Single-Event and Radiation Effect on Enhancement Mode Gallium Nitride FETs

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Abstract--This paper presents responses of the latest MiGaN FETs to space radiation conditions. The new MiGaN has shown radiation tolerance to 1Mrad TID and SEGR and SEB immunity at LET of 85Mev/(mg/cm2) as well as immunity to displacement damage and Low dose (ELDRs) testing.

I. Introduction

Enhancement-mode gallium nitride (eGaN®*) transistors have been commercially available for over four years. In that time they have enabled significant efficiency improvement in commercial DC-DC converters in a variety of topologies and at a variety of power levels [1]. Enhancement-mode transistors from Efficient Power Conversion Corporation (eGaN FETs) used in Microsemi MiGaN™ FETs have also been demonstrated to have remarkable tolerance to gamma radiation [2] and single event effects (SEE) [3]. In September 2013, a new generation of eGaN FETs was introduced that was designed for high power density, multi-megahertz DC-DC conversion. In this paper we present new results characterizing the stability of these new improved eGaN devices under radiation exposures.

As this is a relatively new technology an introduction of the eGaN device structure will be beneficial for future reference. eGaN devices based on EPC process and design are fabricated on a silicon wafer for process compatibility with today silicon manufacturing as well as cost. A thin layer of aluminum Nitride (AlN) is grown on the silicon to provide a seed layer for the subsequent growth of a gallium nitride Heterostructure.

A Heterostructure of aluminum gallium nitride (AlGaN) and then GaN is grown on the AlN. A thin layer of AlGaN layer is grown on top of the highly resistive GaN creating a strained interface between the GaN and AlGaN crystal layers.

This interface combined with the intrinsic piezoelectric nature of the GaN, creates a two dimensional electron gas (2DEG) which is filled with highly mobile and abundant electrons [4]. Further processing of a gate electrode forms a depletion region under the gate. The FET can be turned on by applying a positive bias to the voltage to the gate similar to a N-Channel MOSFET fig.1 show a typical I-V curve of a 40V MGN2915. Additional layers of metal are added to route the electrons to the gate, drain and source terminals as shown by the device cross section fig.2. This structure is repeated many times to form a power device similar to a power LDMOS layout.

