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Low frequency noise study of X-ray irradiated Si/SiGe:C BiCMOS technology bipolar transistors

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I. INTRODUCTION AND EXPERIMENTAL PROTOCOL

The purpose of this work is to study the low frequency noise behavior of X-ray irradiated Si/SiGe:C HBTs. Low frequency noise (LFN) measurements are undertaken after several X-ray irradiation steps.

HBTs are issued from the last BiCMOS technologies developed by STMicroelectronics, based on a CMOS node of 55nm, referred to as B55 technology. Three different types of transistors (i.e., different flavors of transistors): High Speed (HS), Medium Voltage (MV) and High Voltage (HV) are studied, mainly the collector changes [1]. The performance of each transistor is summarized in Table 1. Geometrical characteristics (mask dimensions) are reported in Table 2. Only single-finger HBTs are used here. On wafer DC and LFN measurements are performed using coplanar probes.

	HS	MV	HV
f_t (GHz)	326	178	64
f_{max} (GHz)	376	384	269
J_c (mA/ μm^2)	19	6.1	1.9
BV_{ce0}	1.5	1.9	3.2

Table 1. High frequency and power performances of the 3 HBTs flavors

HBT's ref	W_E (μm)	L_E (μm)	Area(μm^2)
QHFB504	0.2	3	0.6
QHFB505	0.2	5	1.0
QHFB506	0.2	10	2.0
QHFB508	0.3	5	1.5
QHFB510	0.42	5	2.1
QHFB512	0.3	10	3.0
QHFB513	0.35	10	3.5
QHFB514	0.42	10	4.2

Table 2. Emitter geometries of the studied HBTs.

Irradiations are processed in an X-ray chamber facility from the PRESERVE platform (X-RAD320 generator). Several irradiation steps were generated until reaching a Total Ionizing Dose (TID) of 280 krad. During irradiation, the transistors are unbiased.

Prior to LFN measurement, DC characterization is carried out using a Keithley 4200 or an Agilent 89410A semiconductor characterization system.

In our case, the fluctuations of the input base current, S_{I_B} , are obtained using a low noise current-voltage-amplifier (EG&G 5182) associated with a spectrum analyzer (HP 89410A) in the 10 Hz-100 kHz frequency range [2].

II. DC CHARACTERIZATION

DC characterization consists of the measurement of forward Gummel plots as a function of the total ionizing dose (TID). An example is given in Figure 1. As can be seen, no significant impact of irradiation is observed on the collector current. Concerning the base current, a degradation is observed in the low-level injection regime, $0.3 \text{ V} < V_{BE} < 0.6 \text{ V}$, corresponding to the base current generation-recombination component.

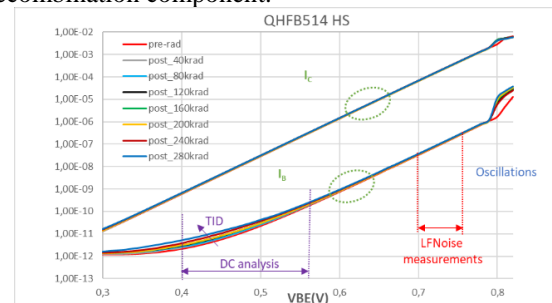


Figure 1: Gummel-Plot characteristics for a B55HBT with $A_e = 4.2\mu\text{m}^2$.

To compare the impact of X-ray exposure between the different transistor geometries, we used the relative excess base current $\Delta I_B/I_B$ (i.e., the difference between post-irradiation and pre-irradiation base current divided by the pre-irradiation base current). In Figure 2, $\Delta I_B/I_B$ is plotted versus V_{BE} for the different TIDs, showing the increase in degradation with the X-ray exposure. To avoid the influence of the tunnel component in the base current and ensure the study of the G-R component, we have chosen the analysis at $V_{BE} = 0.54 \text{ V}$. In Figure 3, we have reported the excess base current as a function of TID for different geometries. A linear increase in excess base current is observed with TID; smaller geometry transistors present a higher degradation. We will discuss the role of the E-B spacer interface traps proposed as the main induced defects.

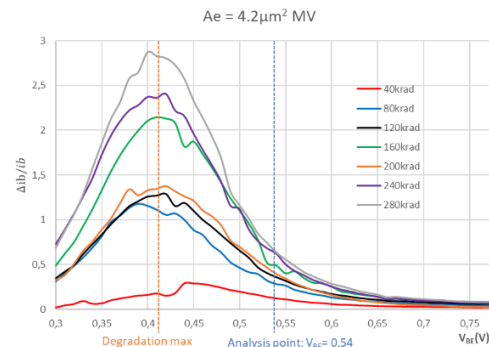


Figure 2. $\frac{\Delta I_b}{I_b}$ vs V_{BE} , B55 MV 514 ($A_e = 4.2\mu\text{m}^2$)

