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HIGH-ENERGY ELECTRON INDUCED GAIN DEGRADATION IN BIPOLAR JUNCTION TRANSISTORS

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ABSTRACT

This paper portrays the effect of 8 MeV electron bar on the forward current increase of room borne business native bipolar intersection semiconductors 2N2219A (npn), 2N3019 (npn) and 2N2905A (pnp). The gadgets are presented to 8 MeV electrons in the one-sided condition. The gatherer qualities and Gummel plots are gotten as an element of collected portion. An abundance base current model as well as Courier Spratt condition have been utilized to represent the noticed increase debasement. The outcomes show that 8 MeV electrons of high portion rate actuate gain corruption by expanding the base current as well as decline in gatherer current. The ongoing addition debasement has all the earmarks of being prevalently because of dislodging harm in the majority of the semiconductor. Off-line estimations of the h_{FE} of the illuminated semiconductors show that the removal incited imperfection and recombination focuses don't temper even at 150 °C.

KEYWORDS: High-energy electron irradiation; Gain degradation; Excess base current; BJT; Thermal annealing

1. INTRODUCTION

The investigation of radiation-prompted effects in semiconductor gadgets, as a rule, is significant both from the essential as well as applied perspective. According to the fundamental perspective, it is essential to have a more extensive comprehension of the harm cycle. According to the applied perspective, it is critical to survey the gadget execution when they should be worked in radiation climate. Various nonradhard adaptations of the gadgets from global merchants have been portrayed for radiation-prompted effects for use in space applications. Nonetheless, a few semiconductor gadgets, which are not accessible in radhard renditions, are as yet being utilized in rocket frameworks. In the new years, there is a rising requirement for some space offices to utilize natively made gadgets for space applications. Subsequently, it is fundamental to describe these for radiation prompted effects and qualify the parts for use in shuttle frameworks.

Discrete BJTs are as yet utilized for space applications because of their ongoing drive capacity, linearity and magnificent matching qualities. One of the significant part of the portrayal of BJTs for radiation-instigated effects is the radiation-actuated gain corruption. The BJTs are especially observed to be powerless against ionizing radiation and semiconductor gain corruption is the essential driver for parametric movements and practical disappointments. In spite of the fact that there are a few examinations investigating the system of gain corruption in BJTs exposed to radiation, a generally acknowledged model representing the equivalent has not arisen. The corruption of the forward current addition in the bipolar intersection semiconductor when presented to radiation is reliant upon many elements including the idea of radiation particulate and portion rate. The radiation-prompted debasement is likewise observed to be reliant upon the assembling innovation. The effects of ionizing radiation on vertical direct bipolar intersection semiconductors have been concentrated broadly. Vertical npn semiconductors display very significant gain debasement, especially when they are lighted at low portion rates (not exactly around 10 rad (SiO_2)/s). Interestingly, vertical pnp semiconductors are somewhat hard to ionizing radiation.

Then again, there are moderately less reports on the dislodging harm effects in discrete BJTs. Relocation harm in silicon because of Co^{60} c-beam openness can be examined as far as the photon prompted optional electron range. The auxiliary electron range of Co^{60} source is known to create optional electrons in the energy range 0.2-1 MeV. These electrons produce dislodging harm in the heft of the semiconductor, which is broke down as far as the Courier Spratt condition]. A few npn type semiconductors have been researched in the writing for momentum gain corruption in light of these contentions. As a general rule, the pnp type semiconductors are likewise expected to show a similar sort of debasement. Notwithstanding, apparently there is minimal trial proof to help this. Dale et al. have concentrated on the high energy electron prompted gain corruption with regards to removal of iotas. Summers et al. and Xapsos et al. have concentrated on the relocation harm delivered by high energy electrons and neutrons. In this work an endeavor is made to evaluate the radiation reaction of vertical discrete npn and pnp semiconductors fabricated in a native innovation from Mainland Gadget India Restricted (CDIL) in examination with the gadgets of comparative configurations revealed currently in the writing. The investigation of the effect of high portion 8 MeV electron light on two npn and one pnp semiconductors has been embraced to distinguish the component answerable for gadget debasement and to contrast their radiation resilience and the gadgets from worldwide merchants.

