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The effect of electron irradiation on BJTs and MOSFETs at elevated temperatures

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ABSTRACT

The studies on the effect of electron irradiation on the current voltage characteristics of commercially available bipolar transistor (BJT) and MOSFETs are carried out at elevated temperature. A small home-made furnace with PID temperature controller is used to rise the temperature of the devices during irradiation. The irradiation induced degradation of the device parameters is found to decrease by increasing the temperature of the devices during irradiation. However, the effect of irradiation induced degradation on the characteristics of the devices is observed even at temperatures as high as 300^{o}C. This indicates that creation of defects dominates over simultaneous thermal annealing of these defects even at high temperatures.

Keywords: Electron irradiation, bipolar junction transistor, MOSFET, Current voltage characteristics.

INTRODUCTION

The study of radiation effects in semiconductor materials and devices has been an active area of research due to their importance in the physics as well as in the applications of semiconductor materials and devices. The radiation induced defects lead to degradation of semiconductor device parameters. The radiation-resistant devices are required in radiation harsh environments like space mission, high energy particle colliders, and military equipments [1]. In the last two decades, there are several studies on the effects of radiation on semiconductor materials and devices following elevated temperature irradiation [2-12]. Jian-Guo Xu et al. reported the electrical and optical properties of defects in silicon introduced by high-temperature electron irradiation [2]. D. C. Schmidt et al. reported the effects of 2 MeV electron irradiation on silicon at elevated temperatures [3]. H. Ohyama et al. studied radiation damages of Si photodiodes, Si p-i-n photodiodes, InGaAs photodiodes, and MOSFETs by high-temperature electron irradiation [4-9]. M. Nakabayashi *et al*. studied radiation damage of IGBTs by electrons at different irradiation temperatures [10-11]. K. Hayama et al. studied the effect of high-temperature electron irradiation in thin gate oxide FD-SOI n-MOSFETs [12]. The aims of such studies were, in addition to the academic interest, understanding the radiation-induced device degradation under actual operating conditions. In this work, the electron irradiation effects on the input and output characteristics of bipolar transistors, transfer and drain characteristics of MOSFETs are studied.

MATERIALS AND METHODS

The Bharat electronics (BEL) Bangalore, India make bipolar junction transistors and n-channel MOSFETs are used in this study. The BEL make samples used in this study are 2N5294 general purpose switch and amplifier LF npn transistor in TO-220 package and n-channel depletion type MOSFET 3N200. The irradiation was carried out at Microtron Centre, Mangalore University with 8 MeV electrons. Initially the devices are irradiated with increasing accumulative electron irradiation dose from 0 kGy to 30 KGy at room temperature to see the effect of electron irradiation on these devices. At elevated temperatures the devices are exposed to electron dose of 20 kGy. The current voltage measurements are carried out using Keithley 236 source measurement set-up. For elevated temperature irradiation of the devices, a small home-made furnace with PID temperature controller is used to rise the temperature of the devices during irradiation.

RESULTS AND DISCUSSION

Fig. 1 shows a plot of base current I_B and collector current I_C versus base emitter voltage V_{BE} (Gummel plot) of transistor 2N 5294 for various accumulative electron irradiation dose of 0 kGy to 30 kGy. The irradiation shows more increase in I_B than I_C for given V_{BE} as the irradiation dose is increased. As shown in Fig. 2 and 3, the forward current gain h_{FE} of the transistor decrease with increase in irradiation dose. The irradiation effects on the output characteristics (I_C versus V_{CE} with I_B = 100 μA) of 2N 5294 transistor is shown in Fig. 4. As the electron irradiation dose is increased the I_C is found to decrease. The decrease is very rapid in low dose levels. The results of electron irradiation on 2N5294 transistor at elevated temperatures are illustrated in Fig. 5 and 6. Fig. 5 a-d shows the effect of 20 kGy electron irradiation on gain (h_{FE}) of 2N 5294 transistor at elevated temperature. Fig. 6 a-d shows the effect of 20 kGy electron irradiation on output characteristics of 2N 5294 transistor at elevated temperatures. At high temperatures the process of simultaneous creation and recovery of the radiation damage is expected. However, as observed from these figures, there is sufficient degradation of electrical characteristics even in the sample maintained at 300°C during irradiation. This indicates that creation of defects dominates the simultaneous thermal annealing of these defects even at high temperatures. Fig. 7 shows the irradiation induced changes in the BEL n-channel depletion type 3N200 MOSFET transfer characteristics. As observed in the figure, the threshold voltage V_{th} of the MOSFET changes from about -1.2 V to -3.7 V as the accumulative irradiation dose is increased from 0 to 30 kGy. The degradation of the drain characteristics of the MOSFET irradiated at room temperature is illustrated in Fig. 8. The irradiation results for the 3N200 MOSFET at elevated temperatures is illustrated in Fig. 9 and Fig. 10. Fig. 9 a - c shows the effect of irradiation on transfer characteristics of the MOSFET at elevated temperatures. Fig. 10 a- c shows the effect of irradiation on drain characteristics of the MOSFET at elevated temperatures. The irradiation induced degradation of the device parameters is found to decrease at 300°C due to the thermal recovery of the radiation induced damages at elevated temperatures. A quantitative comparison of the high temperature data could not be made due to device to device variation in electrical parameters of these devices.

