Heavy Ion Current Transients in SiGe HBTs

Jonathan A. Pellish\textsuperscript{1}, R. A. Reed\textsuperscript{2}, G. Vizkelethy\textsuperscript{3}, D. McMorrow\textsuperscript{4}, V. Ferlet-Cavrois\textsuperscript{5}, J. Baggio\textsuperscript{5}, P. Paillet\textsuperscript{5}, O. Duhamel\textsuperscript{5}, S. D. Phillips\textsuperscript{6}, A. K. Sutton\textsuperscript{6}, R. M. Diestelhorst\textsuperscript{6}, J. D. Cressler\textsuperscript{6}, P. E. Dodd\textsuperscript{3}, M. L. Alles\textsuperscript{2}, R. D. Schrimpf\textsuperscript{2}, P. W. Marshall\textsuperscript{7}, and K. A. LaBel\textsuperscript{1}

\textsuperscript{1}: Radiation Effects and Analysis Group, NASA/GSFC Code 561.4, Greenbelt, MD 20771
\textsuperscript{2}: Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN 37235
\textsuperscript{3}: Sandia National Laboratories, Albuquerque, NM 87175
\textsuperscript{4}: Naval Research Laboratory, Washington, DC 20375
\textsuperscript{5}: The CEA, DAM, DIF, F-91297 Arpajon, France
\textsuperscript{6}: School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332
\textsuperscript{7}: NASA Consultant, Brookneal, VA 25428

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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

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

CASE 1

- Substrate Taps
- Emitter Contact
- Collector Contact

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

CASE 2

- Substrate Taps
- Emitter Contact
- Collector Contact

$V_{\text{C}} = +3 \text{ V}; \ V_{\text{E,B,sub}} = 0 \text{ V}$

CASE 3

- Substrate Taps
- Emitter Contact
- Collector Contact

$V_{\text{sub}} = -3 \text{ V}; \ V_{\text{EBC}} = 0 \text{ V}$

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

Peak Current Magnitude

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

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

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TPA Pulsed Laser vs. Microbeam

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


Heavy Ion Broadbeam Transients

No position correlation

University of Jyväskylä
K-130 Cyclotron

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

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JYFL Broadbeam Transients

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

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 δ-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