High-Speed Single-Event Current Transient Measurements in SiGe HBTs

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Overview

• IBM 5AM SiGe HBT device background...briefly

• High-speed measurement setup
  – Heavy ion microbeam, heavy ion broadbeam, pulsed laser
  – Advantages/disadvantages

• Low-impedance current transient measurements

• Understanding what the transients represent for single-event effects in SiGe HBTs
Device Background and Introduction

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

- **Extend state-of-the-art knowledge**

  Previous tests focused on pulsed laser carrier generation only
  New tests focus on heavy ion carrier generation

IBM 5AM SiGe HBT (0.5 μm)

Microbeam Experimental Setup

General electrical setup
used in all cases

\[ \begin{align*}
Ve & \quad | & \quad Vb & \quad | & \quad Vc \\
\downarrow & & & & \uparrow \\
V_{\text{sub}} & & & & \\
\end{align*} \]

Digital Storage Oscilloscope

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
[SIRIM-2008]

Sandia National Laboratories’ Microbeam Chamber

**Advantages/Disadvantages**
Heavy Ion Broadbeam Experiments

- 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

**Advantages/Disadvantages**
Two-Photon Absorption Testing

Custom High-Speed Package

Six 2.9 mm coaxial connectors

NRL 2-photon setup

1260 nm TPA Electron-hole pair density contour

Electron-hole pair charge packet positioned at DUT in all three dimensions

Bias Conditions of Interest

**CASE 1**

- \( V_{\text{sub}} = -4 \text{ V}; \ V_{\text{EBC}} = 0 \text{ V} \)

**CASE 2**

- \( V_{\text{sub}} = -3 \text{ V}; \ V_{\text{EBC}} = 0 \text{ V} \)
- \( V_{C} = +3 \text{ V}; \ V_{E,B,\text{sub}} = 0 \text{ V} \)

**CASE 3**

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

Peak Current Magnitude

![Graphs showing peak current magnitude for base and collector terminals with $V_{Sub} = -4$ 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)  
Note scale differences

Case 3 ($V_{Sub} = -3$ V)  
Note scale differences

Collector

- 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 ($V_{\text{sub}} = -4 \text{ V}$)


Heavy Ion Broadbeam Transients
JYFL Broadbeam Transients

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

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

Path Forward

• Attempt to uncover reason for increase in collector current for $V_C = +3$ V bias condition
  – Impact ionization, bias scheme or other positive feedback

• 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

• Build new devices and circuits with matching networks to provide appropriate impedances
  – Both “looking in” and “looking out”
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 existing 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
  – What type of device transient constitutes a circuit effect?