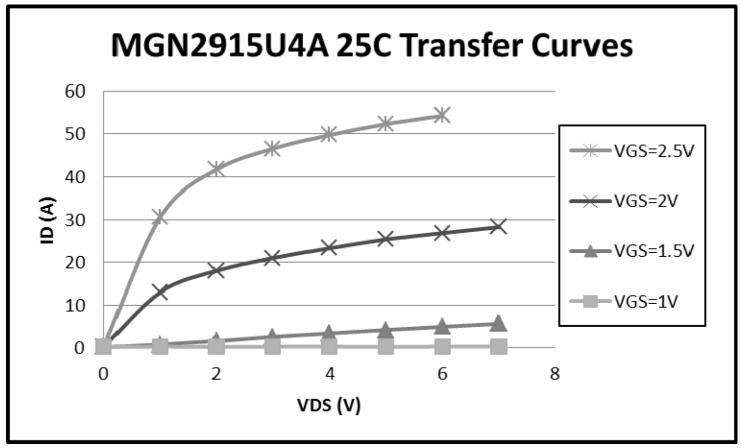

Fig. 1. Typical IV Curves for MGN2915

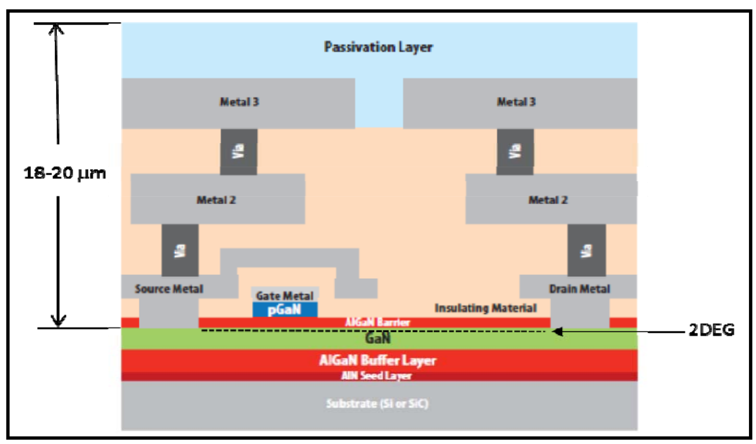

Fig. 2. eGaN FET cross section

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I. EXPERIMENTAL METHODS

Total Ionizing Dose Testing:

TID tests were performed in the "Gamma Cave" at the University of Massachusetts, Lowell. The devices were subjected to a total gamma dose of 1 MRads (Si) at a dose rate of 96 Rads (Si)/sec. A ^{60}Co source was used and all testing was according to MIL-STD-750, Method 1019. Two different test conditions were used. The first test condition biased the drain-source at 80% of rated $V_{DS(MAX)}$ also referred as the "OFF" state with the gate grounded. The second test condition also referred as the "ON" state biased the gate-source at 5 V and the drain grounded.

Low Dose Testing (ELDRs):

Low dose testing was performed at Microsemi on our new JL Shepherd 484 irradiator with a Dual-Hemisphere Cobalt-60. The dual- hemisphere irradiator is capable of a 10mRad (Si)/sec and 100mRad (Si)/sec Low-Dose-Rate gamma simultaneously. The samples were subjected to a total dose of 100kRad (Si) at 100mRad (Si)/sec under three test conditions.

-The ON state with 5V on the gate with the drain and source grounded.

- The OFF state with drain-source at 80% of rated $V_{DS(MAX)}$ with the gate shorted

- Un-biased this condition has shown to have an effect on other technology such as bipolar transistor.

Neutron Testing:

The devices were exposed to neutrons at the University of Massachusetts Lowell 1 MW Research Reactor using the Fast Neutron Irradiation (FNI) facility. This facility was specifically designed to provide an intense fast neutron flux (up to 9E10 n/cm^2-sec 1 MeV Si equivalent) with high beam uniformity (+/- 10%) over a broad area of approximately 500 cm^2. Gamma shielding and thermal neutron filtering are also incorporated into the facility to eliminate gamma (TID) effects and minimized sample neutron activation. The gamma dose associated with a 1E13 1 MeV (Si) n/cm^2 exposures was approximately 1.33 krad (Si), while the fast to thermal neutron ratio was approximately 400:1.

The samples were irradiated in the well characterized portion of the FNI, with all leads grounded in accordance to MIL-STD-750 TM1017. Samples were removed after each exposure point was reached. Sulfur dosimetry was used to verify that each level achieved its desired exposure.

Single Event Effects (SEE) Testing:

SEE Testing is used to quantify the effects of ionizing radiation on electronic devices. Heavy-ion testing of third-generation MiGan™ FETs was performed at the Texas A&M cyclotron following MIL-STD-750E, METHOD 1080. Fig. 3 shows a block diagram of the test setup used during the SEE testing. The FTI1000 ATE is connected to a switch matrix with separate connections for the gate, source and drain to the laptop via a DSB cable. The test equipment is control by software which manages the setting of drain, gate and sources as well as performing the pre-electrical test and post stress measurement including the Post In situ Gate Stress (PIGS) test.

