Radiation-Hardened SiGe BiCMOS Technologies for Analogue and Mixed-Signal ICs

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Abstract

There is a strong need in the Space market, where size, power and weight are a strong concern, for high performance microelectronic processes capable of integrating complex digital functions together with very high operating frequencies even into the THz range [1].

Silicon-Germanium (SiGe) Heterostructure Bipolar Transistor (HBT) devices are well known for their radiation tolerance [3] [4] [5] and their capability to perform in harsh environments [2].

The integration of SiGe HBTs into Bipolar-Complementary Metal Oxide Semiconductor (BiCMOS) technology platforms have proven a valuable technology for the design and implementation of highly integrated Microwave Monolithic Integrated Circuits (MMICs) and Application Specific Integrated Circuits (ASICs) operating at very high frequencies (into the THz range). Integration with low power complex CMOS functions and Emitter-Coupled-Logic (ECL) bipolar digital functions allows MMICs with unprecedented complex functionalities unavailable in other process (i.e. III-V) technologies.

I. Introduction

IHP provides un-restricted access for research and educational purposes as well as for commercial fab-less companies, to Process Design Kits (PDKs) on proprietary high-performance 0.25µm and 0.13µm SiGe-BiCMOS Technologies for prototyping through Multi-Project-Wafer (MPW) and Low Volume Production (LVP).

For the 250nm node, a Radiation Hardened (RH) PDK SGB25RH has been developed and evaluated in accordance to the ESCC-2269010 Basic Specification “Evaluation Test Programme for MMICs” and requesting EPPL listing ,while for the 130nm, PDK SG13RH is presently completing radiation testing (TID, DD, SEEs) in accordance with ESCC-2269010. EPPL for SG13RH can be foreseen within 2020.

The RH PDKs provide tested library elements where Radiation Hardened by Design (RHBD) techniques at layout, circuit and architecture level to the standard commercial processes have been implemented. For example, Enclosed-Layout-Transistor (ELT) for N-Channel MOS devices are available as well as special layout designs for the CMOS library memory elements, i.e. D-Flip-Flops (DFFs) and known DICE FFs.

II. IHP SiGe BiCMOS Technologies for Space

The proposed processes have completed commercial qualification derived from JEDEC JP001.1 for Level-2 Technological Qualification which includes Device Reliability Tests (CMOS+HBT) and Intrinsic Reliability Tests.

Table 1 and Table 2 summarize the Process and Standard-Cell Digital Library options of the offered SiGe BiCMOS Technologies by IHP. In addition both processes include a range of passive devices like Poly-Si resistors, Metal-Insulator-Metal (MIM) capacitors, MOS varactors and other.

Table 1: SGB25RH PDK Process and Library Options

Features	**SGB25V / SGB25RH**
Backend (BEOL)	5 Layer Al incl. 2 µm and 3 µm thick metal layers (TM1, TM2)
Bipolar ($f_T/f_{MAX}/BV_{CEO}$)	High-speed HBT : 75 GHz / 95 GHz /2.4 V Medium Voltage HBT : 45 GHz / 90 GHz / 4.0 V High Voltage HBT : 25 GHz / 70 GHz / 7.0 V
CMOS	Vdd = +2.5 V T_{OX} = 5.8 nm
CMOS Digital Standard Cell Libraries	SESAME-LP2 Dolphin Library + Rad-Hard Library extension elements (~ 70 cells) (TMR-FF, DICE-FF) SAPHYRION SAGL Standard Cell Library (~25 cells)
CMOS Digital Standard Cell IO Cells	SESAME IO Pads +2.5 V IHP25 RH +3.3 V IO Pads

Table 2: SG13RH PDK Process and Library Options

Features	**SG13S / SG13RH**	
Backend (BEOL)	7 Layer Al incl. 2 µm and 3 µm thick metal layers (TM1, TM2)	
Bipolar ($f_T/f_{MAX}/BV_{CEO}$)	High-speed HBT : 250 GHz / 340 GHz /1.7 V High Voltage HBT : 50 GHz / 130GHz / 3.7V	
CMOS	Vdd = +1.2 V T_{OX} = 2 nm	Vdd = +3.3 V T_{OX} = 7 nm

Features	SG13S / SG13RH
CMOS Digital Standard Cell Libraries	IXC013 + Rad-Hard Library extension elements (~80 cells) (TMR-FF, DICE-FF)
CMOS Digital Standard Cell IO Cells	IO Pad Library (+2.5 V and +3.3 V)

III. RADIATION TEST RESULTS

A. Total Ionizing Dose (TID) and Enhanced Low Dose Rate sensitivity (ELDRS)

1) HBT Devices:

Previous [5] [6] [7] TID and ELDRS measurements on SiGe HBTs were carried out at much higher dose rates and total doses, aiming at applications in high-energy physics. However for space-oriented applications, lower dose rates are required. MIL-STD-883 TM1019.8 calls out a dose rate of 50 to 300rad(Si)/s to ensure worst-case test conditions. Re-conducted tests on HBTs in SGB25RH show dependency of the Base-current and Forward Beta with respect to TID (Figure 1) to a tested dose level of 800krad(Si) while SG13RH HBTs do not show any substantial variation to TID (Figure 2) to a tested dose level of 1210krad(Si).

