NEPP Electronic Technology Workshop 2011

National Aeronautics and Space Administration

Single Event Effects (SEE) for Power Metal–Oxide–Semiconductor Field-Effect Transistors (MOSFETs)

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Acknowledgments

Government:

- **Defense Threat Reduction Agency**
- **NASA/GSFC Radiation Effects and Analysis Group**
  - Ken LaBel, Ray Ladbury, Hak Kim, Anthony Phan, Megan Casey, Alyson Topper, and Tim Irwin
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University:

- **University of Maryland**
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- **International Rectifier**
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  - Brian Triggs, Mike Gauthier, Ahmed Iftikhar, Brian Gauthier, and John Parks
- **STMicro**
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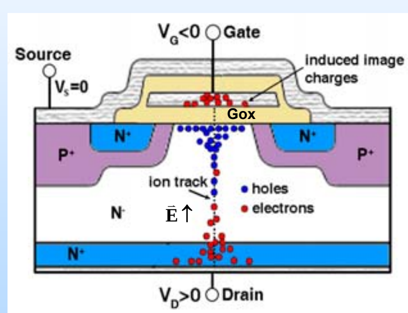
- **Texas Instruments**
  - Jim Salzman, Bruce Holcomb
- **Vishay Siliconix**
  - Dave MacDonald, John Demiray, and Arthur Chiang

Introduction

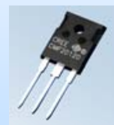
- **Single-event gate rupture (SEGR) continues to be a key failure mode in power MOSFETs**
- **SEGR is complex, making rate prediction difficult**
- **SEGR mechanism has two main components:**
  - **Oxide damage**
    - **Reduces field required for rupture**
  - **Epilayer response**
    - **Creates transient high field across the oxide**

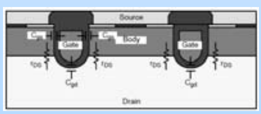


NEPP Focus

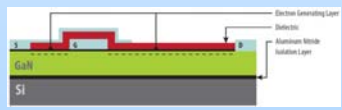
- Develop reliable SEGR rate prediction capability
  - Enhance understanding of failure mechanisms
  - Support test method revision/guideline development
  - Develop a SEGR rate prediction tool
- Evaluate alternative power devices for space applications
  - New technologies
  - New suppliers

SiC





Trench topologies



GaN

FY11 SEGR Modeling and Power MOSFETs (Continuation)

Description:

This subtask is part of a continuing effort to improve and verify prediction techniques for radiation effects through the development of software packages, with emphasis on Single Event Effects (SEE). This subtask focuses on the development of a first-order physics model of Single Event Gate Rupture (SEGR), with emphasis on application to power MOSFETs. Currently, no SEGR tool exists.

Emphasis in FY11 will be on bounding the on-orbit SEGR failure rate. In conjunction, the effect of ion species on SEGR susceptibility will be studied. These efforts will lead into the development of an MRED-based rate-prediction tool.

In addition, the suitability for space applications of alternative power devices will be evaluated, to include both new suppliers and new technologies such as SiC.

Note: Sister task at JPL looking at GaN power devices.

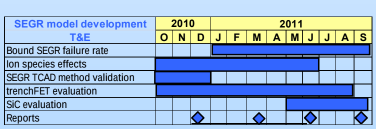
FY11 Plans:

Modeling:
– Bound the upper-limit of on-orbit SEGR failure rate
– Validate method of SEGR determination in TCAD models
– Investigate ion species effects

Test Vehicles:
- Vishay TrenchFETs: 12V, 200V pMOS; 250V nMOS
- STMicro rad-hard power MOSFETs – cont'd partnership
- SemiCOA rad-hard 450V nVDMOSFET
- Int'l Rectifier IRH7250
- Cree SiC power MOSFET (1200V)
- Micross SiC JFET, Schottky diode (1200V)
- TranSiC NPN BJT (1200V)

Test Method Development:
- Support ASTM Method 1080 development
- Support MIL-STD 750E TM1080 revision

Schedule/Costs:



Subtask lead: J.-M. Lauenstein
Co-Is: M. Casey, N. Goldsman, S. Liu, J. Titus, R. Ladbury, R. Schrimpf, L. Scheick

Deliverables:

-Quarterly and test reports
-Summary report due Sep 11

NASA and Non-NASA Organizations/Procurements:

Beam procurements: TAMU, Berkeley
Partners: JPL, NSWC, University of Maryland, Vanderbilt University, Cree, IR, Micross, Semicoa, STMicro, TI, Vishay

Sister task at JPL looking at GaN power devices.

