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Proton irradiation effects on InGaP/GaAs single heterojunction bipolar transistors

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ABSTRACT

The irradiation effects of low energy proton on both Direct Current (DC) and the Radio Frequency (RF) performance of InGaP/GaAs single heterojunction bipolar transistors (SHBTs) are investigated with fluence up to 5×10^{12} protons/cm^2. The current gain in RF and the cutoff frequency (f_T) show a little degradation even at proton fluence of 5×10^{12}/cm^2. The open-collector technique is used to extract the access resistances. Meanwhile 10 MeV proton irradiation is also investigated in order to compare the differences induced by different proton energies. The results indicate that InGaP/GaAs HBT is tolerant to proton irradiation.

1. Introduction

An important emerging market for RF and microwave circuits is in space communications systems such as artificial satellites. These kinds of space-borne applications require high performance devices with not only excellent frequency response, high power gain, good broadband noise, and very good linearity, but also irradiation tolerant [1]. HBTs based on InGaP/GaAs heterojunctions as a major contender are of increasing interest since many of its features are attractive, such as higher valence band offset to suppress the back injection of holes into the emitter, higher etch selectivity between InGaP and GaAs, lower surface recombination velocity, absence of DX centers plaguing the Al-based systems, and better long-term reliability as compared with the AlGaAs/GaAs HBTs [2,3]. Since energetic protons are the most abundant species in space, it is imperative to study the effects of proton irradiation on electronic devices and systems intended for space applications. Low energy protons, namely proton energy <10 MeV, are the most predominant [4]. Most of the irradiation studies on HBTs reported so far have mainly focused on high-energy irradiations induced changes in the measured electrical characteristics of the devices [5–9]. However, to our knowledge, there is not much published information on the electrical characteristics of InGaP/GaAs HBTs subjected to low-energy irradiations. In this paper, the results of our investigation are presented on the irradiation performance of InGaP/GaAs HBTs exposed to 3 MeV and 10 MeV protons.

2. Experiment

The InGaP/GaAs SHBTs used in this study were commercial products from WIN Semiconductors Corp., the device structure is shown in Fig. 1. In the InGaP/GaAs SHBTs with $1 \times 10\ \mu m^2$ emitter area, the base–emitter is an InGaP/GaAs heterojunction and the device is passivated with Si_3N_4. The devices were irradiated by 3 MeV protons up to a maximum cumulative fluence of 5×10^{12} protons/cm^2 in the proton irradiation facility (PIF) in tandem accelerator EN2 × 6. Three devices from the same wafer were used for each experiment to check the variations. All of them showed the similar behavior before and after irradiation. The DC and RF features of the devices were measured immediately after irradiation using an 8363C vector network analyzer and the deembedding techniques presented in Ref. [10]. All the irradiations and measurements were implemented at ambient temperature.

3. DC results and discussion

Fig. 2 shows the forward-mode Gummel plot with different irradiation fluences at room temperature (300 K). As the proton fluence is higher, base leakage current is increased, which is similar trend with the results from InGaP/GaAs HBTs irradiated by gamma

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ray [3]. In order to understand the relation of current degradation with the radiation-induced damage, the variation of ideality factor of base current I_{BE} is extracted from the small current regime of the Gummel plot as shown in Fig. 3. As shown in this figure, the ideality factor is about 3 for the pre-irradiated and larger than 3.2 for the irradiation fluence higher than 1×10^{12} protons/cm^2 and also it is worth noting that the increase of ideality factor occurs with the increased irradiation fluence. The reason to cause the bigger ideality factor is not only because of the space charge region recombination centers around emitter–base depletion region and its periphery, but also the G/R trap centers formed by the proton irradiation, therefore tunneling current is involved. So it is believed that some inactive pre-defects had already been incorporated at the heterointerface during the growth or process and proton irradiation triggered active defect formation.

Fig. 4 shows the I_C–V_{CE} characteristics at the base current of 15 µA before and after irradiations of 10^{11}, 5×10^{11}, 10^{12}, 5×10^{12} protons/cm^2, respectively. One major effect is evident from Fig. 4 that the reduction of collector current I_C for a fixed base current I_{BE}. However, the collector saturation voltage [$V_{CE(sat)}$] does not show change. Also the self-heating effect exhibited in pre-irradiation is gradually disappeared owing to the decrease of collector current for the higher proton irradiation. That is to say, the smaller I_C produces less heat so that less self-heating effect is observed. At the fixed I_{BE} and V_{CE}, value of V_{BE} becomes lower after irradiation, as shown in Fig. 5, leading to the decrease of emitter injected current, so as to the decrease of I_C. Also this can be physically explained as follows: At the fixed V_{BE}, i.e., at same emitter current I_E, the collector current I_C is decreased after proton irradiation due to the increase of base current I_B caused by increased recombination rate nearby emitter region.

