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Study of Defects in Silicon by Photoluminescence for Development of Si-based Optoelectronic Applications

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Abstract – Different types of optically active defect clusters formed by Si implantation and a subsequent anneal have been studied by photoluminescence (PL). The background boron in p-type Si wafer is found to be detrimental to W-line luminescence. By increasing the annealing temperatures, the PL signatures have drastically changed, indicating transformation of defect clusters. Distinct peaks include W (1218 nm), X (1192 nm), Y (1149 nm), and R (1374 nm). The evolution of {311} rod-like defect (RLD) is reported through the intensity of R-line as a function of annealing time. R-line is best observed after 40-minute annealing at 700°C.

Due to its indirect band structure, silicon is a poor light emitter and hence not an ideal optoelectronic material. In the past years, considerable effort has been devoted to enhancing luminescence from silicon. Among the various approaches to obtain a silicon light source, luminescence from defects is one of the most interesting directions, both from a material and a device perspective. A sub-bandgap light emitting diode (LED) based on point defect clusters has been demonstrated in previous work [1].

A combination of Si implantation and thermal annealing has been used to form different types of optically active defects in silicon. Depending on substrate resistivity (background doping concentration), implantation fluence, and thermal budget, different PL signatures have been observed. Typical optically active defects are the W-line (thought to be due to Si tri-interstitial defects) and the R-line (thought to be from {311} rod-like defects). In this work, we report the deleterious effect of boron, which is commonly used for p-type doping in a Si wafer, on W-line (or I1 at 1218 nm) luminescence. In particular, we have found that the W-line, whose PL intensity is maximised after ~275˚C annealing, is totally quenched when the background boron concentration is of the order of 10^{18} cm^{-3} or above. For a wafer with a boron concentration of around 10^{17} cm^{-3}, decrease of the W-line intensity is accompanied by emergence of the Y-line (or I2) at a wavelength of 1149 nm. The Y-line has been assigned to boron interstitial clusters (BIC). A systematic study of the defect evolution has further revealed that the intensity of the luminescence from Y-centres becomes strongest after a thermal treatment at ~400˚C for 2 minutes. This annealing condition simultaneously gives rise to the X-line (or I4 at 1192 nm), which has recently been linked to tetra-interstitial clusters [2]. Broad PL bands are observed after 525°C annealing in the wavelength range from 1300 nm to 1550 nm, indicating a possibility of larger defect cluster formation or associated strain. The results from isothermal annealing at 700°C for up to 90 minutes have led us to believe that these bands are precursors of {311} RLDs, which are claimed to be the origins of R-line luminescence [3]. Indeed, the emission from R-line defects is observed at a wavelength of 1374 nm and the intensity peaks after annealing for 40 minutes. Some selected samples are also characterised by transmission electron microscopy (TEM). The results are correlated to PL signatures and the implications are discussed.

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