2. EXPERIMENTAL

Electrons are a helpful type of research facility radiation and can recreate precisely the effect of high-energy ionizing radiation. Discrete space borne native business BJTs of the sort 2N2219A, 2N3019 (both npn) and 2N2905A (pnp) of CDIL make have been researched for electron actuated effects. Every one of the semiconductors is exchanging semiconductors with standard configurations. The semiconductors have been fabricated by diffusion process. The semiconductors have vertical design and silicon is utilized for the producer. The two npn semiconductors chose for the review differ in element of the producer and gatherer, base thick-ness and doping fixation. The base thickness of the semiconductors 2N2219A, 2N3019 and 2N2905A are 2.0, 3.3 and 1.8 lm separately. In any case, the SiO2 oxide thickness of the multitude of semiconductors are something similar (1.2 lm). The semiconductors were presented to 8 MeV electrons at Microtron Center, Mangalore university, Mangalore. The gadgets are presented to a light emission in the one-sided conditions, VCE = 10 V and IB = 50 lA. Openness of the gadgets to radiation regardless of predisposition application shouldn't have, on a basic level, any effect on the corruption of the gadget boundaries. The semiconductors are decapped utilizing a decamping instrument and the pass on from the semiconductor was presented to the electron shaft [8,9]. Albeit 8 MeV electrons can enter the cover of the gadget (scope of 8 MeV electrons in Sil-symbol is around 10 mm), the gadgets are decapped to dispense with the energy loss of the electrons in the top. The authority attributes and Gummel plots were acquired after each 100 krad gathered electron portion and upto 500 krad. After a portion of 500 krad, the following estimation was made at 1 Mrad electron portion. All estimations of the electrical qualities were made utilizing Keithley instrument (Model No. 236) as a component of gathered portion (the electron pillar office was aligned for portion rather than fluence). The estimations are made quickly when the pillar is turned off after a specific collected portion. To confirm the reproducibility of the outcomes, two semiconductors of a similar group (date code) were uncovered. The outcomes acquired are indistinguishable for both the gadgets. Subsequently, consequences of only one semiconductor are introduced here.

3. RESULTS AND DISCUSSION

The gatherer qualities (I_C versus V_{CE}) of the semiconductors at steady base current I_B = 50 μA and V_{BE} = 0.65 V have been estimated as a component of collected electron portion. The gatherer current in the level district diminishes by around 4-7 Mama as the collected electron portion is expanded from 0 krad to 1 Mrad (these plots are not shown). Following figure shows the variety of gatherer mutt lease as an element of collected portion for every one of the three semiconductors at V_{CE} = 2 V, V_{BE} = 0.65 V and I_B = 50 μA. Gummel plots are likewise gotten by estimating the gatherer current I_C and base current I_B as an element of V_{BE} when V_{CE} is held steady at 5 V. Following figure shows the variety of gatherer current as a component of V_{BE} for different collected electron portion at a fixed worth of V_{CE} = 5 V. The outcomes show that there is not really any adjustment of the col-lector current (even on a lengthy size of the plot).

Fig. 1. Collector current (I_C) as a function of accumulated electron dose.
The lines are guide to the eye

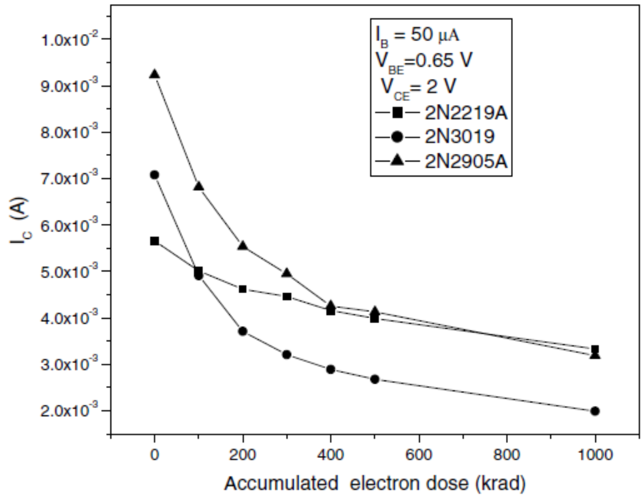
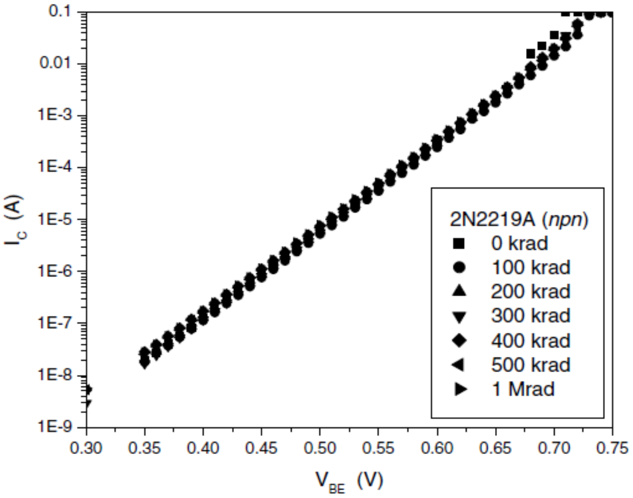