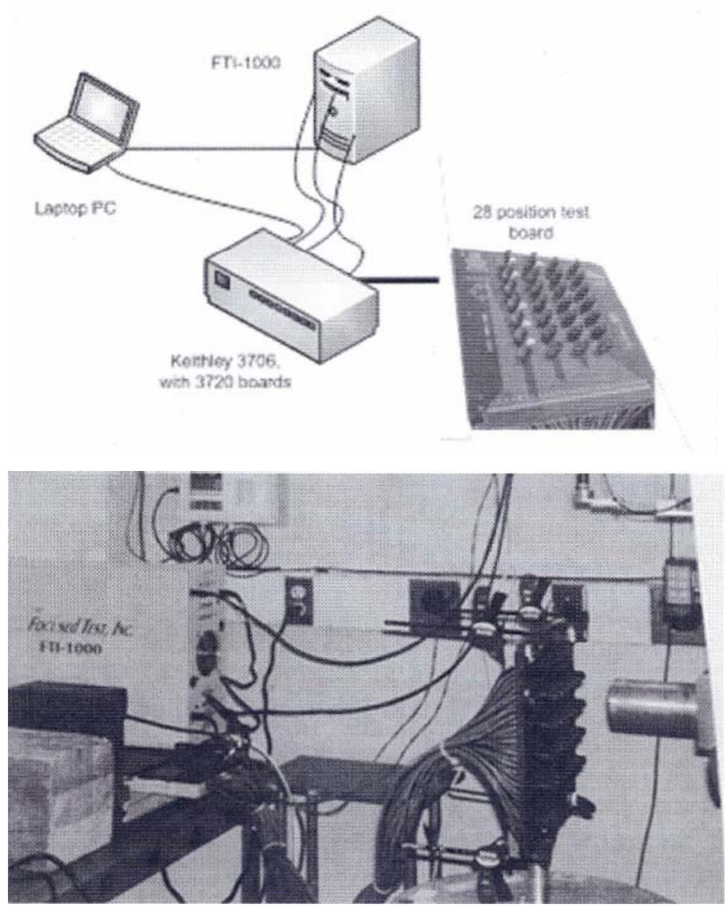

Fig. 3. Block diagram and actual setup at TAMU

Device Tested:

The table below shows the devices tested as well as the radiation screening along with the test conditions performed.

Table I. Summary of the MiGaN device tested

Part Number	BV	Facility	SEE	TID HD	ELDRs	Neutron
MGN2915	40V	TAMU	15 Mev/u Kr,Xe, Au			
MGN2910	200V					
MGN2915	40V	UMASS Lowell		700 KRad 88rad/sec		
MGN2901	100V					
MGN2910	200V					
MGN2915	40V	Microsemi			100Krad 100mRad/sec	
MGN2915	40V	UMASS Lowell				$1x10^{12}$ $1x10^{13}$ $1x10^{15}$

III. RESULTS

Total ionizing Dose Testing:

The devices showed a small threshold shift post 100kRad TID and stabilized up to 700kRad. The devices were within the datasheet specification. With no dielectric beneath the gate for these eGaN FETs, this immunity to TID was expected. Fig 4-6 shows the leakage and threshold response over high dose exposure for the 40V, 100V and 200V eGaN FETs.