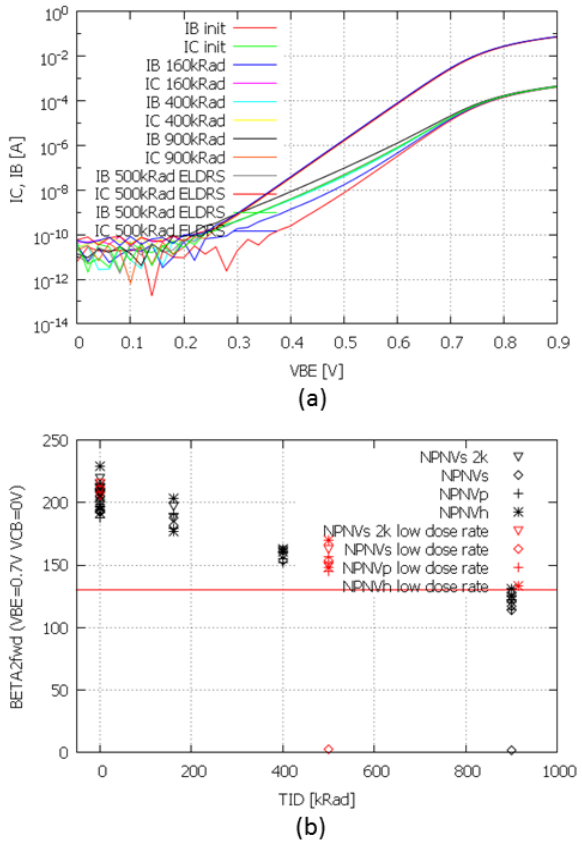

Figure 1: Forward Gummel plots (a) and forward current gain (b) for SGB25RH HBT devices (with emitter area of 1.06x1.48 µm^2) versus TID

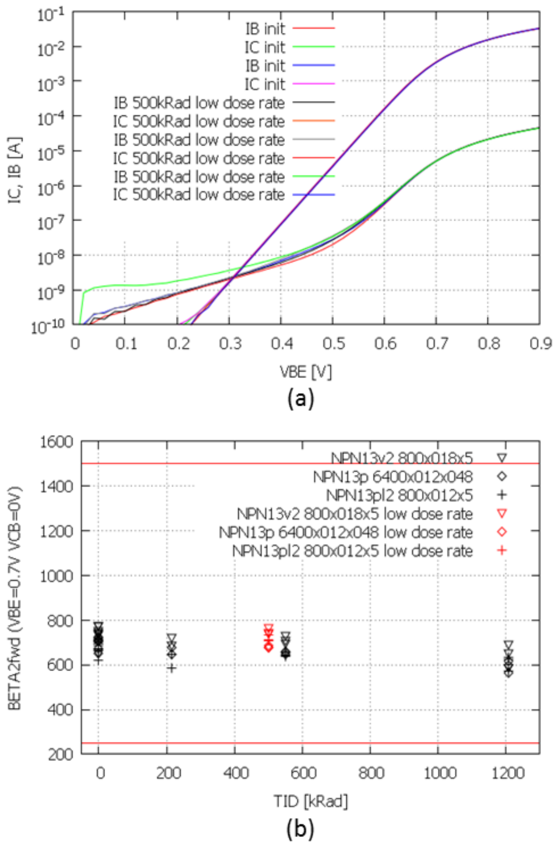

Figure 2: Forward Gummel plots (a) and forward current gain (b) for SG13RH HBT devices (with emitter area between 360 and 720 µm^2) versus TID.

2) CMOS Devices:

In modern CMOS technologies with gate oxide thicknesses <10nm the main TID effect is a strong subthreshold leakage current shift. TID-induced trapped charge accumulates in the trench oxide leading to inter- and intra-device leakage conduction paths. For the former case, accumulation of radiation induced positive charge in the shallow trench isolation oxide leads to parasitic corner devices with reduced (more negative) threshold voltage. For NMOS devices the parallel corner device leads to an increased leakage current.

