Heavy Ion Current Transients in SiGe HBTs

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Overview

- Look at device under test (IBM 5AM SiGe HBT)

- Review bias conditions of interest
  - Relation to findings of previous experiments

- Heavy ion microbeam data
  - 36 MeV $^{16}$O (SNL)

- Heavy ion broadbeam data
  - Low- and high-energy tunes (JYFL and GANIL)

- Path forward and summary
Device Background and Introduction

- **Key device characteristics**
  - Deep trench isolation
  - Subcollector junction
  - Lightly-doped p-type substrate (large)

- **Extend state-of-the-art knowledge**
  - Move beyond charge collection

Previous measurements on SiGe HBTs have only looked at laser-induced transients or heavy ion charge collection.
Microbeam Experimental Setup

Similar setup for 4-terminal measurements

- PSPL Bias Tees: 5542K
- DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)
- 2.9 mm coaxial cable assemblies (40 GHz)

Sandia National Laboratories’ Microbeam Chamber

Microbeam Experimental Setup

36 MeV $^{16}$O dE/dx profile
[SRIM-2008]

Sandia National Laboratories’ Microbeam Chamber

Beamline

Transient Capture

To be presented by Jonathan A. Pellish at the 18th Annual Single-Event Effects Symposium (SEE Symposium)
Bias Conditions of Interest

- **CASE 1**
  - Base Contact
  - Emitter Contact
  - Collector Contact
  - Substrate Taps
  - $V_{\text{sub}} = -4 \, \text{V}$; $V_{\text{EBC}} = 0 \, \text{V}$

- **CASE 2**
  - Base Contact
  - Emitter Contact
  - Collector Contact
  - Substrate Taps
  - $V_C = +3 \, \text{V}$; $V_{E,B,\text{sub}} = 0 \, \text{V}$

- **CASE 3**
  - Base Contact
  - Emitter Contact
  - Collector Contact
  - Substrate Taps
  - $V_{\text{sub}} = -3 \, \text{V}$; $V_{\text{EBC}} = 0 \, \text{V}$

- **3-D TCAD**
- **Rendering from GDSII of actual DUTs**
36 MeV $^{36}$O Microbeam Data: Case 1

Peak Current Magnitude

Case 1 ($V_{\text{Sub}} = -4 \, \text{V}$)

- Base terminal images base-collector junction
- Collector terminal images base-collector junction and subcollector

36 MeV $^{36}$O Microbeam Data: Cases 2 & 3

Peak Current Magnitude

Case 2 ($V_C = 3 \, V$)

Case 3 ($V_{Sub} = -3 \, V$)

- Significant current magnitude increase for $V_C = +3 \, V$
- Observed in two-photon pulsed laser testing too

TPA Pulsed Laser vs. Microbeam

Both data sets for CASE 1
\( V_{\text{sub}} = -4 \, \text{V} \)

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Heavy Ion Broadbeam Transients

No position correlation

• Data collection at the University of Jyväskylä, Finland and GANIL, France
• 9.3 MeV/u cocktail including $^{20}$Ne, $^{40}$Ar, $^{82}$Kr, and $^{131}$Xe and 45.5 MeV/u $^{136}$Xe

JYFL Broadbeam Transients

- Typical events observed from events somewhere within active region
- Position inferred using SNL microbeam data

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JYFL Broadbeam Transients

Maximum amplitude transients as a function of bias

- Saturation of collector current transient with highly ionizing particle
- Some bias dependence, but masked by random hit location

JYFL vs. GANIL Broadbeam Transients

- Similar LET values produce different transient responses
- Trend holds for average of all transients for each LET

Influence of Ion Energy

- Ion energy determines $\delta$-ray energy
- Higher energy ion reduces eh-plasma density
  - Ambipolar and bipolar transport affected by carrier density
  - Space charge screening effects

Path Forward

- Attempt to uncover reason for increase in collector current for $V_C = +3$ V bias condition
  - Impact ionization or other positive feedback mechanism

- Conduct simulation study to understand differences between microbeam and broadbeam data
  - Alleviates some difficulties with modeling TPA data

- Uncover role of ion range and recombination mechanisms in lightly-doped substrates
  - GANIL 45.5 MeV/u $^{136}$Xe vs. JYFL 9.3 MeV/u $^{82}$Kr

Order of Operations

GDSII-to-TCAD  3-D Simulations  Simulation comparison to data

Summary

• Time-resolved ion beam induced charge reveals heavy ion response of IBM 5AM SiGe HBT
  – Position correlation
  – Unique response for different bias schemes
  – Similarities to TPA pulsed-laser data

• Heavy ion broadbeam transients provide more realistic device response
  – Feedback using microbeam data
  – Overcome issues of LET and ion range with microbeam

• Both micro- and broadbeam data sets yield valuable input for TCAD simulations
  – Uncover detailed mechanisms for SiGe HBTs and other devices fabricated on lightly-doped substrates

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