Goals

- **Evaluation of on-orbit SEGR vulnerability**
  - Relative importance of SEGR mechanisms:
    - Ion-species effects (as opposed to linear energy transfer (LET))
    - Substrate charge effects (relative to epilayer, oxide)
  - Upper bound on SEGR failure rate for a given device SEGR response curve
- **Validation of TCAD SEGR simulation method**
- **Evaluation of alternative power devices for space applications**
  - Commercial trench MOSFETs
  - Radiation hardened VDMOS from new suppliers
  - SiC power devices
- **SEGR/SEB test method evaluation and revision:**
  - Provide feedback on JEDEC/ASTM revisions of Standards and Guidelines.
  - Continue collaboration with ESA on SEGR test and qualification methods.

Goals Highlighted in This Talk

- **Evaluation of on-orbit SEGR vulnerability**
  - Relative importance of SEGR mechanisms:
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Expected Impact to Community

- **Minimize power MOSFET derating penalty (maximize performance) through better failure rate prediction**
  - Benefit to designers AND suppliers
- **Strengthen existing and foster new relationships with industry**
  - Expansion of power device options available for insertion into space applications
  - Development of products that meet the needs of spacecraft and instrument designers
- **Streamline test and qualification methods**
  - Foster agreement through collaborative efforts

Status/Schedule

- **Evaluation of on-orbit SEGR vulnerability**
  - Determined that ion atomic number cannot be neglected when considering SEGR failure rate prediction. (FY11 Q1-Q3)
  - Developed method to bound the SEGR failure rate:
    - Based on operation at upper limit of safe-operating area (SOA) defined from any given test data. (FY11 Q2-Q3)
- **Validation of TCAD SEGR simulation method:**
  - Determined Titus-Wheatley expression for the critical oxide field based on ion atomic number is a valid method to determine when SEGR has occurred in VDMOS SEGR simulations. (FY11 Q1-Q2)
- **Evaluation of alternative power devices for space applications**
  - Completed initial SEE evaluation of Vishay commercial trenchFETs. Initial total ionizing dose (TID) evaluation of p-types completed, n-type pending. (FY11 Q1-Q4)
  - Completed initial SEE evaluation of Semicoa radiation-hardened SCF9550 450V nVDMOS. (FY11 Q1)
  - Continued SEE evaluation of STMicro radiation-hardened STRH100N10 100V nVDMOS. (FY11 Q1)
  - Completed initial TID evaluation of Cree SiC 1200V nVDMOS. (FY11 Q3)

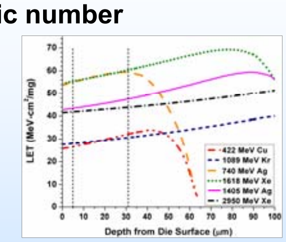
Status/Schedule

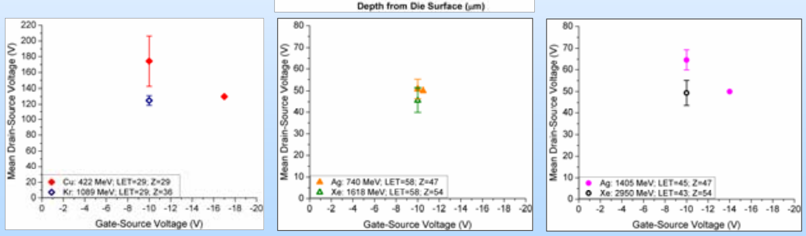
- **SEGR/single-event burnout (SEB) test method evaluation and revision**
  - **Test method refinement:** Continue to provide input and edits to draft revision of MIL-STD750E TM1080 for JEDEC JC13.4 meetings. (FY11 Q1-Q4)
  - **SEGR/SEB test method evaluation:**
    - Participated in multi-agency/organization evaluation of penetration range and species effects on SEB failure threshold. (FY11 Q1)
    - Participating with IR, NSWC, and NRL in two photon absorption (TPA) laser mapping of SEB response vs. depth of charge ionization (FY10 Q3, FY11 Q3)
    - Pursuing TPA laser tests of SEGR with IR, NSWC, and NRL. (FY10 Q3, FY11 Q3)
    - Continue data sharing with ESA to aid their studies of energy straggling effects. (FY11 Q1-Q4)