PMOS devices in both technologies have been tested to a maximum total dose level of 500krad(Si) and exhibited no variations in their characteristics. For SGB25RH NMOS (Figure 3) and SG13RH LV-NMOS pass TID levels of up to 110krad(Si) for the devices used in the standard cell libraries. Leakage current remains within specification up to TID levels of 110kRad .

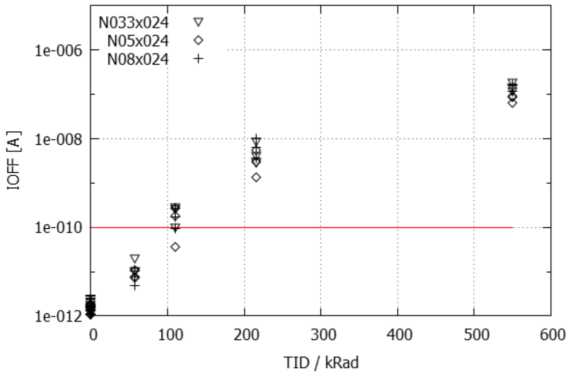

Figure 3: Leakage current IOFF versus total ionizing dose for SGB25V short channel NMOS DUTs with gate length L=0.24µm. Gate width is 0.33, 0.5 and 0.8µm. The red line is the pre- and/or post-irradiation maximum specification value as defined for the pass/fail parameter VTN024 in the SGB25V process specifications.

Annealing tests after irradiation showed a slight improvement after room temperature annealing (simulating low dose rate environments), accelerated annealing tests at 100°C showed no indication of Time Dependent Effects (TDE) (see Figure 4).

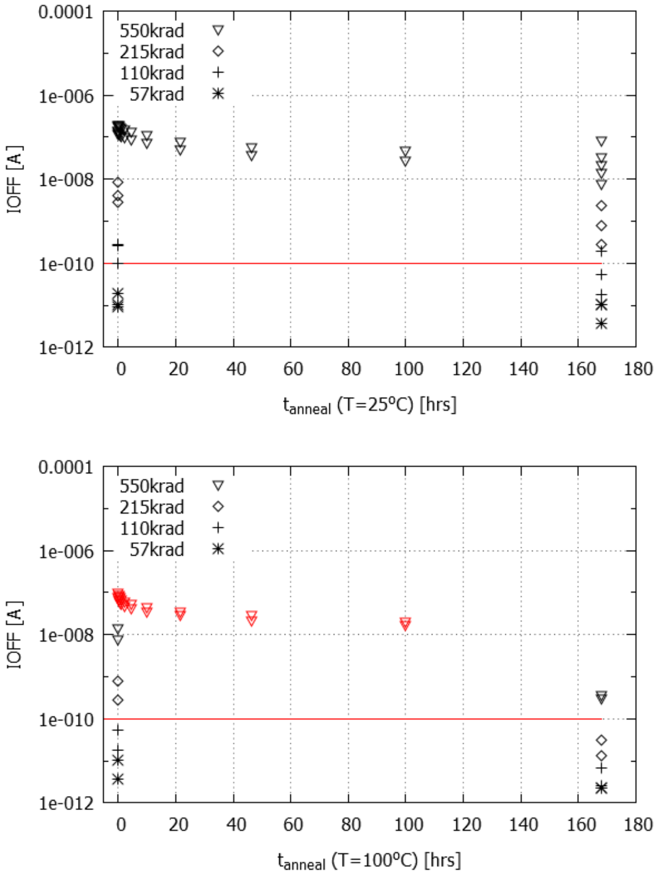

Figure 4: Leakage current IOFF for SGB25 NMOS versus annealing time for room temperature and high temperature accelerated anneal.

As expected the transfer characteristics for the Enclosed Layout (ELT) NMOS Transistor devices in SB25RH and SG13RH (Figure 5) exhibit very stable characteristics for TID well over 500krad(Si).

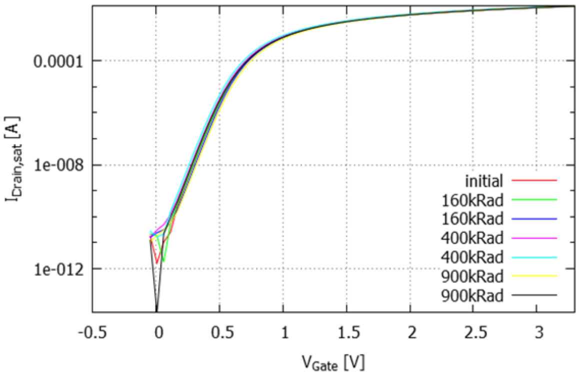

Figure 5: Transfer characteristic of the SG13RH ELT-NMOS (nELT033) high-voltage (HV) device in saturation (VDS=3.3V) before and after irradiation process for TID up to 900krad(Si).