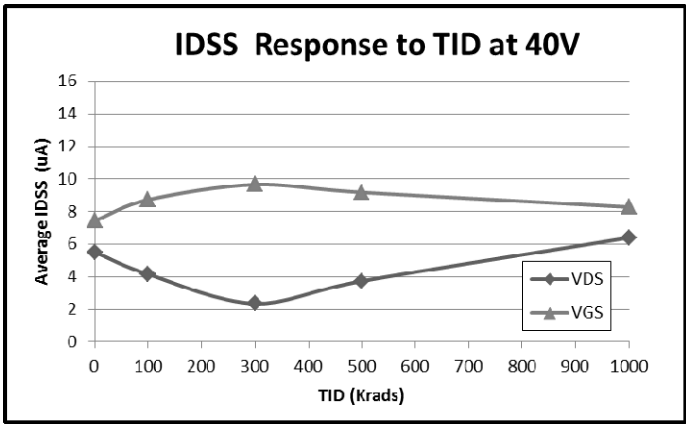

Fig 4.a. MGN2915 Idss response to TID Spec<10uA

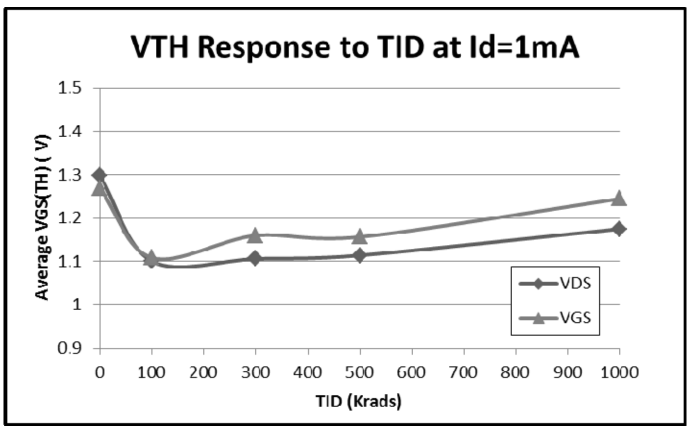

Fig. 4.b MGN2915 threshold response to TID
Spec $0.7<V_{TH}<2.0$

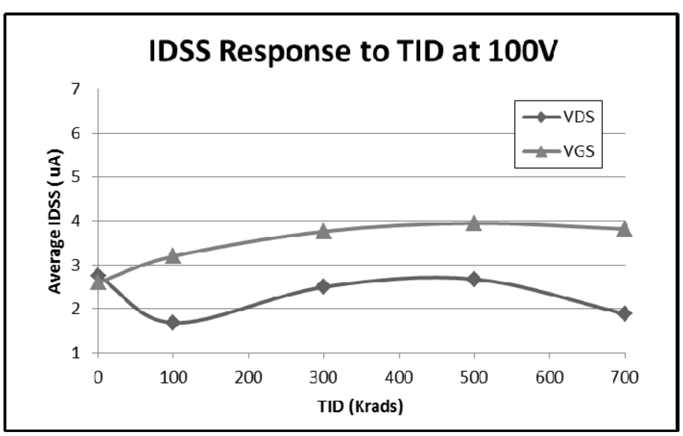

Fig 5.a. MGN2901 Idss response to TID Spec<10uA

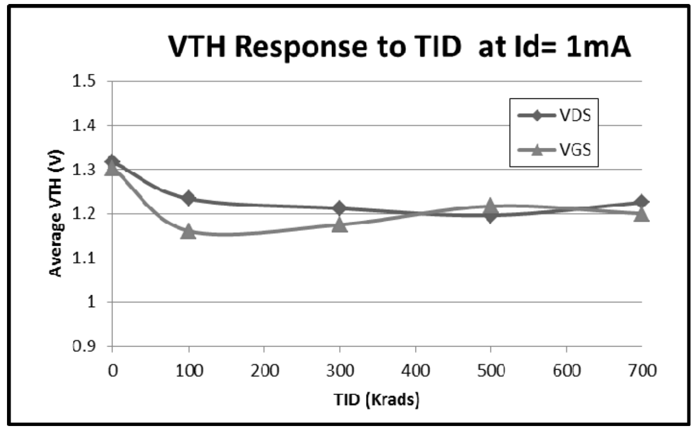

Fig 5.b. MGN2901 threshold response to TID
Spec $0.7<V_{TH}<2.0$

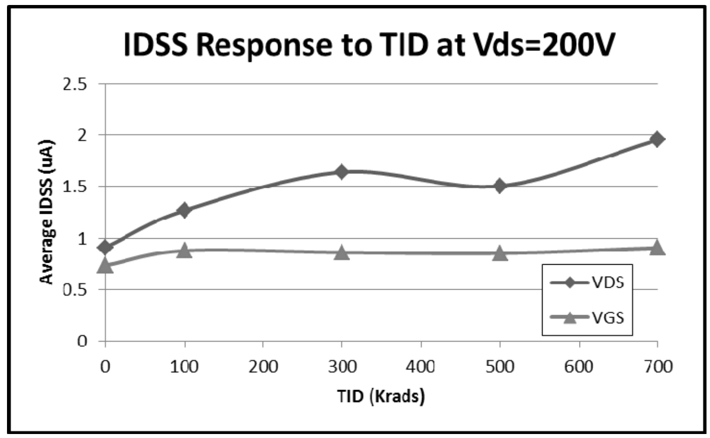

Fig 6.a. MGN2910 Idss response to TID Spec<10uA

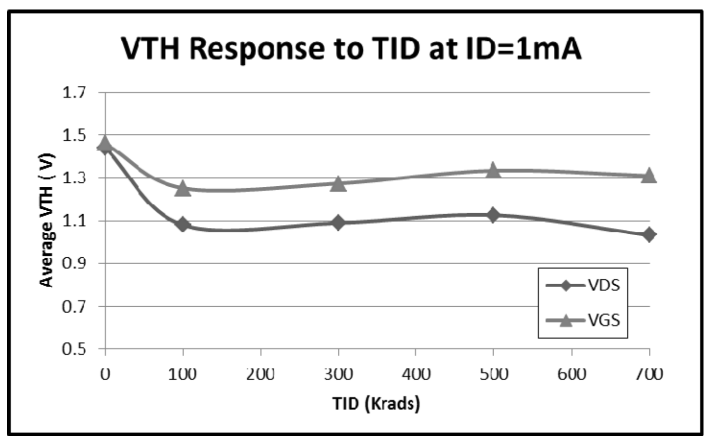

Fig 6.b. MGN2910 threshold response to TID
Spec $0.7<V_{TH}<2.0$

Neutron Testing:

As expected the MiGaN devices tested under Fast Neutron Irradiation did not exhibit any parameter shifts post neutron exposures up to 1e15 fluence. The minimum energy to displace GaN atoms is much larger than Si and GaAs and therefore did not seem to affect the 2DEG layer. Figures 7.a-d show the pre and post response of the MGN2915 (40V). The pre and post data point for each fluence level is from a different sample and not suggesting the devices improve with higher fluence .

