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Point defect production efficiency in ion irradiated 4H–SiC

L. Calcagno [a,*], A. Ruggiero [a], P. Musumeci [a], G. Cuttone [b], F. La Via [c], G. Foti [a]

[a] Dipartimento di Fisica e Astronomia, Via S. Sofia 64, 95123 Catania, Italy
[b] Laboratorio Nazionale del Sud, Via S. Sofia 62, 95123 Catania, Italy
[c] CNR-IMM, Sezione di Catania, Stradale Primosole 50, 95121 Catania, Italy

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Abstract

The defects introduced in 4H–SiC by irradiation with different ions are investigated by deep level transient spectroscopy measurements in the temperature range 100–700 K.

The defects were generated with 60 MeV H^+ and with 6.7 MeV C^+ in the fluence range 3.5×10^{11}–1.5×10^{12} cm^{-2} and 10^9–10^{10} cm^{-2}, respectively. The ion beam cross the entire epitaxial layer and introduce an almost uniform defect concentration. Deep level transient spectroscopy measurements show the formation of three main traps located E_c – 0.68 eV and E_c – 0.98 eV and E_c – 1.5 eV independently on the irradiating ion.

The trap concentration increases linearly with ion fluence suggesting that these traps are associated to the point defects generated by ion irradiation. Surprisingly the determined values of defect production efficiency (defects/eV) depend on the type of ion and they decreases by increasing the elastic energy loss for all the introduced defects. This behaviour can be related to the local point defect (vacancies and self interstitials) recombination which is higher in the denser cascade.

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1. Introduction

Silicon carbide has unique physical and electronic proprieties for high-power, high frequency and high temperature devices. It has a large band gap, high saturation drift velocity, high electrical breakdown field, temperature stability and chemical inertness. This material also has a radiation resistance higher than Si due to the higher displacement energy. Thus SiC is a promising material for power device operating under extreme conditions such as high temperature and radiation environments [1,2]. For these reasons, many physical aspects related to the material processing are continuously objecting of study by the SiC devices community.

One of these aspects regards the effects of ion-irradiation on the material properties and, consequently, on the devices characteristics. In fact, ion implantation is already widely used in SiC technology, as for selective material doping [3–6] and for the fabrication of high resistive edge terminations in Schottky rectifiers [7]. However, the improvement of the devices performances remains strictly related to the understanding of some basic physical mechanisms, like the formation and the thermal stability of irradiation-induced defects, the electrical activation of dopant ions, the effects of irradiation on the carrier's mobility, etc.

Several studies reported on the formation of material defects by ion- or electron-irradiation [8–10] and their influence on electrical properties of SiC [11,12]. In particular, in some specific fields such as the aerospace and the particle detectors industry, it is important to know the effects of ion-irradiation on the material properties because the defects modify the electrical characteristics of devices as

* Corresponding author. Tel.: +39 95 3785319; fax: +39 95 3785231.
E-mail address: lucia.calcagno@ct.infn.it (L. Calcagno).

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diodes, which generally are fundamental units for almost all SiC radiation-hard devices.

In this paper, the defects induced by ion-irradiation with 60 MeV H^+ and 6.7 MeV C^+ ions on 4H–SiC was investigated. In particular, deep level transient spectroscopy allowed following the evolution of irradiation-induced defects by increasing ion fluence. Interestingly, the efficiency of defect production by irradiation with 60 MeV H^+ is higher with respect to 6.7 MeV C^+ irradiation. A comparison with literature results will be performed.

2. Experimental

The n-type 4H–SiC samples used in this work were 4 μm thick nitrogen doped (0001) oriented epilayers grown on n^+-type substrate as purchased by CREE Research. The nitrogen concentration was $7\times10^{18}\ cm^{-3}$ and $2\times10^{15}\ cm^{-3}$ in the substrate and the epilayer, respectively.

The defects were generated by irradiation with 60 MeV H^+ in the fluence range 3.5×10^{11}–$1.5\times10^{12}\ cm^{-2}$ with a flux of 10^9 ions/cm^2 s and with 6.7 MeV C^+ in the fluence range 10^9–$10^{10}\ cm^{-2}$ and with a flux of 10^7 ions/cm^2 s. The ion energy is high enough to cross the entire epitaxial layer and to introduce an almost uniform concentration of defects. The concentration of vacancies introduced in the epitaxial layer, calculated by TRIM simulation, ranges from $2.5\times10^{13}\ cm^{-3}$ to $5.0\times10^{15}\ cm^{-3}$. Current–voltage (*I*–*V*) measurements were performed at room temperature with a Wenworth probe station equipped with a Keithley 236 source meter unit.