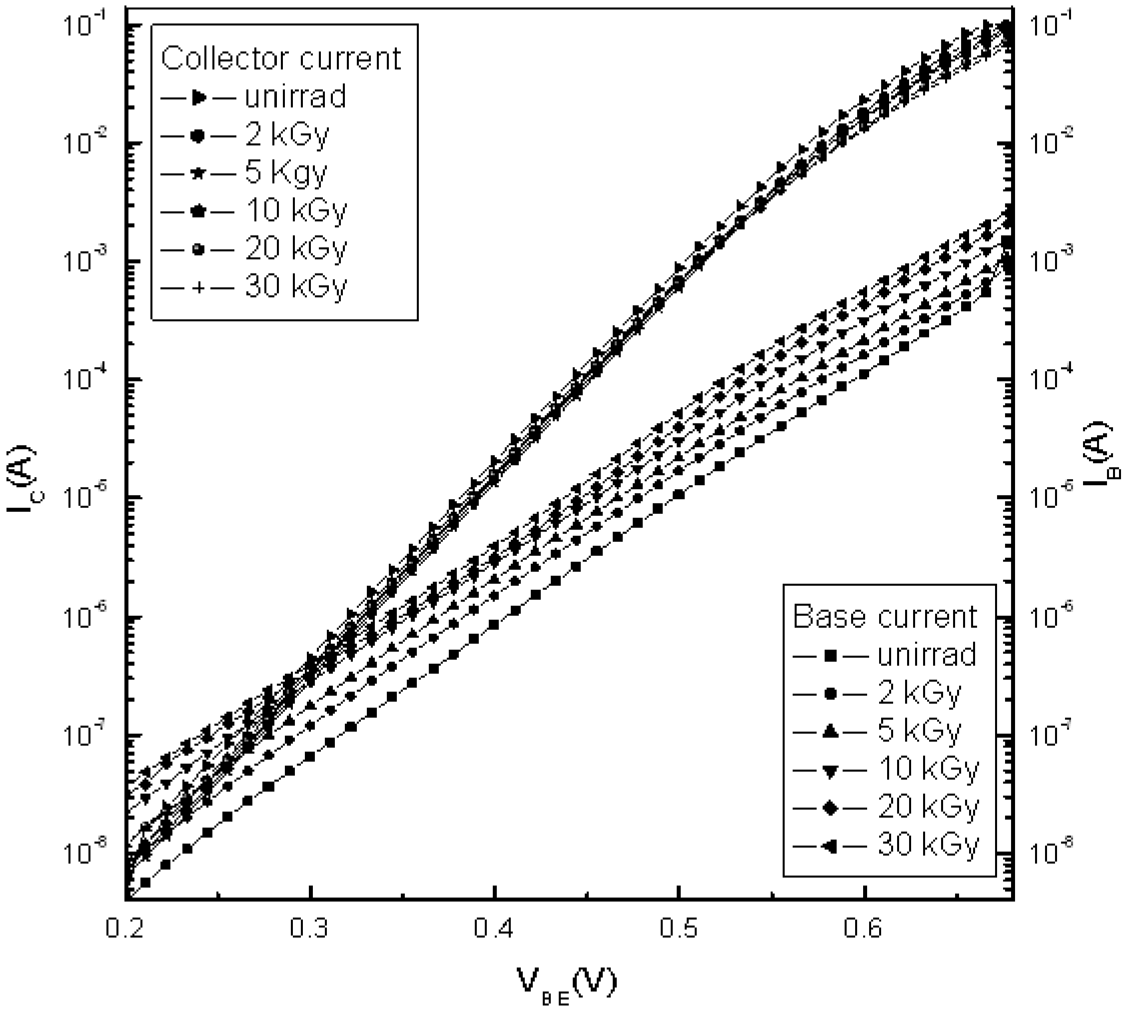

Fig. 1. Combined plot of I_B and I_C versus V_{BE} (Gummel plot) for BEL BJT 2N5294