Highlights

Relative Importance of SEGR Mechanisms

Tests controlling for charge ionized in epilayer to expose effects of ion atomic number



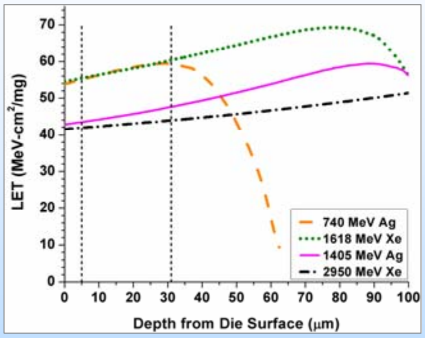


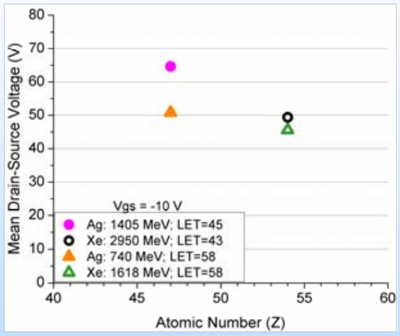
Ion species effects need to be included in efforts to bound the on-orbit risk of SEGR

Highlights

Relative Importance of SEGR Mechanisms

A closer look at silver vs. xenon test results: replotted as a function of ion atomic number





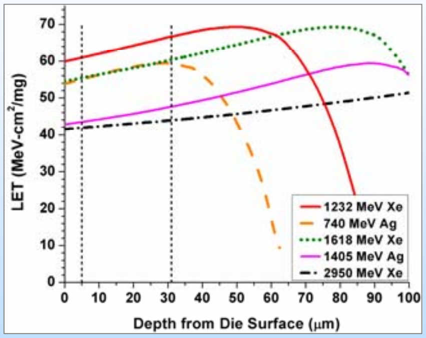
(new abscissa)

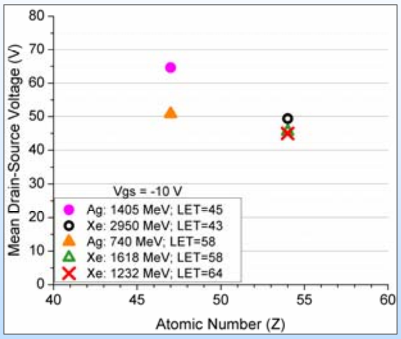
Ion species effects need to be included in efforts to bound the on-orbit risk of SEGR

Highlights

Relative Importance of SEGR Mechanisms

For a given Vgs bias and ion species, a minimum Vds bias is necessary for SEGR in a given device





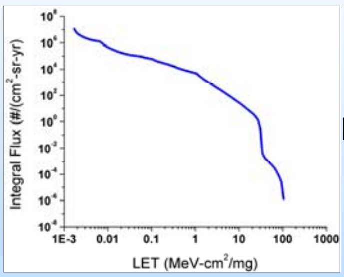
(new abscissa)

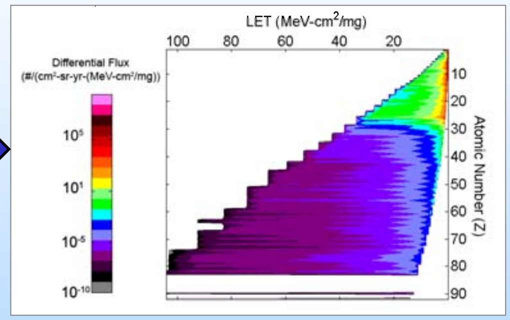
Ion species effects need to be included in efforts to bound the on-orbit risk of SEGR

Highlights

Upper Bound on SEGR Failure Rate

A different way of looking at the potentially hazardous environment: ex/ geostationary orbit (GEO) during solar minimum behind 100 mils Al



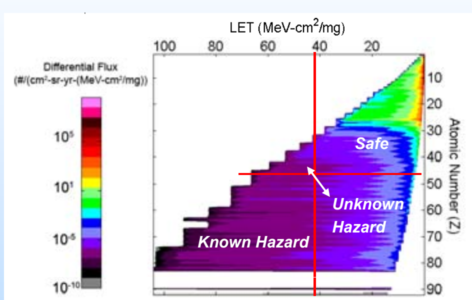


Move from integral flux (Φ) vs. LET to differential flux (ϕ) as a function of Z, LET

