National Aeronautics
and Space Administration

Single-Event Effects in Silicon Carbide Power Devices

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Outline

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- SEEs in other SiC Power Devices
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  - TranSiC BT1206 – 1200 V, 6 A NPN BJT
- Conclusions

List of Acronyms

Acronym	Definition	Acronym	Definition
BJT	Bipolar junction transistor	PIGS	Post-irradiation gate stress
BVdss	Drain-to-source breakdown voltage	SEB	Single-event burnout
GSFC	Goddard Space Flight Center	SEE	Single-event effects
I_B	Base current (BJT)	SEGR	Single-event gate rupture
I_C	Collector current (BJT)	SiC	Silicon carbide
IEEE	Institute for Electrical and Electronics Engineers	TAMU	Texas A&M University Radiation Effects Facility
JFET	Junction field effect transistor	TID	Total ionizing dose
LBNL	Lawrence Berkeley Nation Laboratory's Berkeley Accelerator Space Effects Facility	V_{BE}	Base-emitter voltage
LET	Linear energy transfer	V_{CE}	Collector-emitter voltage
MOSFET	Metal oxide semiconductor field effect transistor	V_{GS}	Gate-source voltage
NEPP	NASA Electronic Parts and Packaging Program	V_{DS}	Drain-source voltage

Test Facilities

Facility	Ion	Energy (MeV)	LET at Normal Incidence (MeV-cm^2/mg)	Range in Si (µm)
TAMU	Ar	944	5.6	193
	Kr	1914	20.3	136
LBNL	Ar	400	9.7	130
	Kr	886	30.9	113
	Xe	1232	58.8	90

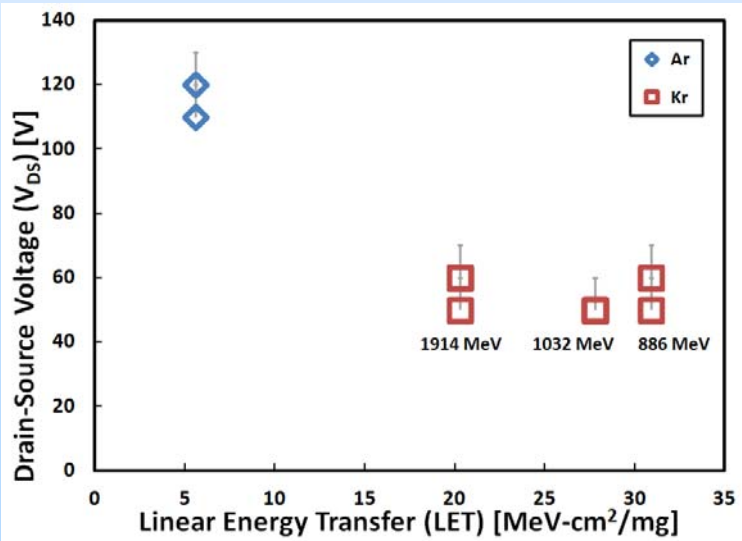
- The fluxes used ranged from $5x10^3$ to $1x10^4$ particles/cm^2-s
- Fluences were the lesser of $3x10^5$ particles/cm^2 or when a failure was observed
- Parts were irradiated off-normal when angular dependences were investigated