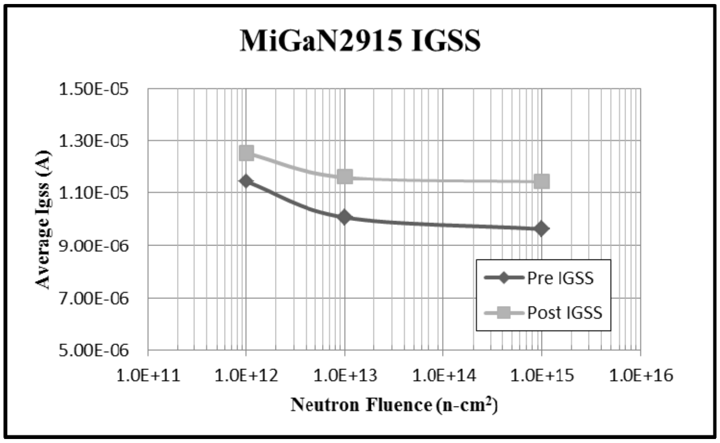

Fig 7.a. I_{GSS} response of MGN2915 Package

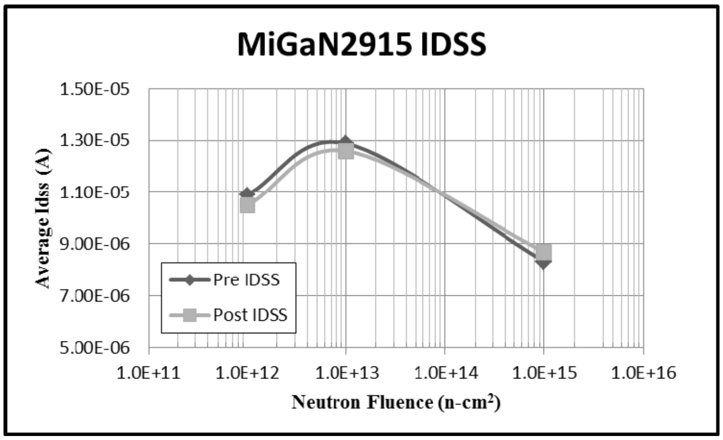

Fig 7.b. I_{DSS} response of MGN2915 in a TO-39 Package

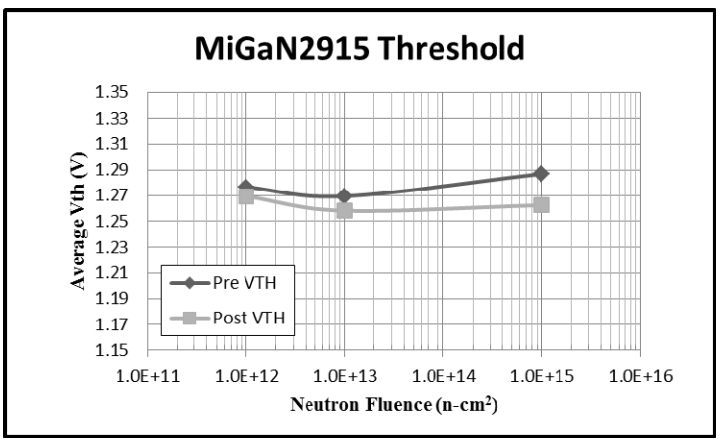

Fig 7.c. V_{TH} response of MGN2915 in a TO-39 Package

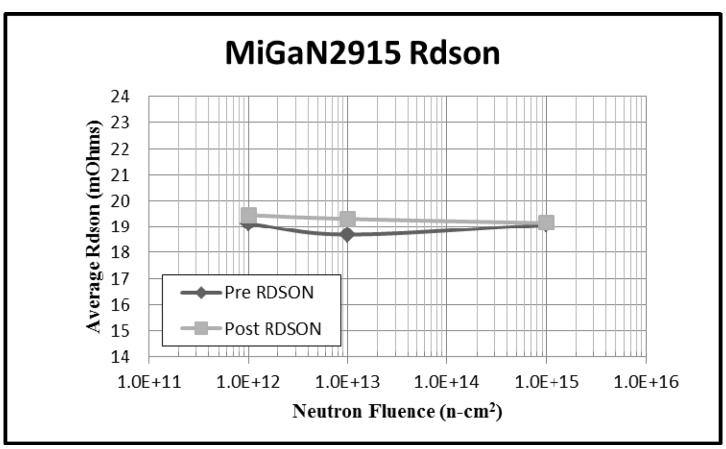

Fig 7.d. $R_{DS(on)}$ response of MGN2915

Low Dose Testing (ELDRs):

Some minor shifts were observed during low dose testing. Fig 8.b shows a decrease in leakage in the unbiased sample, but is probably due to tester equipment.

Fig 8.c. shows a decrease in threshold voltage sample across all conditions, but still remaining within device specification up to 100kRad. This small shift in threshold could be similar to the one observed during the high dose exposure. It will be verified in further testing by carrying the exposure beyond 100kRad.