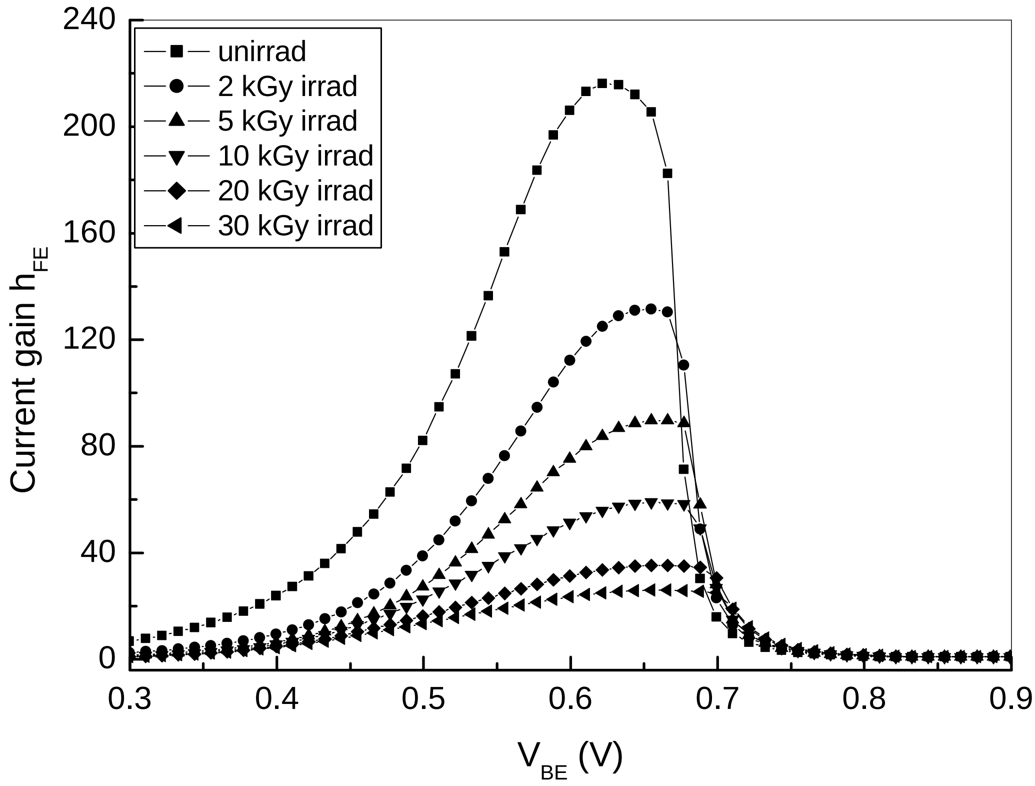

Fig. 2 Current gain versus VBE for BEL BJT 2N5294

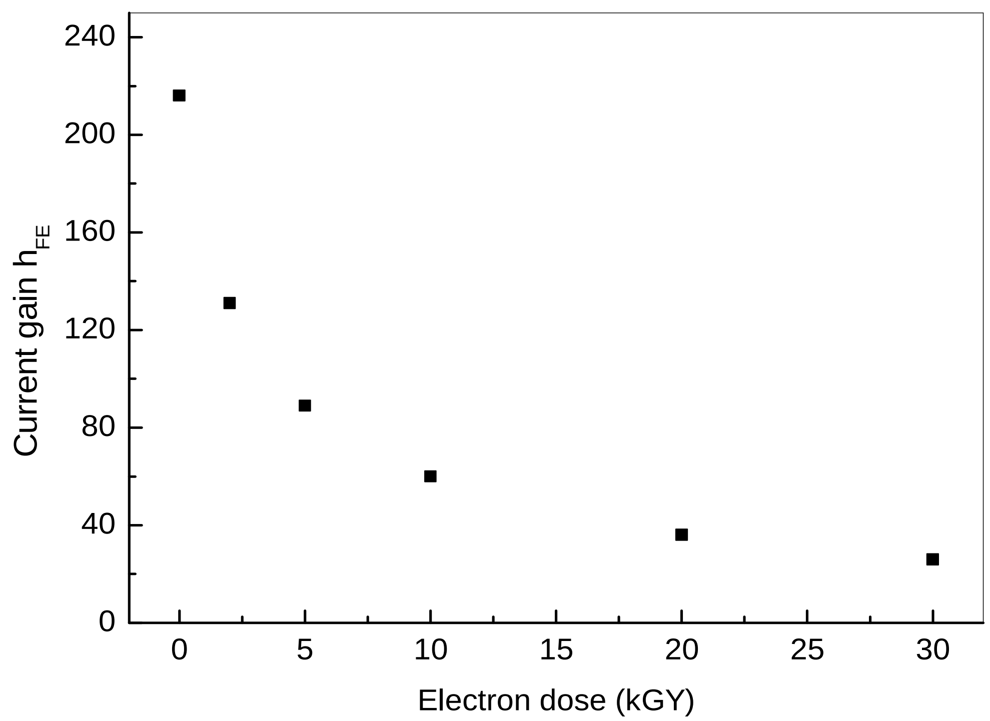

Fig. 3 Current gain versus accumulative electron dose of BEL BJT 2N5294

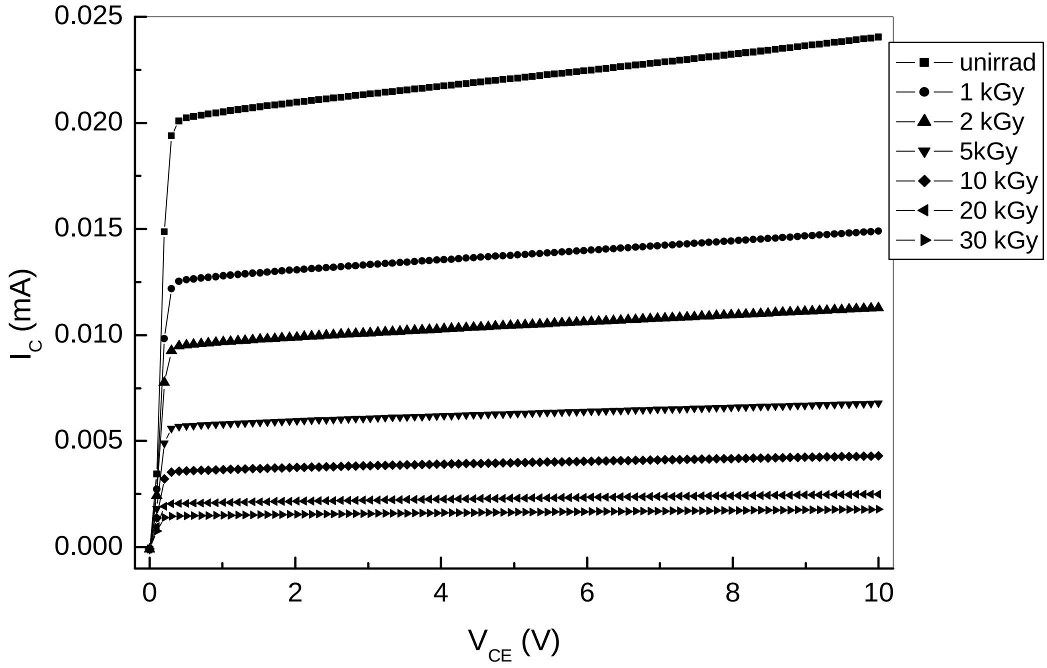

Fig. 4 Output characteristics of BEL BJT 5294 with I_B = 100 μA

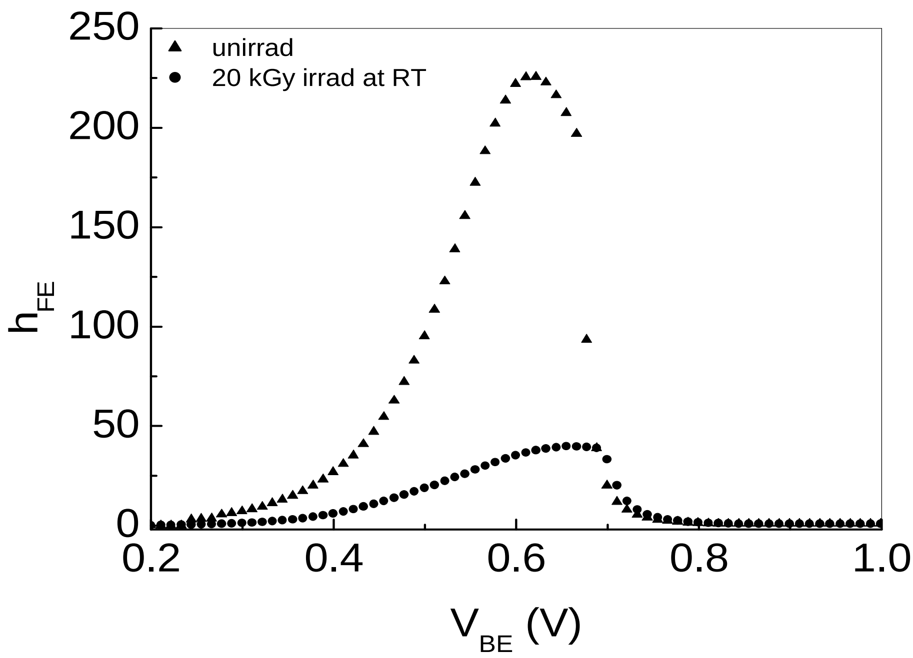

Fig. 5 a Effect electron irradiation on h_{FE} of BEL 2N5294 BJT at room temperature