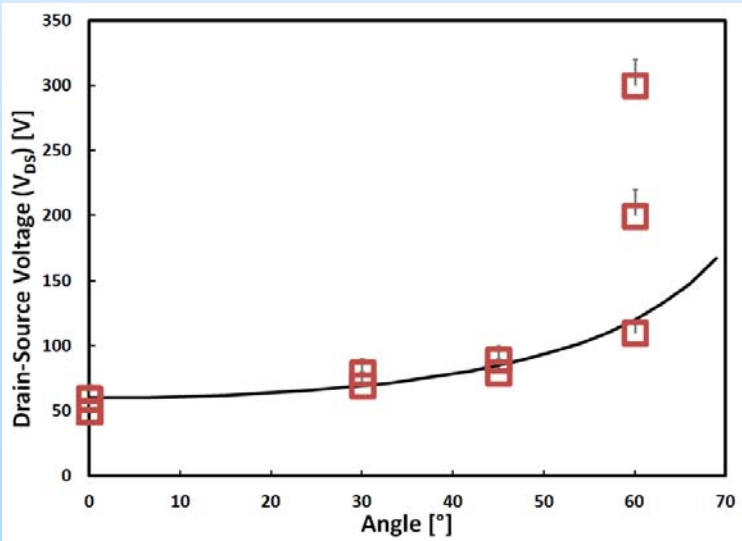
Test Procedure

- Parts are irradiated with heavy ions in the OFF state
  - V_{GS} is held at 0 V and V_{DS} is held constant during the irradiation, and then increased stepwise until a failure is observed
  - V_{DS} is held at 0 V and V_{GS} is constant during the irradiation, and then stepped in the negative direction until a failure is observed
- After each irradiation, a PIGS test was completed for the MOSFETs and the BV_{dss} was measured
  - There are no gate oxides in JFETs or gates in BJTs, so PIGS testing was not conducted on these devices

Cree CMF20120D – 1200 V, 42 A, 80 mΩ n-channel MOSFET

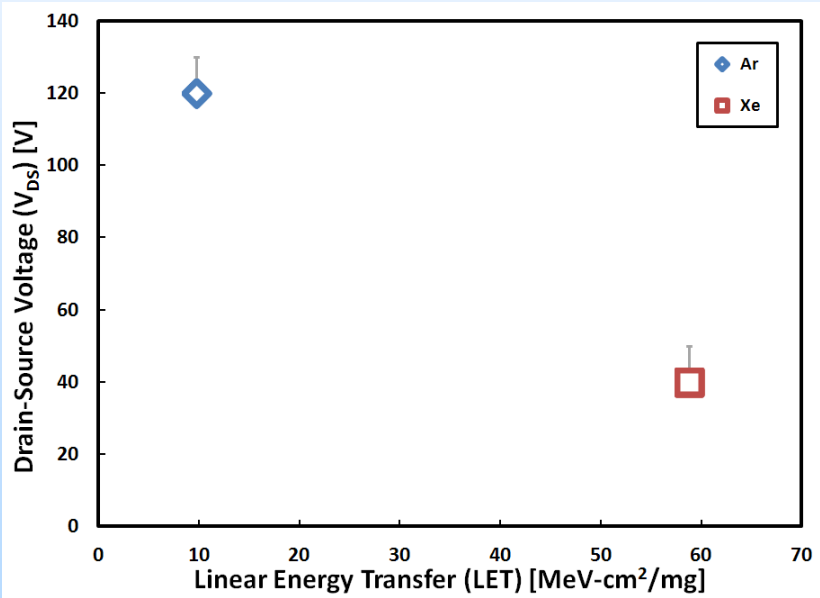
- Irradiated at LBNL and TAMU
- Last passing V_{DS} was 110 V at 944 MeV Ar and 50 V at various energies of Kr (V_{GS} = 0 V)
- No appearance of failure during irradiation
  - During PIGS test gate was found to be broken
  - Large decrease in BV_{dss} was also observed
- Parts follow the cosine law when irradiated at angle
  - Shadowing of die observed at high angles – accounts for large part-to-part variability

