of the preparation method [6-9]. The emission is characterized by a wide band in the wavelength range 600-900 nm. Qualitatively in agreement with the quantum confinement model the emission band red shifts with the increase of the Si-nc mean size, what allows to attribute this band to electron-hole recombination in Si-nc. Often, a second band, centered at 500 nm, can be observed in the luminescence spectra. It is different by the Si-nc related band because it does not shift by changing crystallites size. This second band can be related to recombination in matrix defects which can be quenched by post-growth treatment, such as hydrogen passivation.

Recent results on the photoluminescence properties of silicon nanocrystals embedded in silicon oxide are reviewed and discussed. The attention is focused on Si nanocrystals produced by high temperature annealing of silicon rich oxide layers deposited by plasma enhanced chemical vapor deposition. The influence of deposition parameters and layer thickness is analyzed in detail. Non-linear properties, correlation between structural and optical properties and attempts to find the good growth parameters to get efficient electrical injection will be presented and discussed.

The nanocrystal size can be roughly controlled by means of Si content and annealing temperature and time. Unfortunately, a technique for independently fine tuning the emission efficiency and the size is still lacking; thus, only middle size nanocrystals have high emission efficiency. Interestingly, the layer thickness affects the nucleation and growth kinetics so changing the luminescence efficiency.

Keeping fixed the content of silicon, Si-nc size can be increased by increasing the annealing temperature or, similarly, at a fixed temperature Si-nc size can be increased by increasing the content of Si into the SRO. The search for high luminescent Si-nc imposes to find a trade-off between Si concentration and annealing temperature.

In order to explore the possibility of efficient charge injection at low bias for on-chip device integration a small thickness is required. To explore the formation dynamics and optical properties of Si-nc in very thin films, 50 nm and 200 nm thick SRO layers, with two values of Γ, have been deposited by PECVD and annealed at 1100 °C in N_2 atmosphere. Some samples were covered with a capping layer of Si_3N_4 in order to avoid oxygen in-diffusion during the annealing process. The difference in PL intensity is two orders of magnitude for uncapped samples. A blue shift of the luminescence peak can be observed combined with the efficiency reduction thus indicating the presence of smaller Si-nc.

The reduction of efficiency well correlates with the reduction of mean size and can be attributed to the reduction of nc-Si density and to the increase of Si-nc amorphous fraction.

As a matter of fact [10], SRO can suffer of oxygen in diffusion during the annealing process due to the presence of residual oxygen into the furnace. As a consequence nc-Si are oxidized and consequently their mean size and their density can be reduced. The capping layer has the purpose of blocking the oxidation process. Thick samples (200 nm thick) are marginally affected by the oxygen in-diffusion process. This has to be taken in mind when thinking to device integration.

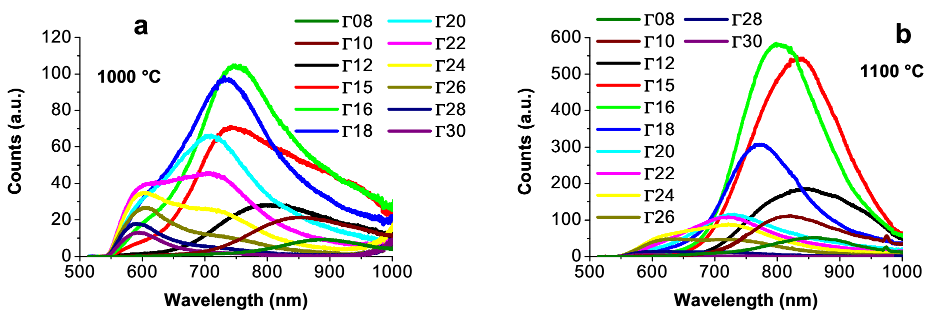

Figure 1 photloluminescence spectra as a function of Γ (N_2O / Si $_4$ flow ratio)of samples annealed at 1000 °C (a) and 1100 °C (b) respectively.

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