Fig. 2. Collector current (I_C) as a function of base–emitter voltage (V_{BE}) for different electron dose (V_{CE} = 5 V).



The other npn and pnp semiconductors additionally show no variety in the authority current. Comparable sort of results have been acquired when vertical pnp BJTs gadgets are presented to 10 keV X-beam and Co^{60} c-beam by Schmidt et al.. However, Ohyama et al. have noticed a lessening in the gatherer current when npn Si semiconductors are presented to 2 MeV electrons which is credited to an expansion in the gatherer series obstruction. Figs. 3 and 4 show the variety of I_B as a component of VBE with expanding gathered electron portion for the npn and pnp semiconductors individually. The other npn semiconductor (2N2219A) likewise shows a similar pattern. The base current I_B is found to increment with amassed electron portion for every one of the three semiconductors. The addition corruption in discrete bipolar intersection semiconductors can fundamentally happen in two ways: (1) corruption by ionization and (2) mass debasement.

Fig. 3. Base current (I_B) as a function of base–emitter voltage (V_{BE}) for different electron dose (V_{CE} = 5 V).

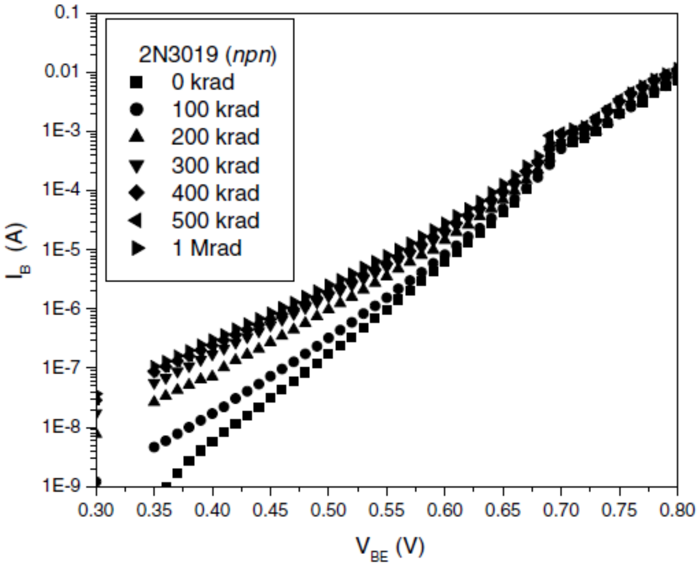
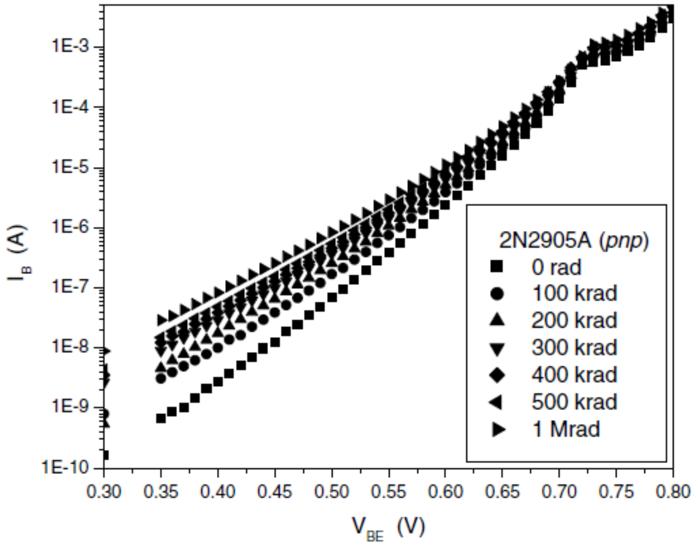


Fig. 4. Base current (I_B) as a function of base–emitter voltage (V_{BE}) for different electron dose (V_{CE} = 5 V).



