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Investigation of deep level defects in copper irradiated bipolar junction transistor

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ABSTRACT

Commercial bipolar junction transistor (2N 2219A, npn) irradiated with 150 MeV Cu^{11+}-ions with fluence of the order 10^{12} ions cm^{-2}, is studied for radiation induced gain degradation and deep level defects. *I–V* measurements are made to study the gain degradation as a function of ion fluence. The properties such as activation energy, trap concentration and capture cross-section of deep levels are studied by deep level transient spectroscopy (DLTS). Minority carrier trap levels with energies ranging from $E_C - 0.164$ eV to $E_C - 0.695$ eV are observed in the base–collector junction of the transistor. Majority carrier trap levels are also observed with energies ranging from $E_V + 0.203$ eV to $E_V + 0.526$ eV. The irradiated transistor is subjected to isothermal and isochronal annealing. The defects are seen to anneal above 350 °C. The defects generated in the base region of the transistor by displacement damage appear to be responsible for transistor gain degradation.

1. Introduction

Bipolar junction transistors (BJTs) are still being extensively used in space and other radiation rich environments. These devices are sensitive to high energy particle irradiation. Considerable amount of data are available on the radiation effects of γ-rays, fast neutrons, electrons and protons on semiconductor devices [1–5]. However, there appears to be rather little work on heavy ion induced effects and consequent characterization of defects by DLTS technique. Deep level defect monitoring plays an important role in designing a semiconductor device suitably for various applications. Thus a study of radiation induced effects in semiconductor devices is important to observe changes in electrical characteristics and to get basic information regarding the generation and annihilation of defects.

Exposure of semiconductor devices to high energy particle radiation is known to generate variety of defects. The nature of these defects generated by irradiation process depends on the properties of target as well as impinging high energy particle. To investigate these deep level defects several techniques are in practice. Deep level transient spectroscopy (DLTS) is now an established technique for detecting and characterizing variety of defects in semiconductor devices. DLTS is a high frequency capacitance transient thermal scanning method useful in observing a wide variety of traps in semiconductor devices [6].

The BJT used in the present study has been thoroughly studied in our earlier work for 24 MeV protons, 8 MeV electrons and ^{60}Co γ-rays induced effects [7–9]. A DLTS study of deep level defects in Li-ion irradiated transistor (chosen from the same batch) is also reported earlier [10].

2. Experimental details

Commercial BJT (2N 2219A, npn) manufactured in an indigenous technology from Continental Device India Ltd. (CDIL) has been selected for the present study. This device is a switching transistor with standard configuration (base thickness is 2.0 μm and oxide thickness is 1.2 μm) suitable for low and high frequency

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operation. Decapped transistor is exposed to 150 MeV Cu^{11+}-ions using 15 UD 16 MV pelletron Tandem Van de Graff accelerator facility at Inter-University Accelerator Centre, New Delhi. The transistor in the biased condition (CE mode) is irradiated by Cu^{11+}-ions with three different fluences 3×10^{11} ions cm^{-2}, 1×10^{12} ions cm^{-2} and 1×10^{13} ions cm^{-2}. During irradiation, the target chamber is maintained at room temperature (300 K) and low pressure (7.5×10^{-9} Torr). The ion fluences are calculated by measuring the ion beam current and irradiation time. The ion beam current is fixed at ∼1 particle nano ampere (pnA). Output characteristics of the transistor are studied at a constant base current (I_B) of 50 μA. The collector voltage (V_{CE}) is varied from −0.1 V to 1.5 V in steps of 0.01 V. Gummel plots are acquired by varying base emitter voltage (V_{BE}) from 0 V to 0.7 V in steps of 0.01 V at constant collector voltage (V_{CE}) of 5 V.

DLTS spectra are recorded for both unirradiated transistor and three different transistors of the same batch (date code) exposed to Cu^{11+}-ion for different fluences. The DLTS system (IMS-2000, M/s. Lab Equip, India) employed for the present study consists of a boxcar averager, a pulse generator, a thousand point digitizer, a voltage generator and a high speed capacitance meter. The pulse generator is capable of generating pulses of widths ranging from 100 ns to 10 s. The pulse height could be programmed from −12 V to +12 V. The boxcar averager is capable of generating seven rate windows. The time constants can be varied from 1 ms to 2 s. In the present study, DLTS spectra are recorded with a reverse bias of 5 V and pulse width of 19.2 ms applied to base–collector junction. The trap concentration, activation energy and capture cross-section of different deep levels are determined by DLTS spectra.

The transistors are subjected to isothermal and isochronal (30 min) annealing. The annealing temperature in the furnace can be maintained constant for several hours with an accuracy of 1 °C. During isochronal (30 min) annealing, the temperature is varied from 100 °C to 500 °C. During isothermal (100 °C) annealing, the annealing time is varied from 30 min to 480 min. DLTS spectra are recorded at different stages of thermal annealing and the characteristics of several deep level defects are monitored.