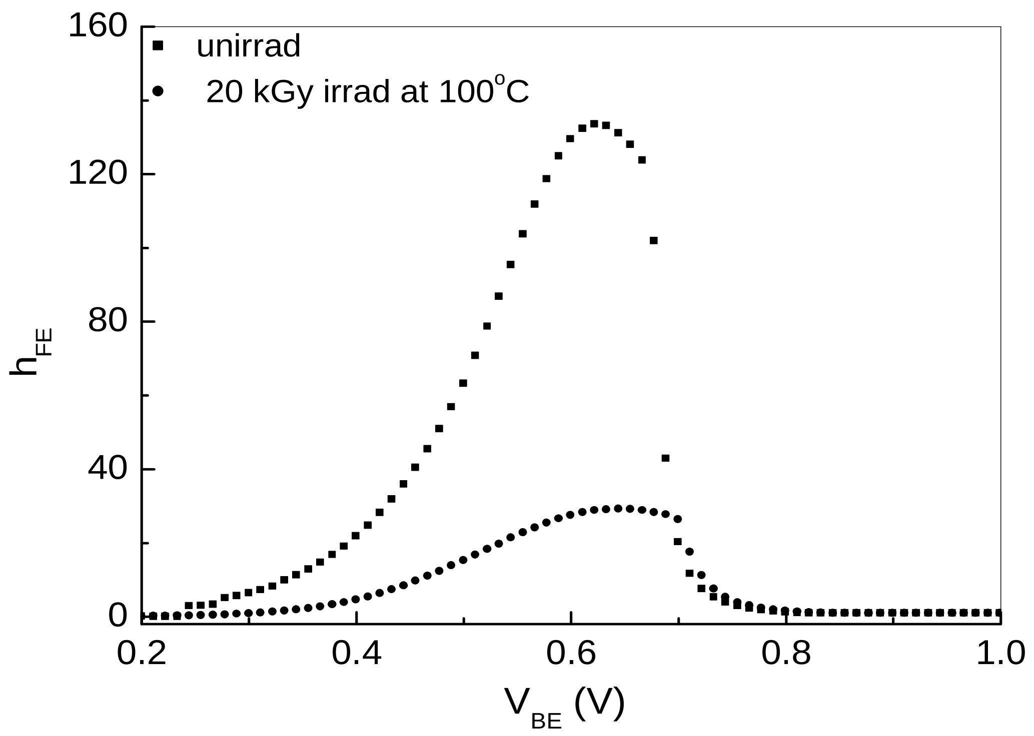

Fig. 5 b Effect 20 kGy electron irradiation on h_{FE} of BEL 2N5294 BJT at 100°C

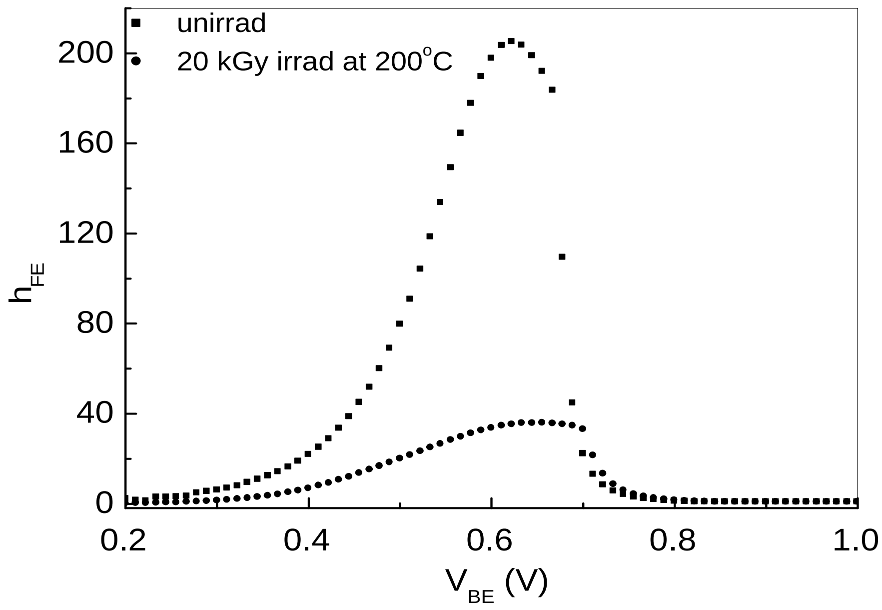

Fig. 5 c Effect 20 kGy electron irradiation on h_{FE} of BEL 2N5294 BJT at 200°C

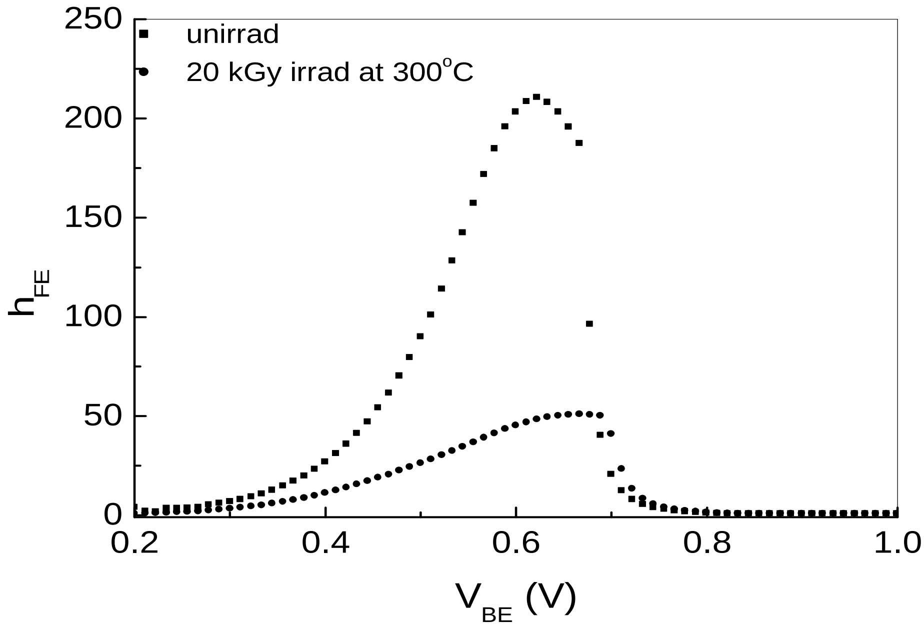

Fig. 5d Effect electron irradiation on h_{FE} of BEL 2N5294 BJT at 300°C

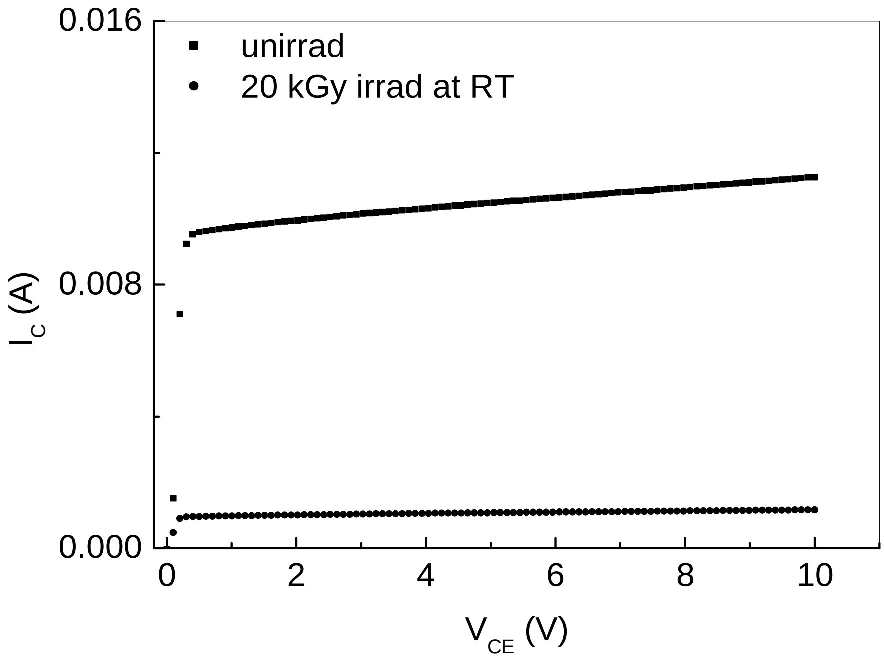

Fig. 6a Effect of electron irradiation on output characteristics of BEL 2N5294 BJT with I_B = 50 μA at room temperature