Corruption by ionization is a surface effect and principally happens in the oxide passivation layer, especially the oxide covering the producer base intersection locale. Debasement by ionization (surface corruption) prompts expansion in base current basically because of two components: (I) the amassing of caught charges in the oxides, (ii) the collection of connection point states at the silicon dioxide interface. Expansion in base current can likewise happen because of absolute ionizing portion (TID) effect in the producer base district. The expansion in the base current can be defined as $\Delta I_B = I_B — I_{B0}$, and is given by the articulation

$$\Delta I_B = \Delta I_{B0}\ exp\left(\frac{qV_{BE}}{nkT}\right),$$

where IB0 is the pre-light base current, IB is the post-illuminated base current and DIB0 is the capture current in ΔI_B versus V_{BE} diagram; q, V_{BE}, k and T have regular importance and n is known as ideality factor which might shift with base-producer voltage and is removed from the incline of the plot of overabundance base current ($1 < n < 2$). Schmidt et al. have noticed two particular districts of ideality factors with a change from n = 1 to n = 2 in the complete portion effects (TDE) in bipolar semiconductors. For npn semiconductors, worth of n somewhere in the range of 1 and 2 (for $V_{BE} < 0.7$ V) is credited to the surface recombination and n of 2 (for $V_{BE} > 0.7$ V) to the recombination top being underneath the surface.

The overabundance base current as a component of V_{BE} for npn and pnp semiconductors are displayed in following figure and 6. In the current estimations, despite the fact that there is little dispersing of data of interest above V_{BE} = 0.6 V (perhaps because of voltage fluctuations and ensuing estimation mistakes), obviously there is no adjustment of the slant of the plot of overabundance base current for V_{BE} values > 0.7 V.

Fig. 5. Excess base current as a function of base–emitter voltage (V_{BE}) for different electron dose

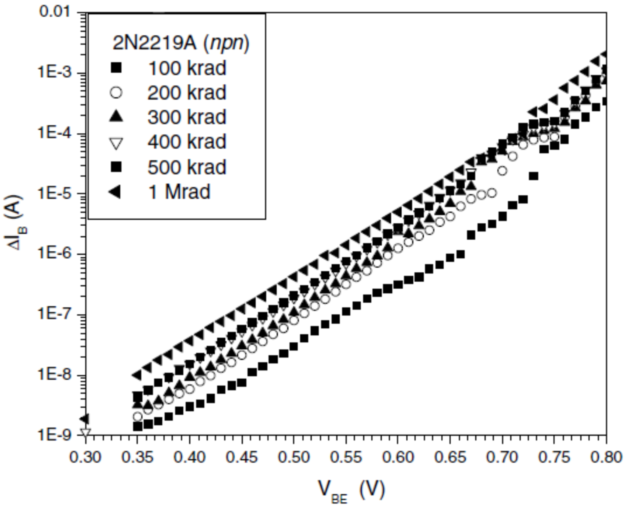
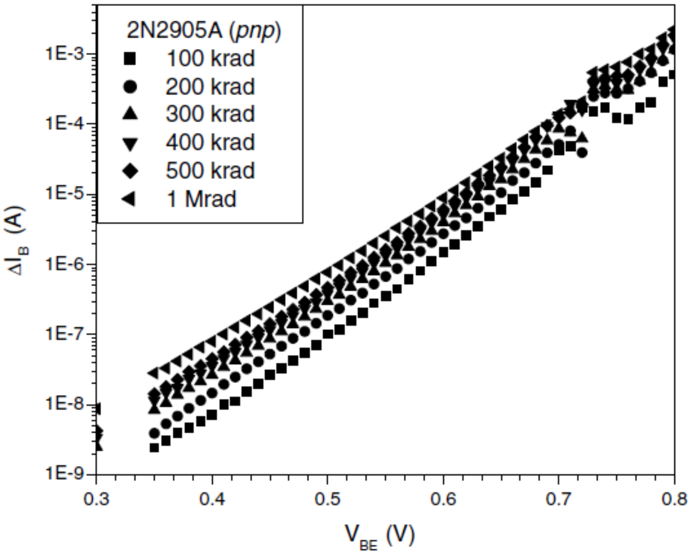


Fig. 6. Excess base current as a function of base–emitter voltage (V_{BE}) for different electron dose.