B. *SEL / SEU on CMOS Digital Standard Cell Libraries*

Several Test Vehicles have been designed and tested under Heavy Ions (HI) for Single Event Latch-up (SEL) and Single Event Upsets (SEU) characterization. No SEL has been detected up to 65MeV/cm²/mg on the CMOS standard cell library elements. Achieved SEU LET thresholds and Cross-Sections on the different Flip-Flops (TMR, DICE, etc..) were measured on 1024-bit Shift Registers Test Vehicles and are shown in Figure 6 for SGB25RH. Similar curves are available for SG13RH.

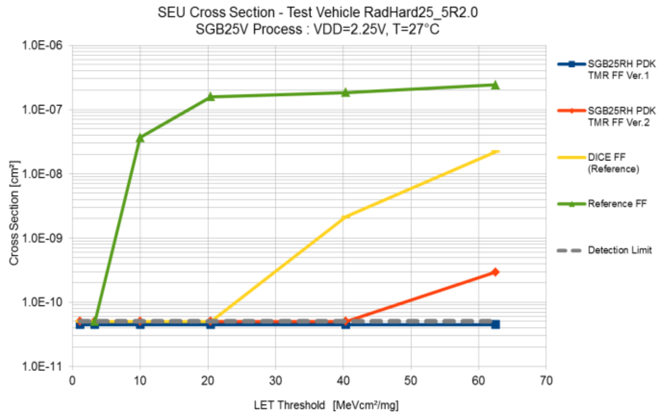

Figure 6: Heavy-Ion (HI) SEU test results on 1024-bit Shift Registers built around different Flip-Flops (TMR, DICE, etc..) for SGB25RH

IV. STATUS OF ESCC EVALUATIONS

A. *SGB25RH*

Rad-Hard PDK SGB25RH has been developed and has been evaluated in accordance to the ESCC-2269010 Basic Specification "Evaluation Test Programme (ETP) for MMICs" and will be requesting EPPL Listing in 2016 upon update completion of the Process Identification Document (PID) and Capability Domain (CD). Radiation tests (TID, ELDRS) have also been re-performed on the active devices to confirm the process and SEL/SEU characterization has been completed on the digital standard cell libraries. Test Vehicles requested by ESCC-2269010 (TCV, DEC, RIC shown in Figure 7) have completed all Long Term Tests (LTT) as in Table 3.

Table 3: SGB25RH ESCC-2269010 ETP Test Summary

Test Vehicle	**Long Term Test**
TCV	4000h, 150°C – completed successfully with predicted degradations and expected failures during stress test
DECs	up to 3000h, 150°C and Room Temperature – completed with some failures due to EOS / ESD handling issues CMOS HCI degradation leading to lifetime estimation (~20 years / 300MHz / +2.7 V) HBT no degradation
RIC	4000h, 150°C – completed successfully with no failures

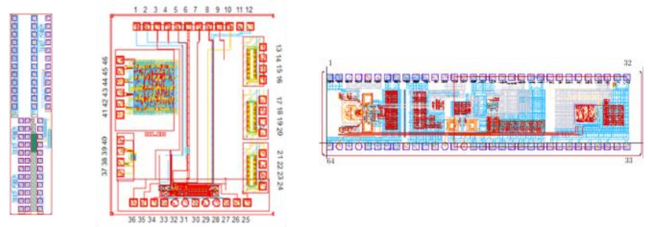
(a) TCV (b) DEC (b) RIC

Figure 7: SGB25RH Test Vehicles (dies only) : Technology Characterization Vehicle (TCV) (a) consisting of standard technology test segments (HBTs, NMOS, PMOS, etc…), (b) Dynamic Evaluation Circuit (DEC) consisting of Shift-Registers, Ring-Oscillators, and VCO and (c) Representative Integrated Circuit (RIC) a 20 GHz VCO with integrated divider chain, 6 GHz RF Output and Serial to Parallel (SPI) Interface.

B. SG13RH

130nm Technology node, PDK SG13RH is under development and sensitivity to radiation (TID, DD, SEEs) is being completed on several Test Vehicles (including TCV and DEC) before continuing with the tests defined in ESCC-2269010 Evaluation Test Programme. Expected application for EPPL for SG13RH would be in the timeframe 2018/2020.

V. CONCLUSION

SGB25RH and SG13RH PDKs enable SiGe BiCMOS technologies for the development of MMIC/ASICs intended for space applications and harsh environments .

VI. REFERENCE PUBLICATIONS

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