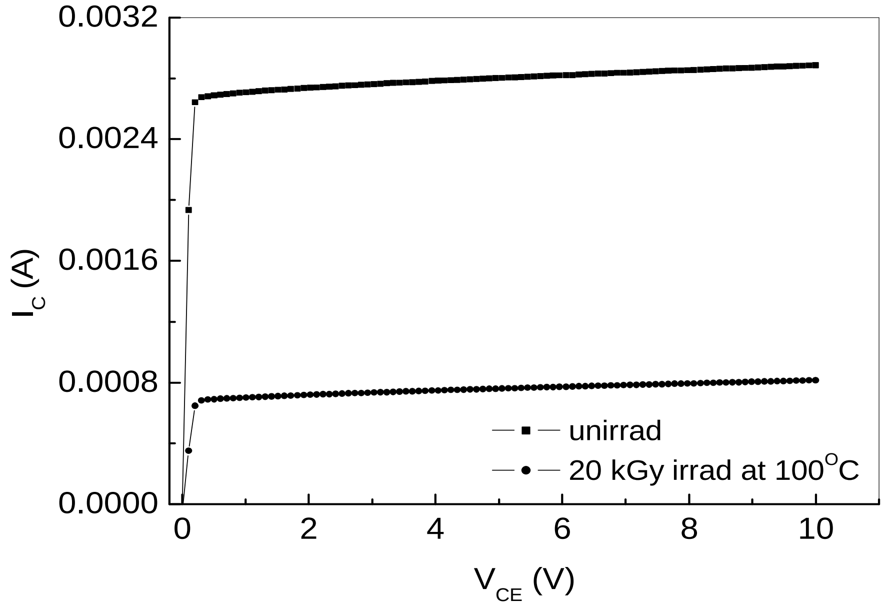

Fig. 6b Effect of electron irradiation on output characteristics of BEL 2N5294 BJT with I_B = 50 µA at 100°C

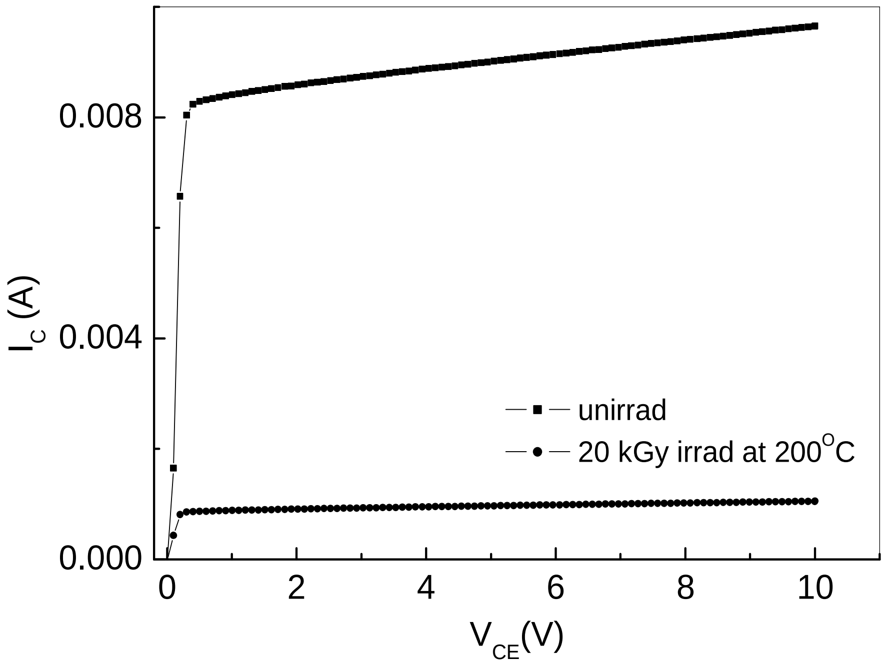

Fig. 6c Effect of electron irradiation on output characteristics of BEL 2N5294 BJT with I_B = 50 µA at 200°C

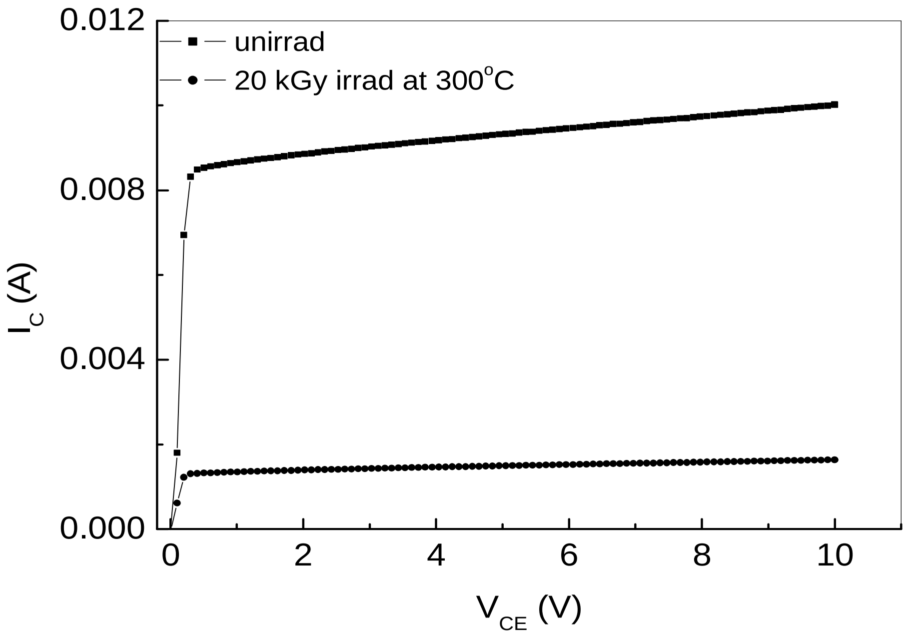

Fig. 6 d Effect of electron irradiation on output characteristics of BEL 2N5294 BJT with I_B = 50 µA at 300°C