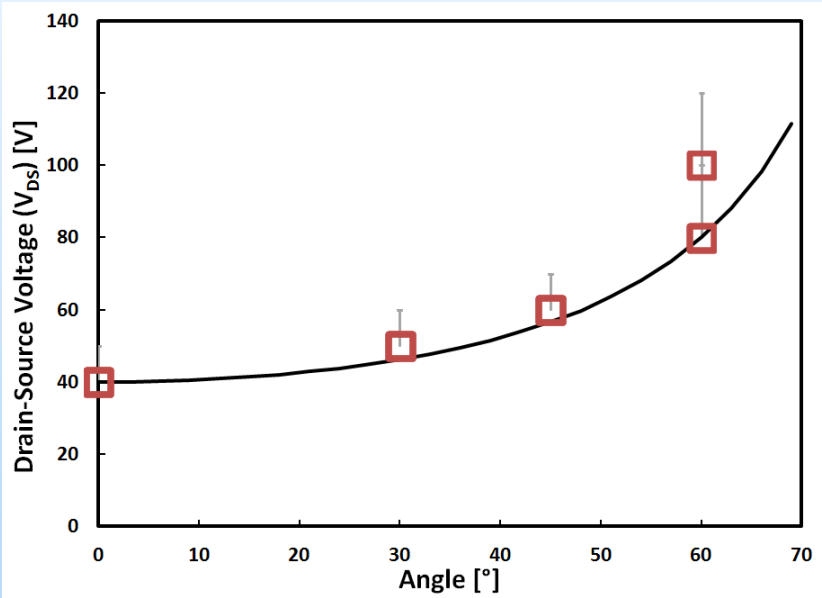




Cree CMF10120D – 1200 V, 24 A, 160 mΩ n-channel MOSFET

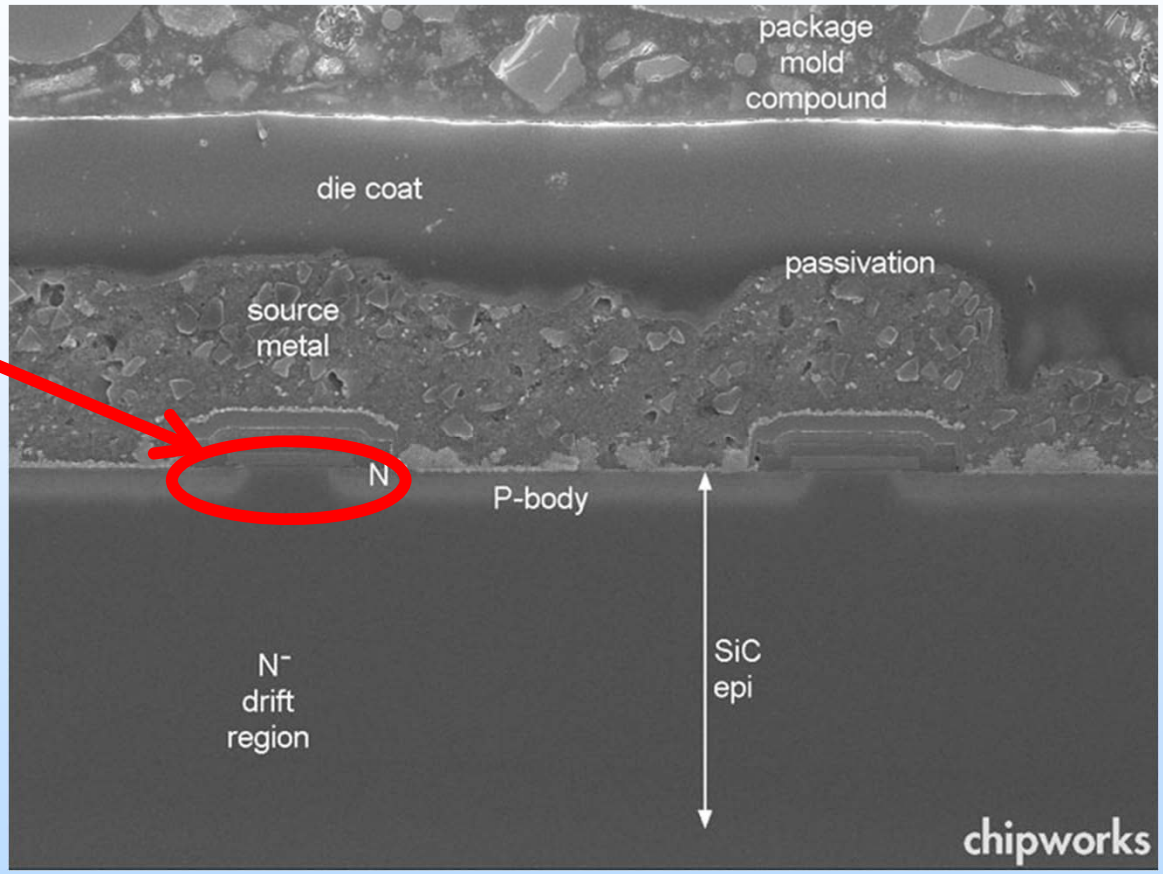
- Irradiated at LBNL
- Last passing V_{DS} was 120 V at 400 MeV Ar and 40 V at 1232 MeV Xe (V_{GS} = 0 V)
  - Similar performance to the CMF20120D