Deep level transient spectroscopy was performed using a Sula spectrometer in the temperature range 100–700 K. The same apparatus was used for room temperature *C*–*V* measurements. The back contact of the diodes used in this work was formed, before irradiation, by Ni deposition followed by thermal annealing at 1223 K. After irradiation circular Schottky contacts with diameters ranging from 0.3 to 0.6 mm were fabricated by nickel evaporation.

3. Results and discussion

The formation and evolution of irradiation-induced defects in the SiC material were monitored by means of the DLTS technique. Fig. 1 reports the DLTS spectra, taken with a window of 50 ms of unirradiated sample and of samples irradiated with 6.7 MeV C^+ at fluences of $1\times10^9\ cm^{-2}$, $3\times10^9\ cm^{-2}$ and $1\times10^{10}\ cm^{-2}$. The spectrum of the as-prepared material exhibits only the presence of a peak at about 300 K. After irradiation the intensity of this peak increases and the spectrum shows the formation of two more peaks, located at 430 K and 650 K, respectively.

The intensities (trap concentration) of these three peaks increase with increasing the ion fluence thus indicating an accumulation of the damage induced by ion-irradiation.

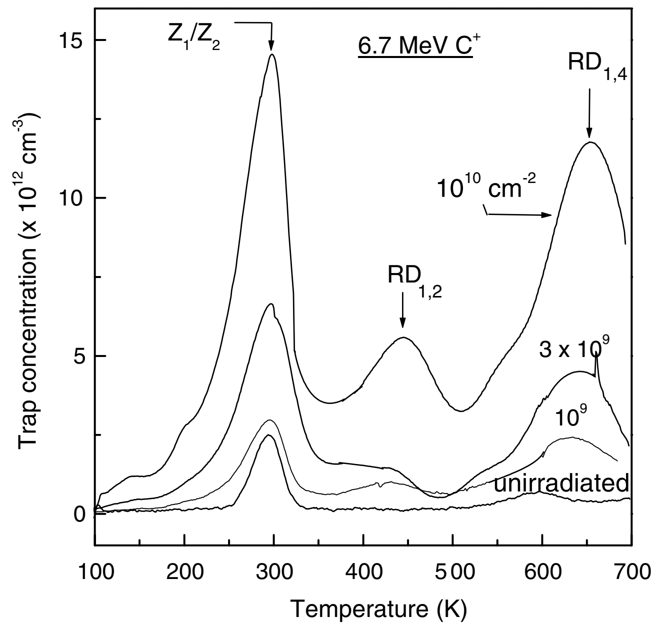

Fig. 1. DLTS spectra of 4H–SiC diodes irradiated with different fluences of 6.7 MeV C^+. The spectrum of unirradiated samples is also shown.

At the highest fluence (1×10^{10} ion/cm^2) the concentration of the deeper centre (650 K) was around $1.2\times10^{13}\ cm^{-3}$.

From the DLTS analysis at different rate windows, an Arrhenius plot of the emissivity allowed us to determine the values of the activation energy of the deep levels formed in the material. The determined values of the deep centres activation energies were $E_c - 0.68$ eV, $E_c - 0.98$ eV and $E_c - 1.52$ eV, respectively.

The level located at 0.68 eV below the conduction band has the same activation energy of the peak generally detected in the as-grown material and could be associated to the well known Z_1/Z_2 centre. A great debate is still opened in the SiC community on the nature of this defect and many interpretations on its nanoscopic nature have been given [9,13]. However, on the basis of its thermal stability, the Z_1/Z_2 centre is often attributed to a carbon interstitial or to an antisite [9]. Indeed, other authors reported that on high-quality 4H–SiC epilayers, the Z_1/Z_2 centre is the only residual defect detectable in as-grown n-type layers [14], but we have recently shown [15] that by improving the growth condition of the epilayer material this centre disappears.

The two other levels present in the irradiated material, instead, located at 0.98 eV and 1.52 eV below the conduction band, can be associated to the $RD_{1/2}$ and $RD_{1,4}$ centres, respectively [13]. The $RD_{1/2}$ and $RD_{1,4}$ centres have been already observed to simultaneously appear in the material after irradiation [13]. However, the $RD_{1/2}$ can be undoubtedly regarded as irradiation-induced defects of 4H–SiC, while the $RD_{1,4}$ level is found also in as grown material [15]. As regards their microscopic nature the $RD_{1,4}$ level has been associated to a carbon vacancy [16] or a C–Si divacancy [17], while no identification was reported for the $RD_{1/2}$ level.