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Generation of vacancy cluster-related defects during single MeV silicon ion implantation of silicon

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ABSTRACT

Deep Level Transient Spectroscopy (DLTS) has been used to study defects formed in bulk silicon after implantation of 8.3 MeV $^{28}Si^{3+}$ ions at room temperature. For this study, Schottky diodes prepared from *n*-type Czohralski-grown silicon wafers have been implanted in the single ion regime up to fluence value of 1×10^{10} cm^{-2} utilizing the scanning focused ion microbeam as implantation tool and the Ion Beam Induced Current (IBIC) technique for ion counting.

Differential DLTS analysis of the vacancy-rich region in self-implanted silicon reveals a formation of the broad vacancy-related defect state(s) at $E_c - 0.4$ eV. Direct measurements of the electron capture kinetics associated with this trap at $E_c - 0.4$ eV, prior to any annealing do not show an exponential behaviour typical for the simple point-like defects. The logarithmic capture kinetics is in accordance with the theory of majority carrier capture at extended or cluster-related defects. We have detected formation of two deep electron traps at $E_c - 0.56$ eV and $E_c - 0.61$ eV in the interstitial-rich region of the self-implanted silicon, before any annealing. No DLTS signal originating from vacancy-oxygen trap at $E_c - 0.17$ eV, present in the sample irradiated with 0.8 MeV neutrons, has been recorded in the self-implanted sample.

1. Introduction

A new semiconductor device technology, providing better radiation hardness, is required for applications in high-energy physics, accelerator-based science, aerospace technology, i.e. the research communities developing and/or using semiconductor devices in harsh ionising radiation environments [1–5]. Novel devices are usually a result of complex manufacturing processes and therefore scarce and highly valuable [6,7]. Defect studies and radiation hardness testing procedures utilizing a low ionizing particle radiation provided by large accelerators or nuclear reactors usually require large particle fluences and corresponding long exposure times. A widely used alternative testing methodology utilizes a MeV ion beam irradiation to simulate radiation damage created by high energy neutrons, protons, pions, electrons, etc. With respect to low ionizing particles, ions having the energy per unit mass in 0.1–1 MeV/u range have the advantage of higher nuclear energy deposition per particle [8–10], thus creating comparable defect concentrations required for testing purposes at much lower fluence values and therefore at corresponding shorter exposure times. One major disadvantage of this approach is that the utilization of a broad ion beam requires the investigation of one test sample per each desired irradiation condition.

The capability of high-energy heavy-ion microprobes [11,12] to perform high-flux, high-frequency and high-precision scanning, compared to conventional ion broad-beam sources, offer advantages of: (a) selecting a particular region of interest on the device, (b) a computer controlled positioning of an ion micro-beam, (c) minimising irradiation area, (d) rapid irradiations, i.e. minimising exposure times and (e) single ion implantation.

The Ion Beam Induced Current (IBIC) is a mature and versatile ion microprobe technique for the characterisation of transport properties of charge carriers generated by single ions in active regions of semiconducting devices [13,14 and all Refs. therein].

We combine sub-micrometre ion beam sensitivity and IBIC technique for accurate implantation of desired number of ions in each pixel in order to create low level radiation damage in complex geometry patterns in simple planar test devices [15]. Each implanted ion dose is monitored *in vivo* by single ion counting, as well as the leakage current flowing in the IBIC sensing circuit. The total accumulated fluence from all irradiated areas is kept below

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