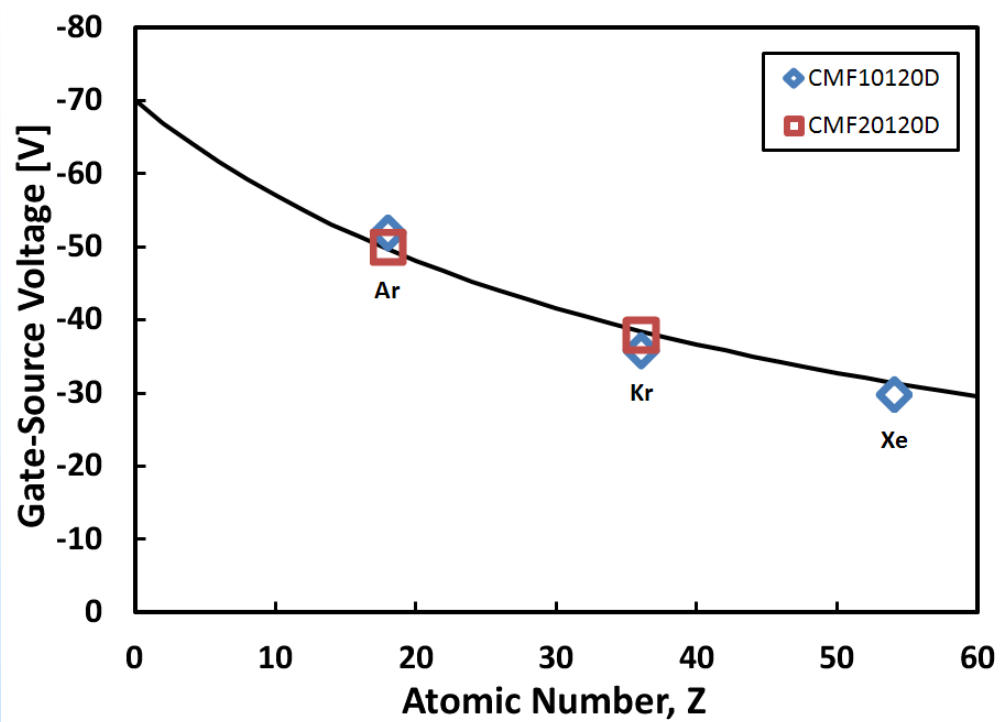
Cree CMF20120D – 1200 V, 42 A, 80 mΩ n-channel MOSFET

Large Neck Width



Chipworks Technology Blog, "Inside Cree's SiC Power MOSFET";
http://www.chipworks.com/blog/technologyblog/2012/03/05/inside-crees-sic-power-mosfet/

Cree CMF20120D and CMF10120D



$$V_{gs(crit)} = \frac{10^7 \times t_{ox}}{1 + \frac{Z}{44}}$$

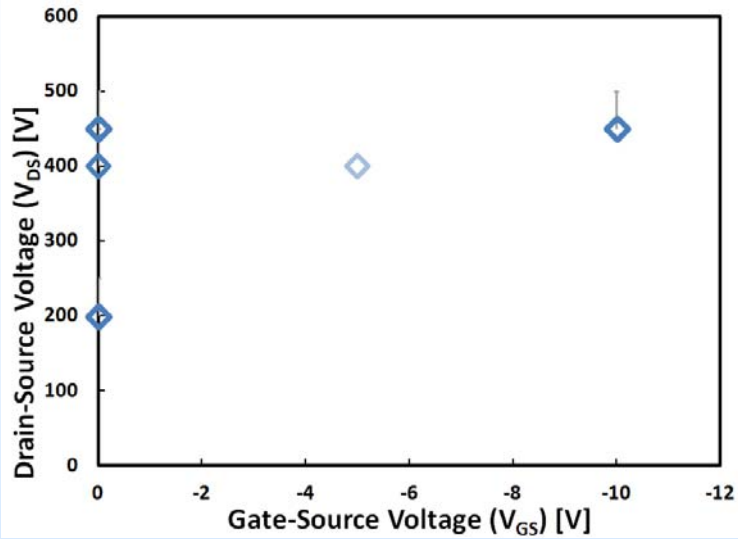
- $V_{gs(crit)}$ → critical V_{gs} for SEGR with V_{ds} = 0V
- t_{ox} → gate oxide thickness (70 nm [2-4])
- Z → atomic number