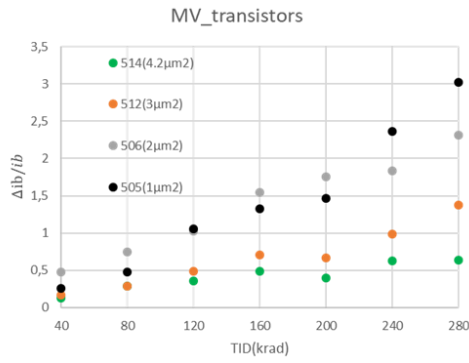


Figure 3. $\frac{\Delta i_b}{i_b}$ (@ $V_{BE} = 0.54 V$) vs TID : for different emitter areas (MV HBTs)

III. LOW FREQUENCY NOISE

A. Spectral Analysis

After each irradiation step (40 krad), the input base current noise, S_{IB} , is measured at 3 input base currents: 50 nA, 100 nA, and 500 nA. The maximum TID for LFN was 240 krad. The LFN study versus TID is performed on HS HBTs only.

As already presented [3], LFN spectra measured on pristine devices can be described by two main characteristics: the $1/f$ noise and shot noise components, and the presence or absence of Generation-Recombination component(s) (G-R), presented by Lorentzian spectra, associated with a trapping/de-trapping process. An example is given in Figure 4. When the $1/f$ noise is unambiguously observed, classical SPICE modeling ($S_{IB}^{1/f} = K_F \frac{I_B^{A_F}}{f}$) leads to a value of A_F equal to 2, and K_F is found to be inversely proportional to the emitter area. In Figure 4, a Lorentzian component with a cut-off frequency close to 10 Hz is present for the HV transistor. This G-R component is mainly observed at high bias currents.

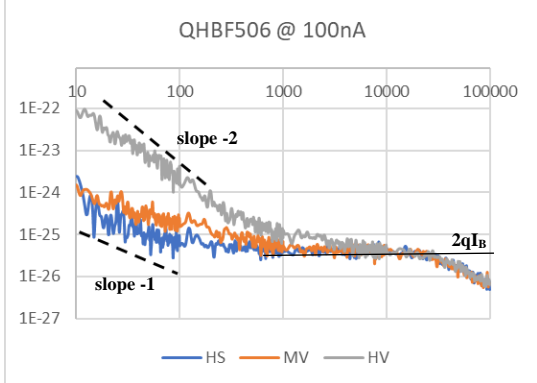


Figure 4. Sib of HS, MV and HV for $A_e = 2 \mu m^2$ at I_b of 100nA.

After irradiation, depending on several parameters (TID, bias current, and geometry), several behaviors have been observed, making LFN analysis quite complex. For instance, as presented in Figure 5, at high biased current (i.e., 500 nA), the low frequency G-R component signatures (cut-off frequency of around 10 Hz and plateau level) present an independence from irradiation.

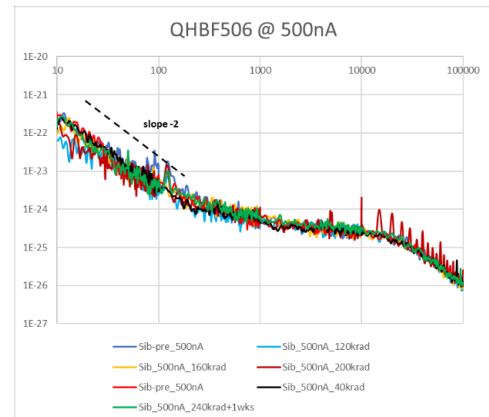


Figure 5. Sib@500nA vs TID of an HS HBT ($A_e = 2 \mu m^2$).

A second behavior (Figure 6) is characterized by $1/f$ noise presenting a stable level at low TID, generally below 40 or 80 krad, followed by the presence of a new G-R component with a cut-off frequency around 200 Hz and a plateau that can be very sensitive to irradiations.

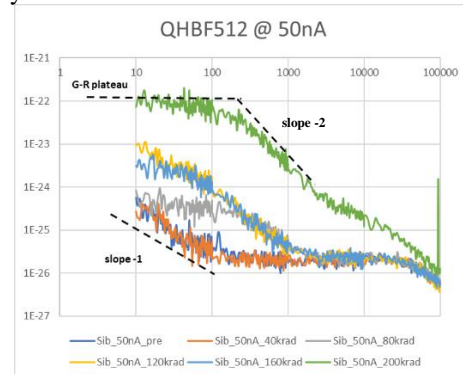


Figure 6. Sib@50nA vs TID of an HS HBT ($A_e = 3 \mu m^2$).

IV. DISCUSSION

Irradiation damage under X-ray irradiation is mainly associated with the creation or activation of trap centers in oxide regions. For bipolar transistors, the STI oxide on the collector side and spacer oxide in the E-B region are generally proposed as potential degradation locations.

From DC and LFN results versus TID, the discussion will deal with the location of the noise sources and related traps. In particular, we will underline the role of the SiO_2/Si E-B spacer interface.

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