Depth profiling of silicon quantum dots formed in ion-implanted thermal oxide thin film

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Quantum dots (QD) are nanoscale (1-10nm) crystals of semiconductor material that exhibit quantum confinement of excitons when formed within a matrix of dielectric. The resulting exciton energy is characteristic of the QD dimension and has a high probability of radiative recombination. This results in a "tunable" luminescent device.

The Si-QD/SiO_2 system can be formed by the subsequent annealing of thermal oxide films grown on (100) Si wafers and subjected to high (in excess of $10^{16}/cm^2$) doses of Si^+ implanted at energies up to 1 MeV. This system has numerous advantages: 1) the difference in band-gap between Si-QD and SiO_2 satisfies quantum confinement, 2) the Si-implanted/thermal oxide system has a low concentration of foreign impurities, which have an unknown or detrimental effect on QD formation and radiative recombination, 3) the fine control over implant energy and dose potentially translates into precise engineering of defect and implant concentration, and, 4) though Si and SiO_2 are immiscible, the mobility of lone Si^+ ions implanted in SiO_2 is very low. This allows for their diffusion, as well as many defect annihilation and creation processes, to be "switched" on and off by tailoring the thermal treatment of samples.

Our current understanding fails to explain the precise way in which synthesis and treatment of implanted films affects the luminescent properties. Previous work has shown [1-2] that the size of QD formed in an implanted film (as determined by high resolution transmission electron microscopy) is less strongly correlated with the concentration of implanted ions than the expected concentration of atomic vacancies caused by collision-induced atomic displacements. It is also known [3] that the thermal processing history of the material has a strong impact on QD formation and luminescent properties.

The current work expands upon this knowledge by investigating the relative abundance and spatial distribution of different defect species, as well as the depth-dependent stoichiometry and short to medium range order, of SiO_2 thin films with different Si^+ implant dose and energy. Positron Annihilation Spectroscopy is sensitive to open-volume defects, such as vacancies and voids, in thin films and has been used [4] to identify the presence of non-bridging oxygen hole centres (NBOHC) in fused silica. The slow positron beam at The University of Western Ontario allows for depth-resolved PAS with resolution as small as tens of nm. Electron spin resonance (ESR) does not allow depth resolution, but is in many ways complementary to PAS in studying thin-film defects in that it is most sensitive to paramagnetic defects and provides greater detail of defect structure. Its use [5] to measure the oxygen vacancy E' centre is widely known. By combining these techniques with structural and phase information from x-ray diffraction (XRD) and x-ray absorption near-edge spectroscopy (XANES) we gain a greater understanding of the formation of Si QD as a function of implantation and thermal treatment of thin films.

References.

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