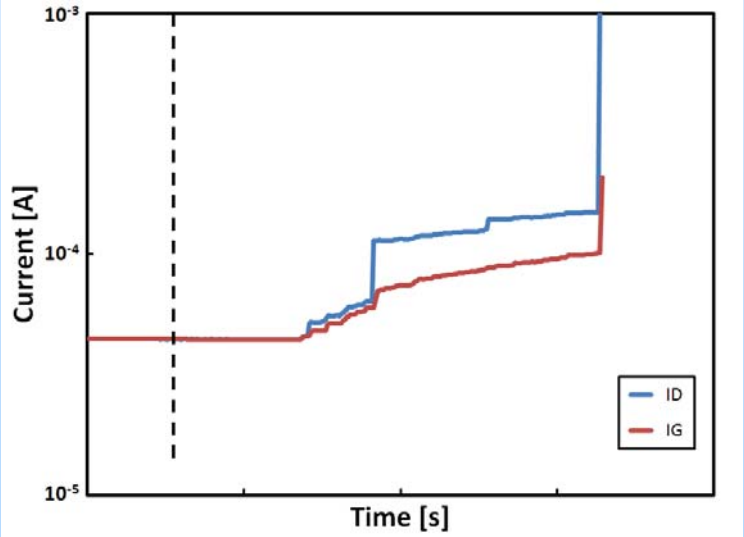
- Parts show good correlation with Titus-Wheatley[1] formula for the critical field in the gate oxide necessary for gate rupture
- Failures more likely due to large neck width than to differences in oxide qualities between SiC and Si MOSFETs

[1] J. L. Titus, IEEE TNS, 1998.
[2] S.K. Dixit, IEEE TNS, 2006
[3] C.X. Zhang, IEEE TNS, 2011
[4] A. Akturk, IEEE TNS, 2012.

SemiSouth SJEP120R100 – 1200 V, 100 mΩ Normally-Off Trench JFET

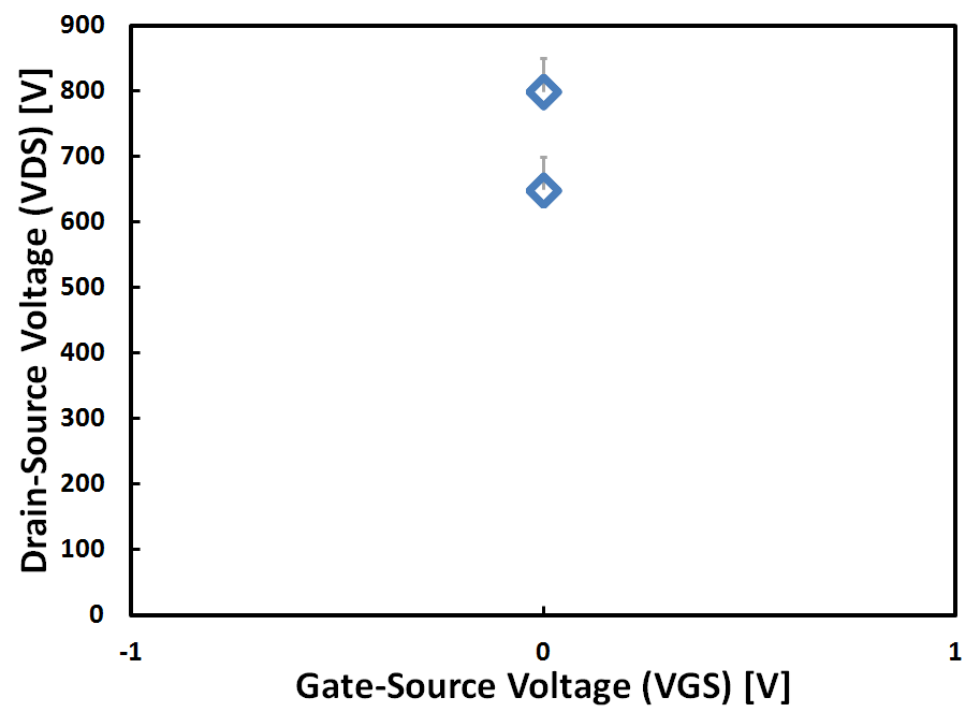
- Irradiated at TAMU
- Last passing V_{DS} (V_{GS} = 0V) was 400-450 V for all values of V_{GS} tested
- Failure was observed during irradiation
- Large decrease in BV_{dss} was observed