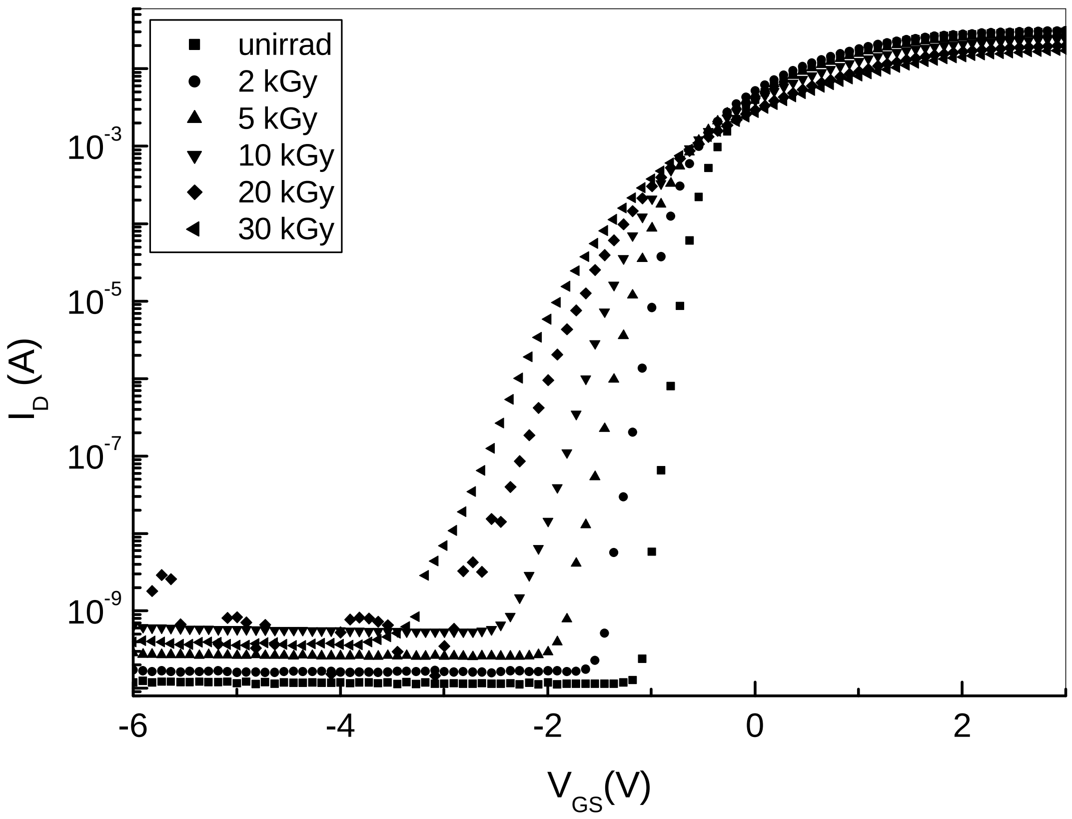

Fig. 7 Transfer characteristics of BEL MOSFET 3N200 with increase in cumulative electron dose irradiated at room temperature

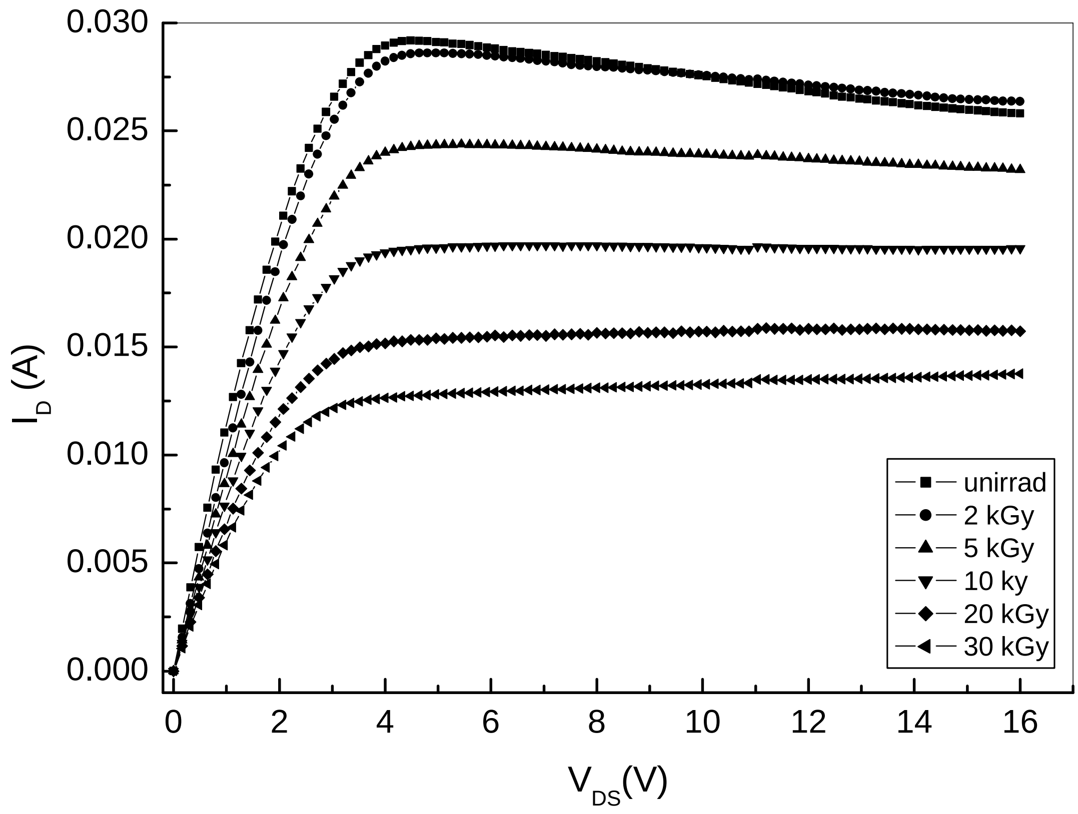

Fig. 8 Drain characteristics of BEL MOSFET 3N200 with increase in cumulative electron dose irradiated at room temperature