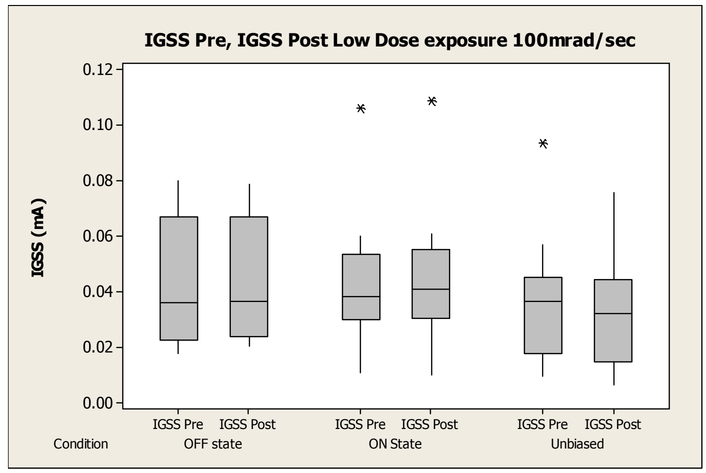

Fig 8.a. I_{GSS} response to ELDRs MGN2915

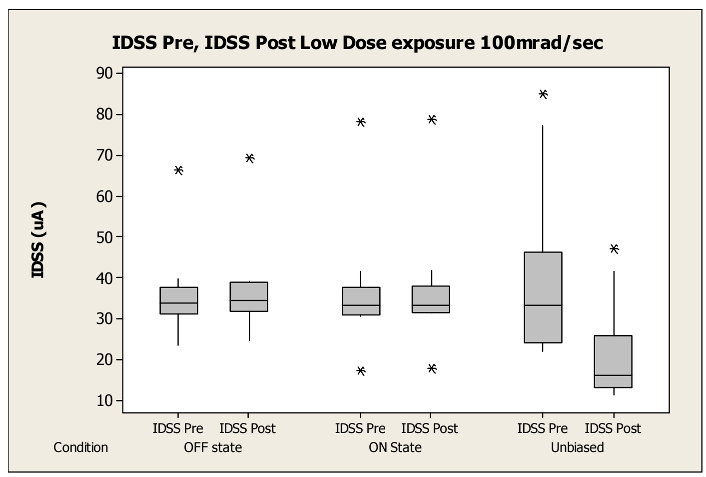

Fig 8.b. I_{DSS} response to ELDRs MGN2915

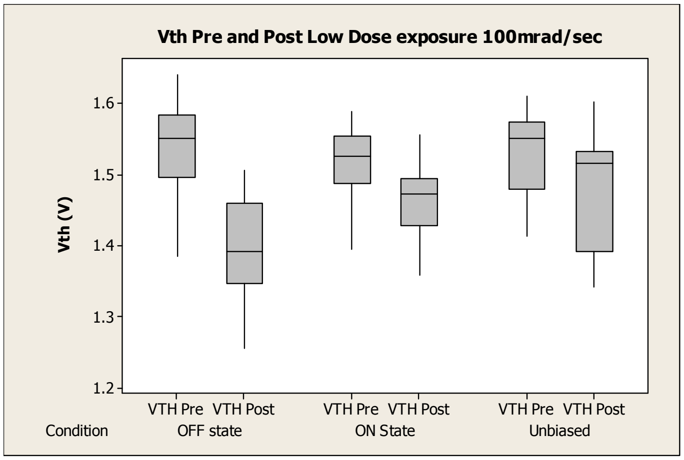

Fig 8.c. V_{TH} response to ELDRs MGN2915

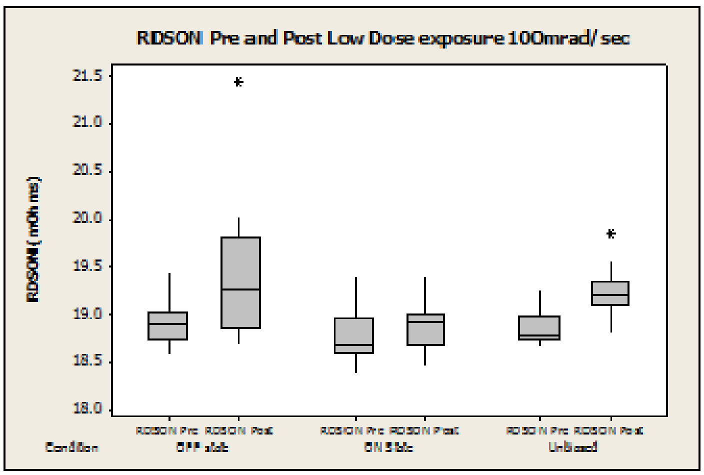

Fig 8.d. $R_{DS(on)}$ response to ELDRs MGN2915

Single Event Effects (SEE) Testing:

Being a lateral device, the worst case beam condition was at normal incidence with the highest surface LET. The Bragg peak was targeted to be near the 2DEG layer. The MGN2910 200V device did not show any shift in BV_{DSS} voltage with Kr and Xe ions. A decrease to 180V was observed with Au ions when the Bragg peak was positioned near the 2DEG layer. Fig. 9.a shows the SEE SOA. The MGN2915 40V device was extremely stable to its full rated V_{DS}, showing no degradation under worst condition and high fluence. Fig. 9.b shows the SEE SOA response. The new process improvements made to the third generation of MiGaN has shown the devices to be near immune to single event exposure.

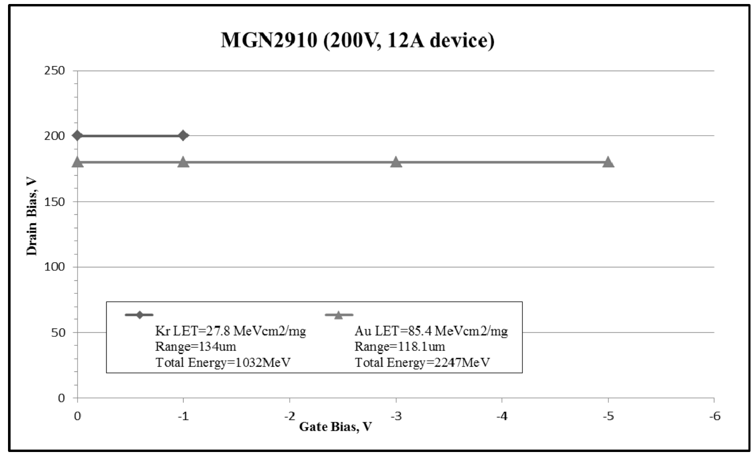

Fig. 9.a. MGN2910 SEE SOA curve under worst condition

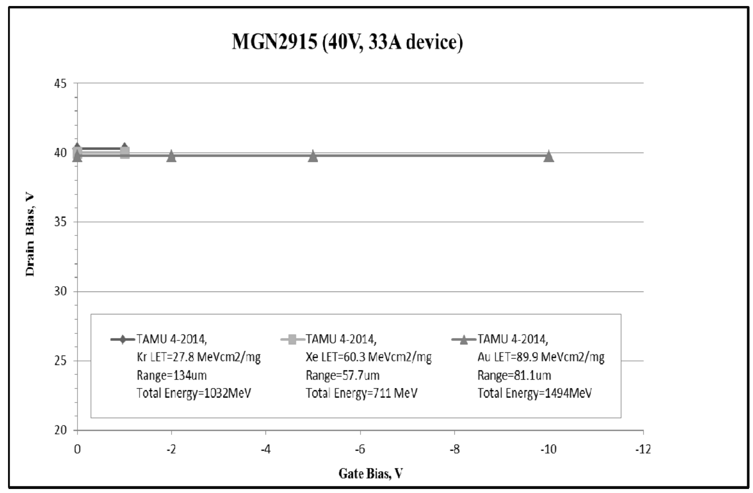

Fig. 9.b. MGN2915 SEE SOA curve under worst condition

IV. CONCLUSION

The new and third generation MiGaN devices manufactured by EPC for Microsemi HiRel space have demonstrated high radiation tolerance under TID, ELDRs, SEE and displacement damage.

Further radiation testing will be performed in the coming year such as; angle testing, higher fluence, and low-dose testing across all the voltage platforms.

IV. ACKNOWLEDGMENT

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V. REFERENCES

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