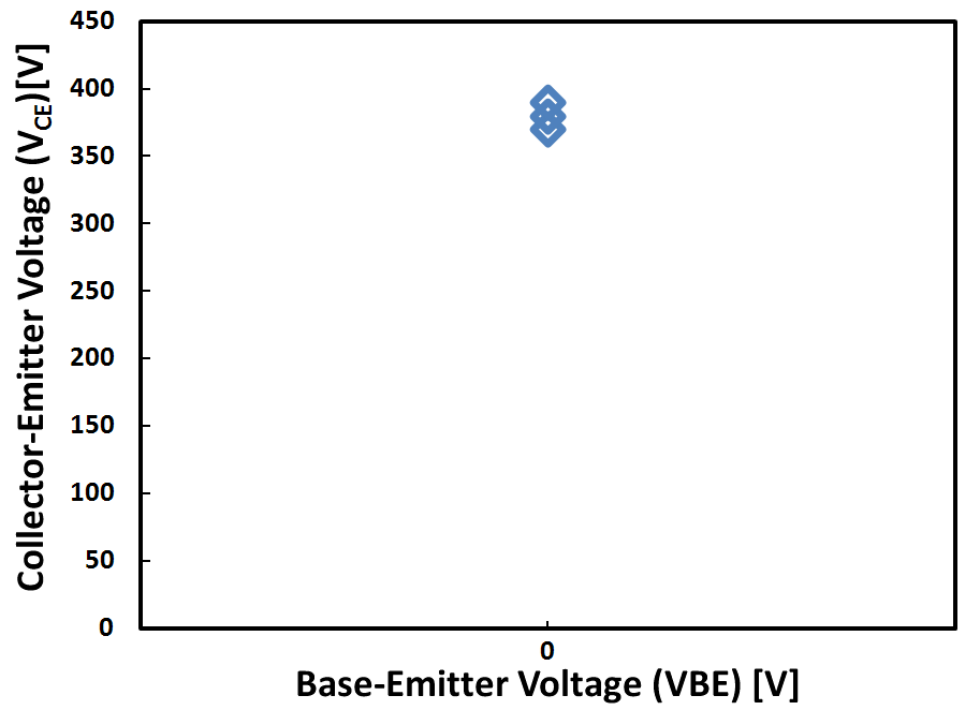


SemiSouth SJEP170R550 – 1700 V, 550 mΩ Normally-Off Trench JFET

- Irradiated at TAMU
- Last passing V_{DS} (V_{GS} = 0V) was 650 V at 400 MeV Ar
- Failure was observed during irradiation
- Large decrease in BV_{dss} was observed



TranSiC BT1206 – 1200 V, 6 A NPN BJT



- Irradiated at TAMU
- Last passing V_{CE} at 1914 MeV Kr was 360 V
- Failure was observed during irradiation

Conclusions

- SiC devices show high TID tolerance, but low SEE tolerance
  - Must be improved for use in space
  - Similar challenges occurred initially in TID-hardened Si MOSFETs
  - Hardening requires a trade-off in electrical performance

- SiC MOSFETs failed due to single-event gate rupture, whereas JFETs and BJTs exhibited failures due to SEB