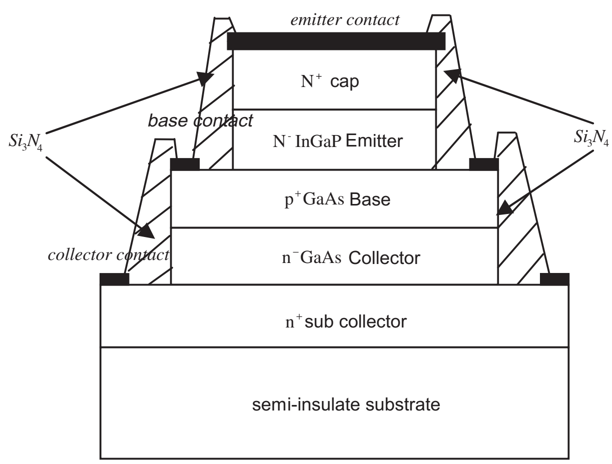

Fig. 1. The layer sequence of InGaP/GaAs SHBT.

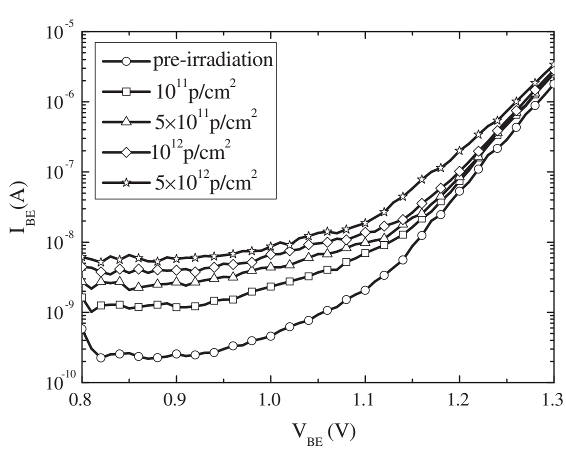

Fig. 2. Forward-mode Gummel characteristics with different irradiation fluences of 3 MeV proton.

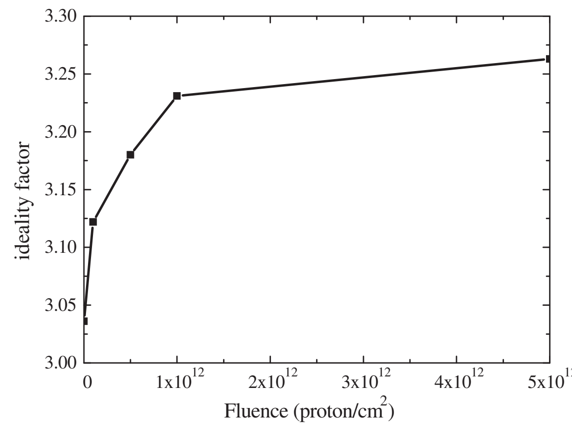

Fig. 3. Extracted the ideality factor from the slope $\log I_{BE}$ versus V_{BE}.

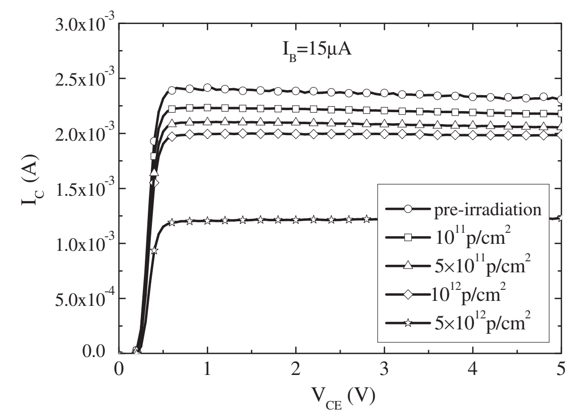

Fig. 4. The I_C–V_{CE} characteristics before and after 3 MeV proton irradiations at I_{BE} = 15 µA.

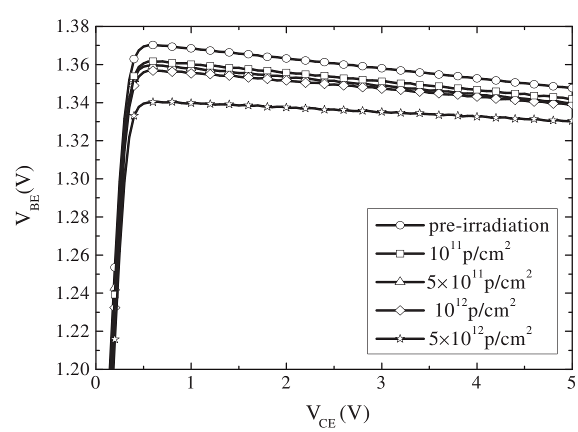

Fig. 5. The measured V_{BE} before and after 3 MeV proton irradiations at I_{BE} = 15 µA.