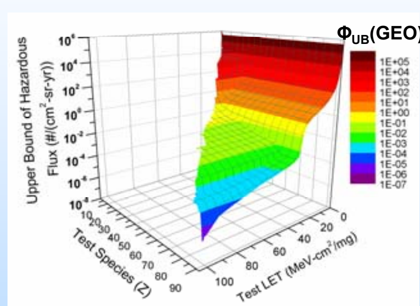
Highlights

Upper Bound on SEGR Failure Rate

Defining the upper bound of hazardous flux at a given orbit for a given safe operating area curve: ex/ GEO at solar min



Environment



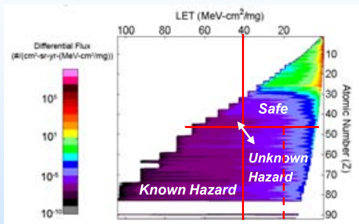
Calculated upper bound of hazardous flux as a function of the test ion species and LET

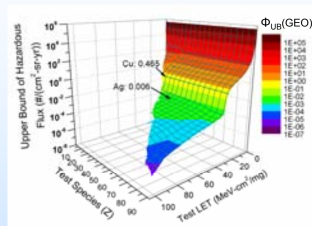
$$\Phi_{UB}(Z_i, LET_i) = \int_1^{92}\int_{LET_{i+\Delta}}^{105} \phi(Z, LET)\,dLET\,dZ + \int_{Z_{i+1}}^{92}\int_{(LET_i/2)}^{LET_i} \phi(Z, LET)\,dLET\,dZ$$

Highlights

Upper Bound on SEGR Failure Rate

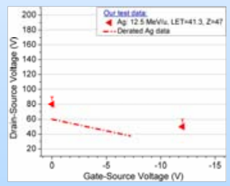
Defining the upper bound of hazardous flux at a given orbit for a given SOA curve: examples

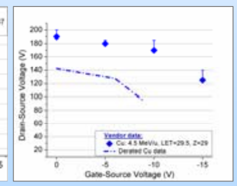




Ex/ Ag test ions:

$$\Phi_{UB}(Z_{47}, LET_{41.3}) = \int_1^{92}\int_{41.3+\Delta}^{105} \varphi(Z,LET)dLETdZ + \int_{48}^{92}\int_{20.7}^{41.3} \varphi(Z,LET)dLETdZ = 0.006\ \text{ions}/(\text{cm}^2 \cdot \text{sr} \cdot \text{yr})$$





$$\Phi_{UB}(Z_i, LET_i) = \int_1^{92}\int_{LET_{i+\Delta}}^{105} \phi(Z,LET)dLETdZ + \int_{Z_{i+1}}^{92}\int_{(LET_i/2)}^{LET_i} \phi(Z,LET)dLETdZ$$

NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop (ETW) 2011.
To be published on nepp.nasa.gov web site.

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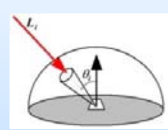
Highlights

Upper Bound on SEGR Failure Rate

Upper Bound on SEGR Failure Rate Defined From Φ_{UB} :

$$\text{Rate}_{UB} = \Phi_{UB} \cdot N \cdot A \cdot 4\pi(1-\cos(\theta)) \cdot f$$

- N = # devices to be flown
- A = SEGR cross-section
  - Gate area of die
- θ = max off-normal angle of incidence of SEGR vulnerability
- f = off-state duty cycle



Current form is overly-conservative.

Next step: Refine inclusion of angular effects

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Highlights

Evaluation of alternative power devices

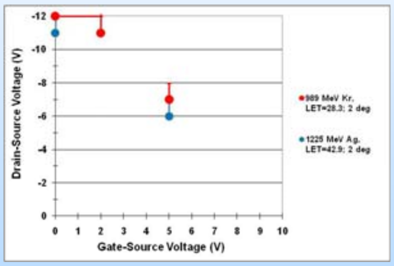
Vishay p-type trenchFET® test results:

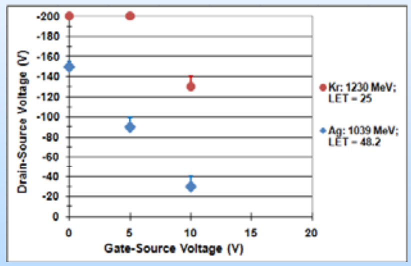
12V pMOS SiB455EDK:

- Failure modes = SEGR and SEB
- Less vulnerable to SEE at angle
- TID hardness >100 krad(Si)

200V pMOS Si7431dp:

- Primary failure mode = SEGR
- Less vulnerable to SEE at angle
- TID hardness to 30 krad(Si)





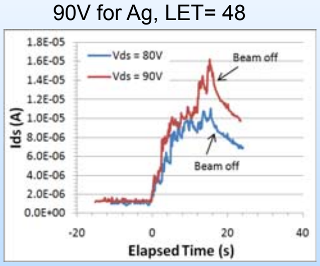
Vishay p-type trenchFETs look promising for space applications

Highlights

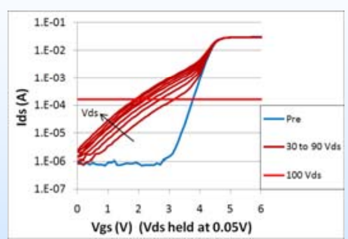
Evaluation of alternative power devices

Vishay n-type trenchFET® test results: 250V SUM45N25

- Failure mode = SEB
- Last pass Vds at 0 Vgs:
  80V for Kr, LET= 25
  90V for Ag, LET= 48



Non-catastrophic dosing at normal (worst-case) incidence



Dose effects from Ag ($3x10^5$ ions/run)

Vishay n-type trenchFET will require further evaluation of dose effects with small angles

FY11 Publications/Proceedings

Interpreting Space-Mission LET Requirements for SEGR in Power MOSFETs

Jean-Marie Lauenstein, *Student Member, IEEE*, Raymond L. Ladbury, *Member, IEEE*, Neil Goldsman, Hak S. Kim, David A. Batchelor, *Member, IEEE*, and Anthony M. Phan

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 57, NO. 6, DECEMBER 2010

Current Single Event Effects Compendium of Candidate Spacecraft Electronics for NASA

Martha V. O'Bryan, Kenneth A. LaBel, Jonathan A. Pellish, Dakai Chen, Jean-Marie Lauenstein, Cheryl J. Marshall, Ray L. Ladbury, Timothy R. Oldham, Hak S. Kim, Anthony M. Phan, Melanie D. Berg, Martin A. Carts, Anthony B. Sanders, Stephen P. Buchner, Paul W. Marshall, Michael A. Xapsos, Farokh Irom, Larry G. Pearce, Eric T. Thomson, Theju M. Bernard, Harold W. Satterfield, Alan P. Williams, Nick W. van Vonno, James F. Salzman, Sam Burns, and Rafi S. Albarian

2010 IEEE RADIATION EFFECTS DATA WORKSHOP PROCEEDINGS

- ***Evaluation of the 0.75 Vds derating factor for VDMOS suggesting it is reasonable for avoiding on-orbit SEGR when applied to higher-energy accelerator test data;***
- ***Report of SEE test results on the TI NexFET^{TM} CSD16403Q5A***

FY11 Presentations

- **J.-M. Lauenstein, *et al.*, "Effects of Ion Atomic Number on Single-Event Gate Rupture (SEGR) Susceptibility of Power MOSFETs," to be presented at the *2011 IEEE Nuclear Space Radiation Effects Conf.*, Las Vegas, NV.**
- **S. Liu, *et al.*, "Effects of Ion Species on SEB Failure Voltage of Power DMOSFET," to be presented at the *2011 IEEE Nuclear Space Radiation Effects Conf.*, Las Vegas, NV.**
- **S. Liu, *et al.*, "Probing the SEB Sensitive Depth Using a Two-Photon Absorption Method," to be presented at the *2011 IEEE Nuclear Space Radiation Effects Conf.*, Las Vegas, NV.**

Plans (FY11/FY12)

- **SEGR modeling**
  - **Refine calculation of upper bound of SEGR failure rate:**
    - Simulation-based angular dependency studies with test validation.
    - TPA laser studies to examine SEGR in absence of direct oxide damage from the heavy ion.
  - **Begin development of a Monte-Carlo-based SEGR response model for failure rate calculations.**
- **Testing**
  - **Cree SiC 1200V VDMOS, SEE testing**
  - **Vishay 250V nMOS TrenchFET®, TID testing**
  - **Semicoa 100V pVDMOS, SEE testing**
  - **Micross SiC 1200V JFET, SEE and TID testing**
  - **TranSiC SiC 1200V NPN BJT, SEE and TID testing**
  - **EPC GaN 200V FET, SEE and TID testing**
  - **Continue/foster relationships with suppliers of power devices potentially suitable for space applications**
- **Continue support of JEDEC/ASTM revisions of Standards and Guidelines**