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

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under Contract DE-AC04 94AL85000.
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

[SIRIM-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
- Base Contact

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

CASE 2

- Substrate Taps
- Emitter Contact
- Collector Contact
- Base Contact

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

CASE 3

- Substrate Taps
- Emitter Contact
- Collector Contact
- Base Contact

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

- 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

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

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

TPA Pulsed Laser

Microbeam


To be presented by Jonathan A. Pellish at the 18th Annual Single-Event Effects Symposium (SEE Symposium)
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 $^{20}$Ne, $^{40}$Ar, $^{82}$Kr, and $^{131}$Xe and 45.5 MeV/u $^{136}$Xe

To be presented by Jonathan A. Pellish at the 18th Annual Single-Event Effects Symposium (SEE Symposium)
JYFL Broadbeam Transients

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

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


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