THE PHYSICS OF SILICON QUANTUM DOTS FROM SINGLE DOT STUDIES

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Abstract

The luminescent properties of nanoscale silicon were demonstrated in 1990 triggering the interest in Si nanostructures for optical emission. While the luminescence was quite strong even at room temperature, the micro-second long PL lifetimes revealed an inherited indirect bandgap from bulk Si. The luminescence mechanism was heavily debated whether quantum confinement really played a role or the emission would be due entirely from surface states. Many studies have confirmed the quantum confinement model but it has also been shown that the emission can be widely tuned by changing the surface passivation or by adding different ligands to the shell. The physics of the emission was however obscured by inhomogeneous line broadening due to the large size dispersion of the emitting entities in porous silicon or in matrices containing silicon nanocrystals. This called for single-dot spectroscopy studies as demonstrated for single molecules and later for nanocrystals of direct bandgap semiconductors.

In this talk I will review our work on PL emission and spectroscopy of individual Si quantum dots. These were initially fabricated using electron-beam lithography, plasma etching and oxidation resulting in micron spaced Si quantum dots that could be individually distinguished in an optical microscope. More recently we have also looked at more “randomly” spaced Si nanocrystals as well as colloidal nanocrystals fabricated from HSQ (hydrogen silsesquioxane). These studies have revealed many of the phenomena observed for the II-VI nanocrystals such as on/off intermittency (blinking), spectral diffusion and narrow linewidth. Indeed, the linewidth at low temperatures was found to be ~250 μeV, limited by system resolution while the room temperature homogenous linewidth was shown to depend on the surface passivation and ligand shell. Finally, recent data on the quantum yield of colloidal Si nanocrystals suggest that near 100 % internal quantum efficiency can be reached paving the way for many applications.

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