3. Results and discussion

3.1. *I*–*V* measurements

In general, any disturbance of lattice periodicity in the bulk of the semiconductor may give rise to energy levels in the band

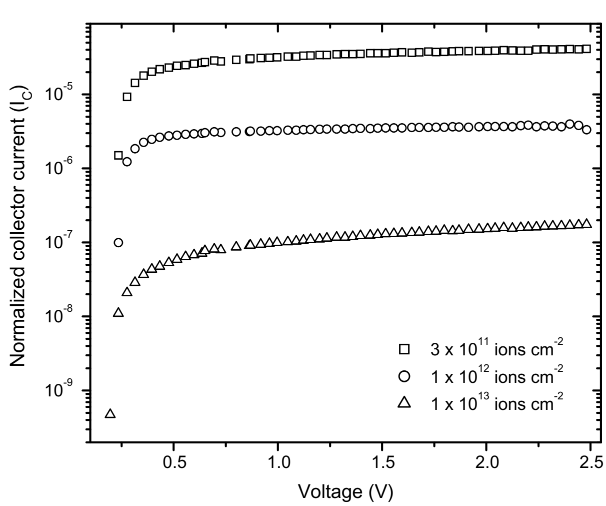

Fig. 1. Collector characteristics of Cu-ion irradiated transistor for three different ion fluences (at constant I_B = 50 μA).

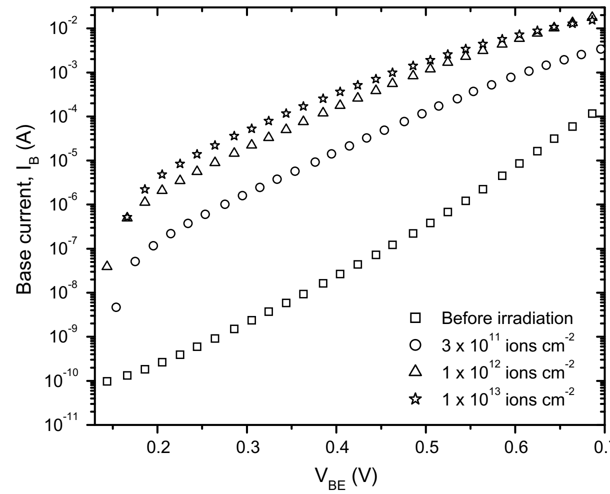

Fig. 2. Variation of I_B with V_{BE} for three different ion fluences (at constant V_{CE} = 5 V).

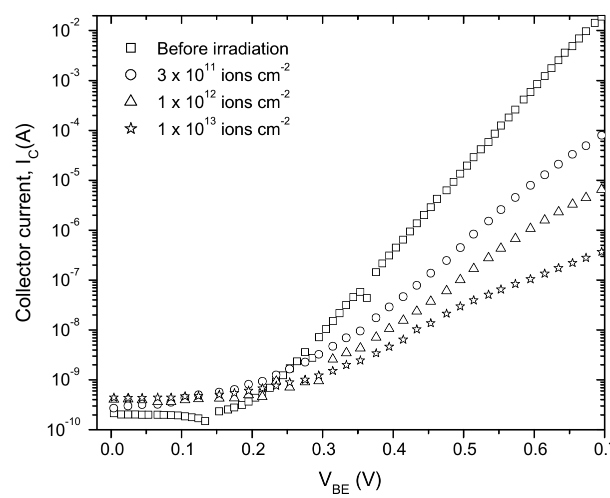

Fig. 3. Variation of I_C with V_{BE} for three different ion fluences (at constant V_{CE} = 5 V).

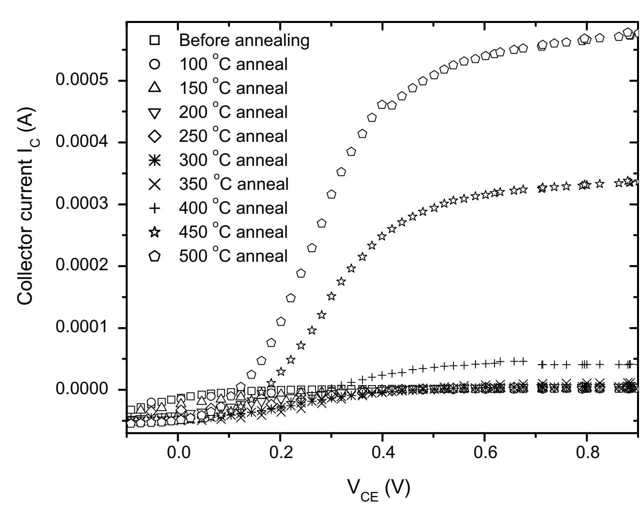

Fig. 4. Collector characteristics of the Cu-ion irradiated transistor at different isochronal annealing temperatures (at constant I_B = 50 μA).