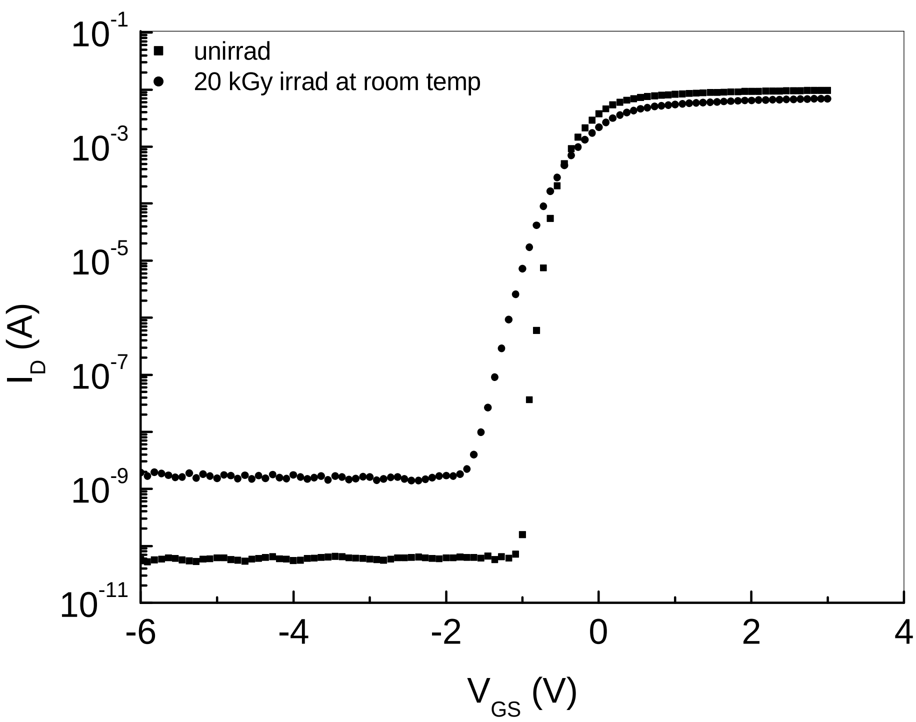

Fig. 9a Transfer characteristics of BEL 3N200 MOSFET electron irradiated at room temperature

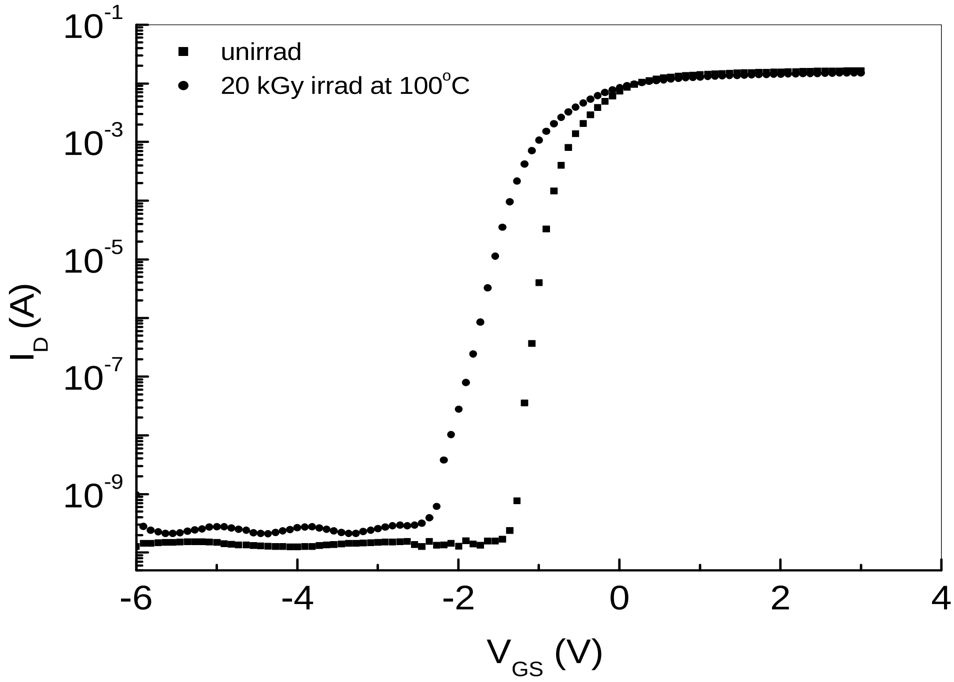

Fig. 9b Transfer characteristics of BEL 3N200 MOSFET electron irradiated at 100°C

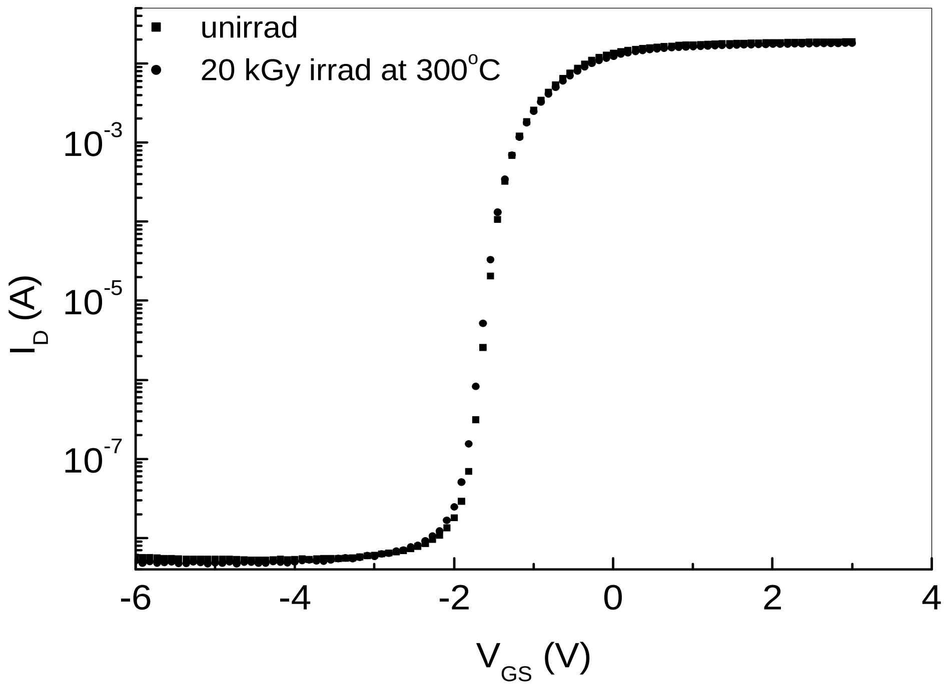

Fig. 9c Transfer characteristics of BEL 3N200 MOSFET electron irradiated at 300°C

