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Random telegraph noise in SiGe HBTs: Reliability analysis close to SOA limit

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ABSTRACT

In this paper, we present extensive random telegraph signal (RTS) noise characterization in SiGe heterojunction bipolar transistors. RTS noise, observed at the base, originates at the emitter periphery while at the collector side distinct RTS noise is observed at high-injection that originates from the traps in the shallow trench regions. Time constants extracted from RTS during aging tests allow understanding of trap dynamics and new defect formation within the device structure. This paper provides the first demonstration of RTS measurements during accelerated aging tests to study and understand generation of defects under bias stress in SiGe HBTs operating at the limit of their safe-operating area.

1. Introduction

Radio-Frequency (RF) performances of silicon germanium heterojunction bipolar transistors (SiGe HBTs) have entered THz range of operation at the expenses of high current density and lower breakdown voltages thus leading to several reliability issues that can impact the long-term operation of SiGe HBT-based circuits, especially when operated close to the safe-operating area (SOA). Noise spectroscopy has been demonstrated as an efficient diagnostic tool for analyzing quality and reliability through understanding of evolution of imperfections and failure mechanisms in bipolar transistors [1–5]. Understanding of the underlying physics that correlate degradation mechanisms and low-frequency noise in advanced SiGe HBTs is scarce yet severely important from the reliability viewpoint. Although there have been earlier attempts [4,5] of linking low-frequency noise sources with the degradation modes, most of the previous works present analysis of the degradation modes in advanced SiGe HBTs through the impact on the base current. One of the major sources of defects in HBTs is often attributed to generation–recombination noise at low frequencies, originated mostly in the device external surface and periphery [6–9]. These noise sources can lead to random telegraph signal (RTS) noise [9–12], and in long-term operation of the HBTs, these sources can pronounce the effects of degradations that can affect device performances [13–17]. In our previous results reported in [10–12] extensive analysis of low-frequency and RTS noise was presented. Additionally, in [18] a comprehensive set of aging tests close to the SOA was reported for SiGe HBTs. In this paper, for the first time, we attempt to provide crucial insights into the degradation modes of SiGe HBTs using RTS noise characterization performed along the aging time. Accelerated aging tests are carried out in order to analyze the failure mechanisms at the boundary of SOA. Extractions of RTS noise time constants and their evolution with bias and aging time both at the base and the collector sides are analyzed to get deeper insight into the active G-R mechanisms associated with the defect locations. The rest of this paper is organized as follows: Section 2 will provide details of the aging tests, the associated evolution of DC characteristics with aging time and the mechanism of defects using TCAD analysis; Section 3 will demonstrate RTS noise characterization results including evolution of base and collector RTS and their trapping time constants as a function of aging time in order to study the impact of degradation on the device during the aging tests, followed by the conclusion.

2. Aging tests

The dynamic performances of the advanced SiGe HBTs can be mainly attributed to the miniaturized device dimensions and the associated optimized doping profiles [19]. Technology evolution achieved through both the above factors result in a decrease of the collector-base and open base collector-emitter breakdown voltages (BV_{CB0} and BV_{CE0}, respectively), which are measured as 5.2 V and 1.5 V for the technology investigated

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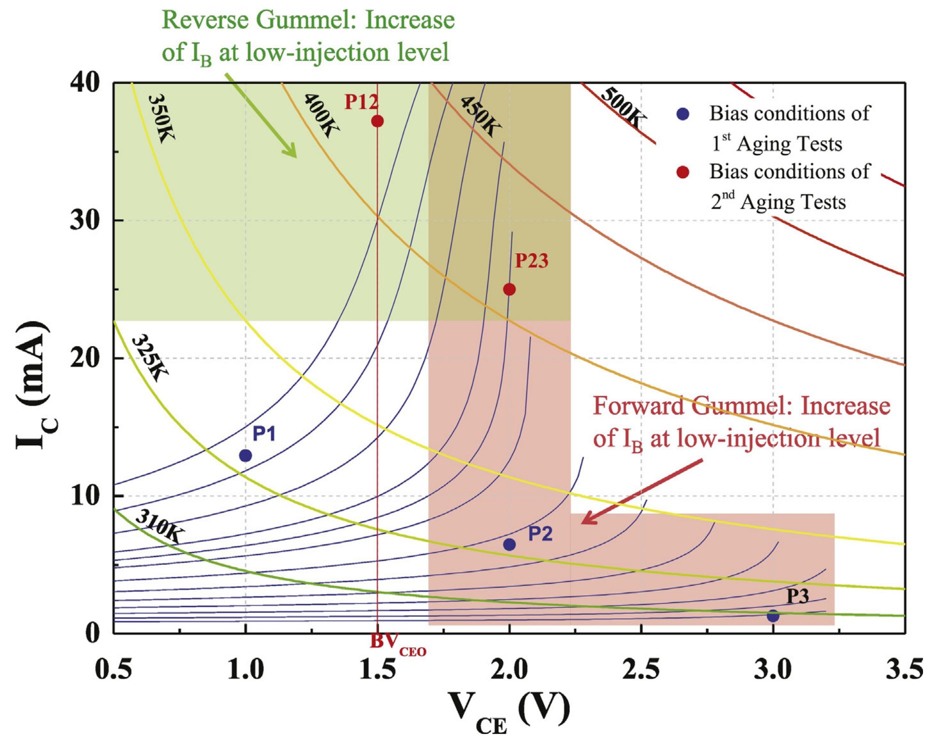

