Recovery of Crystalline and Optoelectronic Properties in Si(100) after Focused Ion Beam Implantation of Ga^+ and Annealing

by

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ABSTRACT

With the end of the road for the ever decreasing size of CMOS electronic devices predicted by Moore's Law approaching within the next decade or so, researchers are seeking other nano-electronic architectures for digital logic. One such possibility is found in quantum dots – nanometer scale clusters that appear as a result of strain in the growth of lattice mismatched semiconductor films. By templating pits on the silicon substrate surface with a focused ion beam, the location of these dots can be controlled. More complex nanostructures, such as "quantum dot molecules" that consist of four quantum dots surrounding a central pit may also be templated.

However, Ga^+ focused ion beam irradiation of a sample is known to lead to extensive lattice damage. In this work, we seek to determine the effects of Ga^+ focused ion beam implants on structural and electronic quality of the target sample, and the recovery of damage during subsequent annealing. Doses of 10^{11} - 10^{17} Ga^+ ions/cm^2 were implanted in Si(100) and annealed at 600, 700, and 800°C consecutively. The lower end of this dosage range, 10^{11} to 10^{15} ions/cm^2, corresponds to the typical range of volume concentrations (taking into account the implanted depth of the material) that are relevant to doping of semiconductors (~ 10^{16} – 10^{20} cm^{-3}). The middle dose of 10^{15} ions/cm^2 represents the dose that would occur during silicon templating for quantum dot formation, and the high end of doses represents steady state concentrations that would result from ion milling.

The crystalline and electrical properties were analyzed after the initial implantation and following each annealing step using Raman and photoluminescence spectroscopy, respectively. Doses higher than 10^{15} ions/cm^2 were shown to completely destroy the silicon crystallinity with peak intensities of less than 1% of the Raman peak intensity for non-implanted silicon. Doses of 10^{11} through 10^{14} ions/cm^2 were shown to almost completely suppress radiative recombination in photoluminescence spectroscopy with peak intensities after implantation lower than 1% of the reference non-implanted sample.

It was found for Raman spectroscopy with doses of 10^{11} to 10^{15} ions/cm^2, more than 97% of the peak intensity of an non-implanted Si(100) sample could be recovered after annealing for ten minutes at 800°C. Significant recovery on the order of 95% of

non-implanted silicon was also obtained for doses of 10^{11} - 10^{14} ions/cm^2 after annealing at 600°C for ten minutes. Doses of 10^{16} and 10^{17} ions/cm^2 showed significant recovery of the Raman peak intensity, on the order of 76 and 78% after annealing to 800°C, but never complete recovery to the non-implanted intensity.

Photoluminescence measurements showed that a significant amount of the initial peak intensity for non-implanted Si(100) could be recovered (on the order of 20 to 60% of the non-implanted silicon reference) for the range of doses 10^{11} – 10^{14} ions/cm^2 studied when annealed at 800°C . The reduced recovery (when compared to the almost complete recovery of crystalline structure indicated by Raman spectroscopy at these doses) is believed to be due to the domination of electron-hole recombination by non-radiative Shockley-Read-Hall processes that occur as a result of the creation of deep energy levels within the band gap by defects from ion implantation.

It was concluded that for Ga^+ doses 10^{11} – 10^{14} cm^{-2} that represent most of the range of concentrations relevant to doping in semiconductors (~10^{16} to 10^{19} ions/cm^3) structural and electronic recovery was relatively complete. For the implantation damage that results from templating silicon for quantum dot formation (10^{20} ions/cm^3), the recovery of crystalline and electronic properties are significant enough to use as a substrate for future growth.