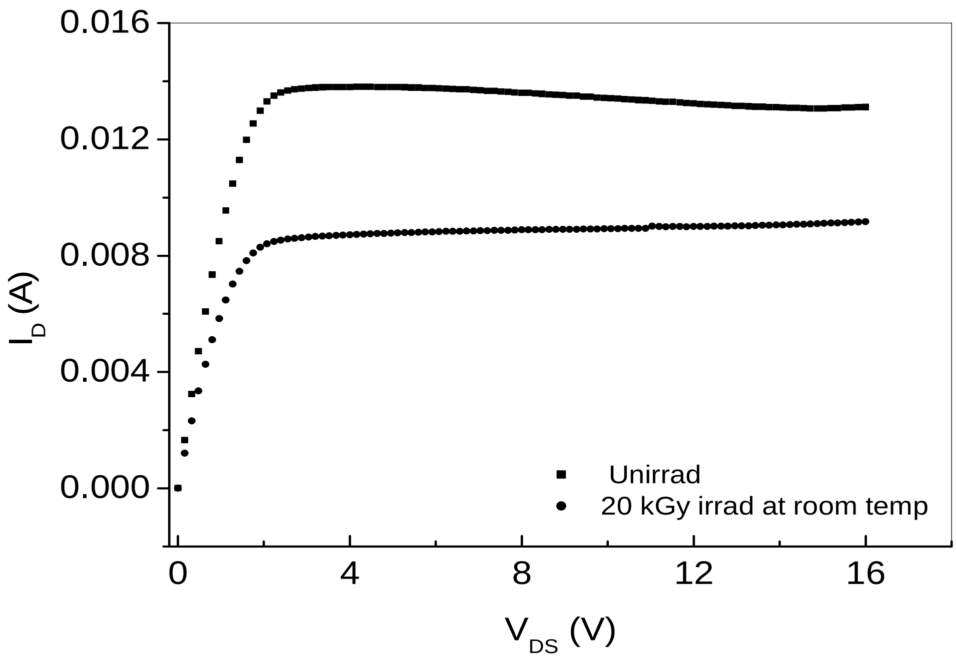

Fig. 10a Drain characteristics of BEL 3N200 MOSFET electron irradiated at room temperature

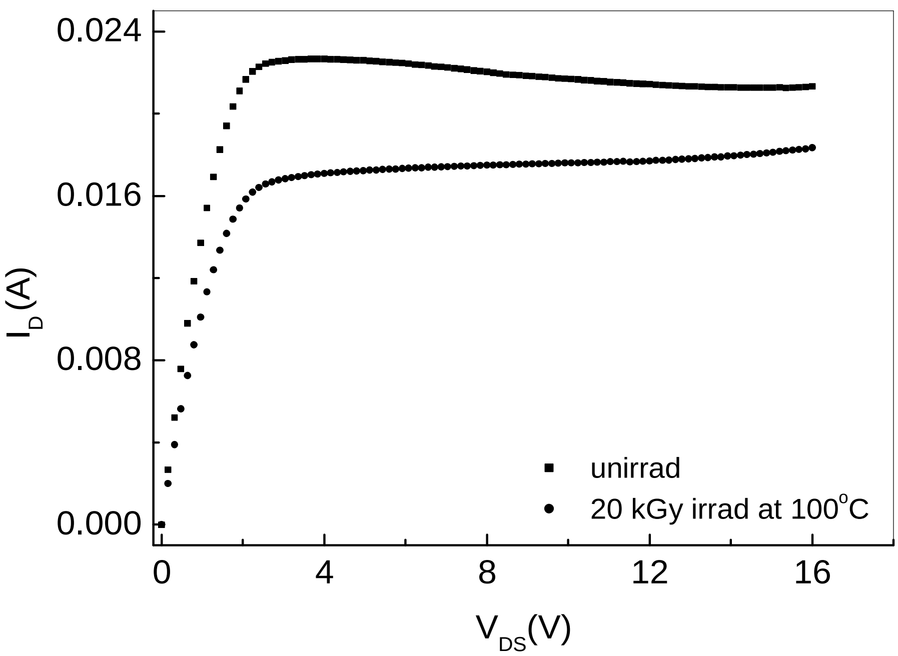

Fig. 10b Drain characteristics of BEL 3N200 MOSFET electron irradiated at 100°C

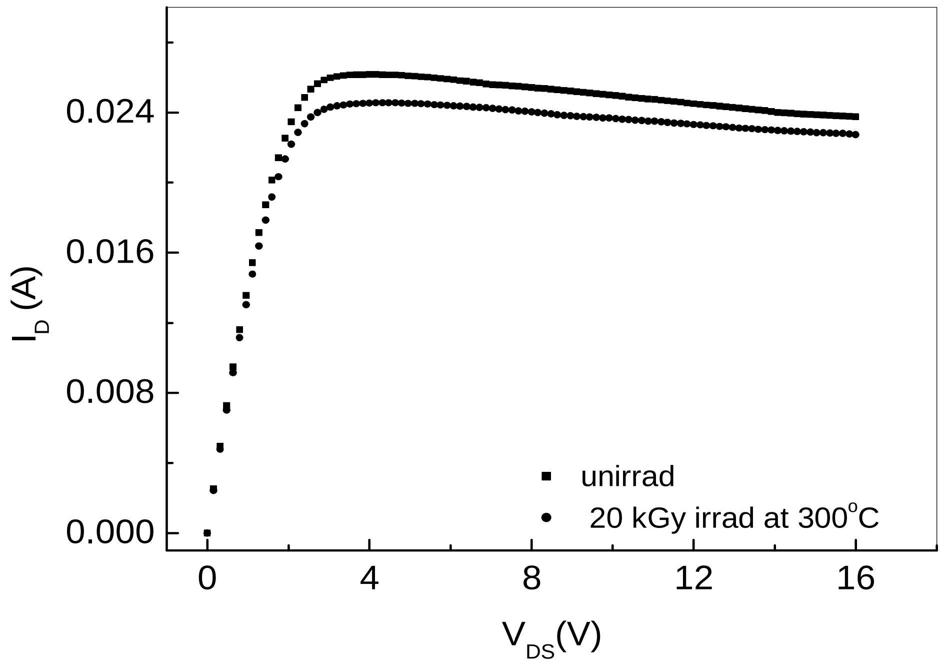

Fig. 10c Drain characteristics of BEL 3N200 MOSFET electron irradiated at 300°C

CONCLUSION

The electron irradiation studies on the current voltage characteristics of commercially available bipolar transistors and MOSFETs are carried out at elevated temperature. The degradation of the device characteristics are observed with irradiation temperature even above 200°C. This indicates that creation of defects dominates over simultaneous thermal annealing of these defects even at high temperatures.

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