Fig. 1. Output characteristics of the transistor geometry 0.13 × 9.93 μm^2 simulated using HICUM L2. Bias conditions of the first (P1, P2 and P3) and the second (P12 and P23) aging tests are also shown. The isothermal hyperbolic curves indicate the junction temperatures between 310 and 500 K. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

in this paper, limiting the safe operating area (SOA). Although BV_{CE0} is not a physical limit of the technology and the operating area can be extended above this value, these bias conditions could limit the long-term reliability of the future applications. To investigate this, transistor level aging tests have been performed under electrical stress close to the SOA limit [18].

The devices under test (DUTs) are SiGe:C BiCMOS HBTs from Infineon Technologies having $f_T = 250$ GHz, $f_{max} = 370$ GHz [20]. Aging tests and noise characterization have been carried out on transistors with single emitter finger in CBEBC configuration. The details of the noise measurement setup can be found in [10]. To eliminate process variation, noise has been measured on at least 5 to 8 different devices with the same geometry but from different dies. Low-frequency noise measurement results on all available geometries are extensively reported in [10]. Besides, extensive aging test results on this technology are

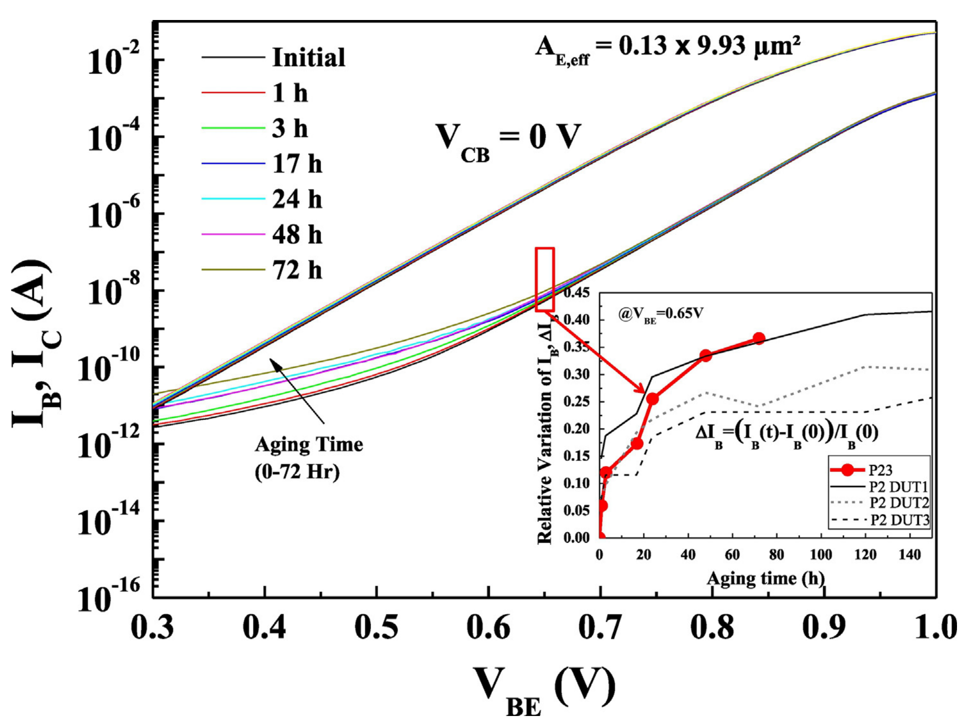

Fig. 2. Evolution of Gummel characteristics with aging time; inset: relative variation of I_B at $V_{BE} = 0.65$ V.