The noticed worth of n is 1.1 for practically the whole voltage range. Further, as aggregated portion increment, there is no significant change in n. In this way apparently both surface corruption at the oxide layer as well as TID effect in the producer base district could be adding to the noticed overabundance base current.

It is known that electrons with dynamic energy more noteworthy than 220 keV can deliver relocation harm in the main part of the semiconductor. This mass harm creates different sorts of deformities, which could go about as recombination focuses. A definite examination of the idea of the deformities and their densities require a DLTS investigation of the producer base intersection. At the point when recombination focuses are made in the base district of the semiconductor, it prompts builds the base current by diminishing the minority transporter lifetime. The decline in the minority transporter lifetime will be reflected on the corruption in the forward current addition of the semiconductor. Following figure shows the debasement of forward current increase as a component of collected electron portion for every one of the three kinds of semiconductors.

The relocation harm factor is a proportion of gain debasement; it very well may be determined utilizing the Courier Spratt condition. For our situation relocation harm factors for the every one of the three semiconductors are determined utilizing the Messen-ger-Spratt condition by changing over the collected electron portion into 8 MeV electron fluence. The decrease in h_{FE} with episode molecule fluence is given by Courier Spratt condition

$$h_{FE} = \frac{h_{FE0}}{(1 + h_{FE0}K\varphi)},$$

where hFE0 and h_{FE} are the addition values when illumination, ϕ is the fluence and k is the relocation harm steady. Fig. 8 shows the relocation harm factor as a component of collected electron portion.

Fig. 7. Forward current gain as a function of accumulated electron dose. The lines are guide to the eye

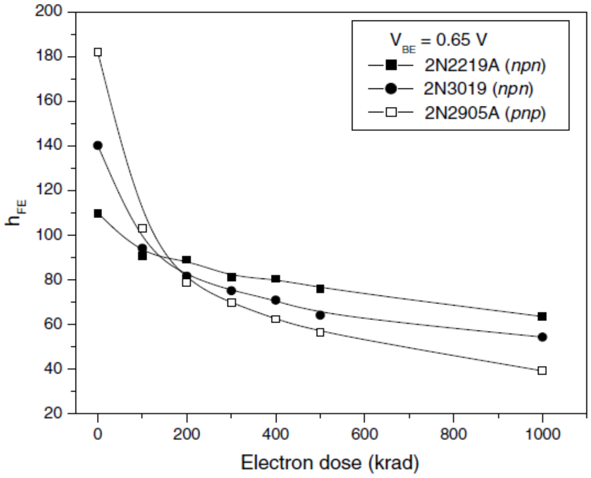
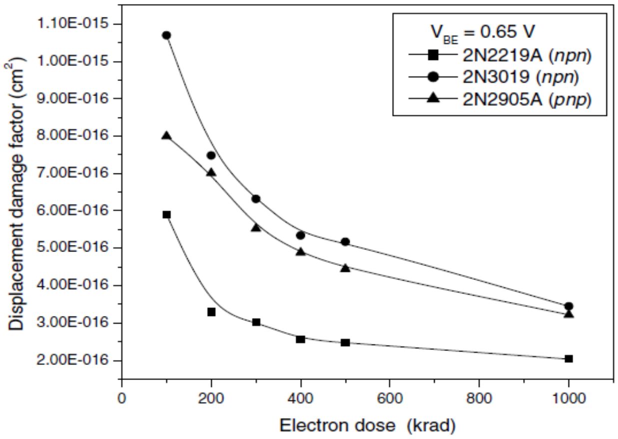


Fig. 8. Displacement damage factor as a function of accumulated electron dose. The lines are guide to the eye.



It is notable in the writing that the addition debasement in discrete BJTs could happen because of both expanded recombination in the producer base area (TID effect) and expanded recombination in the nonpartisan base chiefly by dis-arrangement harm. The decline in the gatherer current as a component of collected portion displayed in Fig. 1 and Gummel plot displayed in Fig. 2 appear to show that both TID-actuated harm and relocation harm in the main part of the semiconductor appear to add to the noticed addition debasement. To confirm which of the two components is predominant, off-line estimations of the increase of the semiconductors after warm tempering have been made.

Off-line estimations of the forward current increase for every one of the three kinds of semiconductors have been made after the gadgets are presented to a greatest collected portion of 1 Mrad. The h_{FE} of the gadgets are estimated at different biasing conditions. Off-line estimations are completed utilizing the TESEC semiconductor analyzer unit. The upsides of pre-and post-light h_{FE} alongside h_{FE} of post-illuminated gadgets strengthened at 150°C for 2 h are given in Table 1. It is seen that openness of the gadgets to electrons, brings about significant decrease in h_{FE}. At the point when the lighted gadgets are tempered at 150°C for 2 h, the addition is found to recuperate, without a doubt, somewhat. It is notable that the dislodging harm is fairly long-lasting and don't strengthen after warm toughening upto 175°C

Table 1a TESEC measurement results of the transistor of the type 2N2219A (npn)

	Biasing conditions	Pre-irradiation	Post-irradiation 1 Mrad	Post-irradiation, 1 Mrad, annealed at 150 °C for 2 h
h_{FE}	V_{CE} = 10.0 V I_C = 0.10 mA	92.85	35.56	38.00
	V_{CE} = 10.0 V I_C = 1.0 mA	107.8	58.03	60.35
	V_{CE} = 10.0 V I_C = 10 mA	116.5	79.49	82.03
	V_{CE} = 10.0 V I_C = 150 mA	111.9	88.28	90.68
	V_{CE} = 10.0 V I_C = 500 mA	65.34	53.58	54.38

Table 1b TESEC measurement results of the transistor of the type 2N3019 (npn)

Test item	Biasing conditions	Pre-irradiation	Post-irradiation 1 Mrad	Post-irradiation, 1 Mrad, annealed at 150 °C, for 2 h
h_{FE}	V_{CE} = 10.0 V I_C = 0.10 mA	116.8	16.82	16.86
	V_{CE} = 10.0 V I_C = 1.0 mA	49.38	49.38	49.89
	V_{CE} = 10.0 V I_C = 10.0 mA	62.11	62.11	62.53
	V_{CE} = 10.0 V I_C = 150 mA	90.47	90.47	90.14
	V_{CE} = 10.0 V I_C = 500 mA	75.31	75.31	76.12
	V_{CE} = 10.0 V I_C = 1.0 A	29.52	29.52	30.53

Table 1c TESEC measurement results of the transistor of the type 2N2905 A (pnp)

Test item	Biasing conditions	Pre-irradiation	Post-irradiation 1 Mrad	Post-irradiation, 1 Mrad, annealed at 150 °C, for 2 h
h_{FE}	V_{CE} = 10.0 V I_C = 0.10 mA	187.1	29.66	32.96
	V_{CE} = 10.0 V I_C = 1.0 mA	200.6	54.37	56.03
	V_{CE} = 10.0 V I_C = 10 mA	210.1	82.98	85.49
	V_{CE} = 10.0 V I_C = 150 mA	176.6	88.28	90.98
	V_{CE} = 10.0 V I_C = 500 mA	102.6	53.05	55.58

This recommends that sufficient imperfection and recombination focuses are created in the current gadgets when presented to 8 MeV electrons. The addition corruption of the semiconductors examined in this manner has all the earmarks of being prevalently because of uprooting harm created in the greater part of the gadget. The way that the addition of the semiconductors don't recuperate subsequent to strengthening demonstrates that the surface recombination and TID effect in the producer base locale maybe contribute practically nothing to acquire debasement.

4. CONCLUSION

The native business BJT's of type 2N2219A, 2N3019 and 2N2905A corrupt, when presented to high-energy electrons, as much as the gadgets of different sellers. 8 MeV electrons at high portion rate prompt current addition corruption by diminishing the authority current and expanding the base current. There gives off an impression of being two contending systems liable for the noticed addition corruption. The abatement in the authority current might be ascribed to the relocation harm in the impartial base. The expansion in the base current might be credited to the deformities and recombination focuses created in the producer base area of the semiconductor. Nonetheless, gain estimations after warm strengthening at 150°C shows that the electron actuated imperfections and recombination focuses don't toughen. In this way, the noticed addition debasement seems, by all accounts, to be overwhelmingly because of deformities and focuses actuated by mass harm. Estimations made at low portion pace of electrons would per-haps give extra data on the instrument of gain corruption.

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