GaN in Space Applications

Gallium nitride power device technology enables a new generation of power converters in space operating at higher frequencies, higher efficiencies, and greater power densities than ever achievable before. GaN power devices can also exhibit superior radiation tolerance compared with Silicon MOSFETs depending upon their device design. **Max Zafrani, CTO, EPC Space; Alex Lidow, CEO Efficient Power Conversion, USA**

Here we discuss the capabilities of GaN devices which have been specifically designed for critical applications in the high reliability or commercial satellite space environments. Some of the failure mechanisms in GaN and how they impact radiation performance are explored. Lastly, the electrical performance of radiation hard GaN transistors is compared with the most popular radiation hardened (Rad Hard) MOSFETs in the market.

Radiation in space

There are three primary types of radiation experienced by semiconductors used in space applications. Regardless whether devices are being employed in satellites orbiting around our earth or incorporated in exploration satellites visiting the most distant parts of our solar system, all experience some form of high-energy radiation bombardment. These types of radiation are gamma radiation, neutron radiation, and heavy ion bombardment.

An energetic particle can cause damage to a semiconductor in fundamentally three ways; it can cause traps in non-conducting layers, it can cause physical damage to the crystal, also called displacement damage, or the particle can generate a cloud of electron-hole pairs that will cause the device to momentarily conduct, and possibly burn out in the process.

In eGaN devices, energetic particles cannot generate momentary short-circuit conditions because mobile hole-electron pairs cannot be generated. Thus, this article will focus on the first two failure mechanisms ? trapping and physical damage.

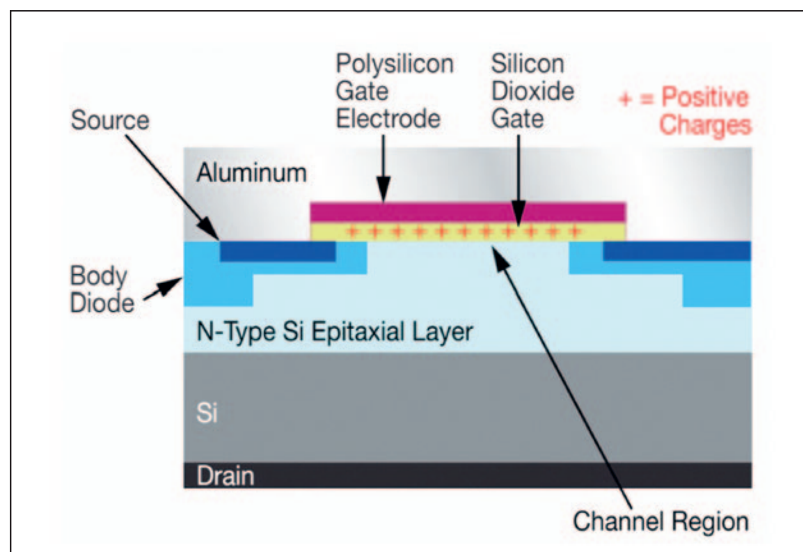
Gamma radiation in Silicon MOSFETs

Gamma radiation consists of high energy photons that interact with electrons. Figure 1(a) is a cross section of a typical Silicon MOSFET. It is a vertical device with the source and gate on the top surface and the drain on the bottom surface. The gate electrode is separated from the channel region by a thin silicon dioxide layer.

In a Silicon-based MOSFET, the gamma radiation knocks an electron out of the Silicon dioxide layer leaving behind a positively charged 'trap' in the gate oxide. The positive charge reduces the threshold voltage of the device until the transistor goes from normally off – or enhancement mode – to normally on, which is a depletion mode state. At this point the system will need a negative voltage to turn the MOSFET off. Typical ratings for rad-hard devices range from 100 kRads to 300 kRads. In some cases, devices can be made to go up to 1 MRad, but these tend to be very expensive.

Gamma radiation in enhancement mode GaN transistors

Enhancement mode GaN devices are built very differently from Silicon MOSFETs. As shown in Figure 1(b), all three terminals; gate, source, and drain, are located on the top surface. As in a



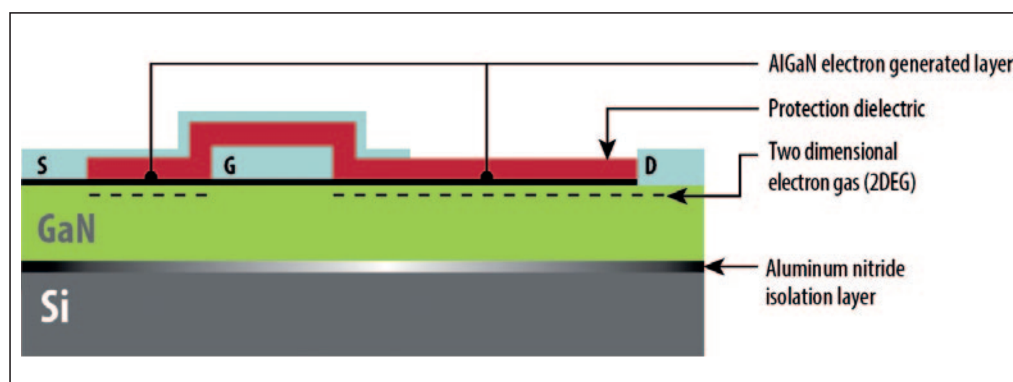


Figure 1 (above right): Cross section of a typical Silicon MOSFET (a) and cross section of a typical enhancement mode GaN (eGaN®) device (b) (right)

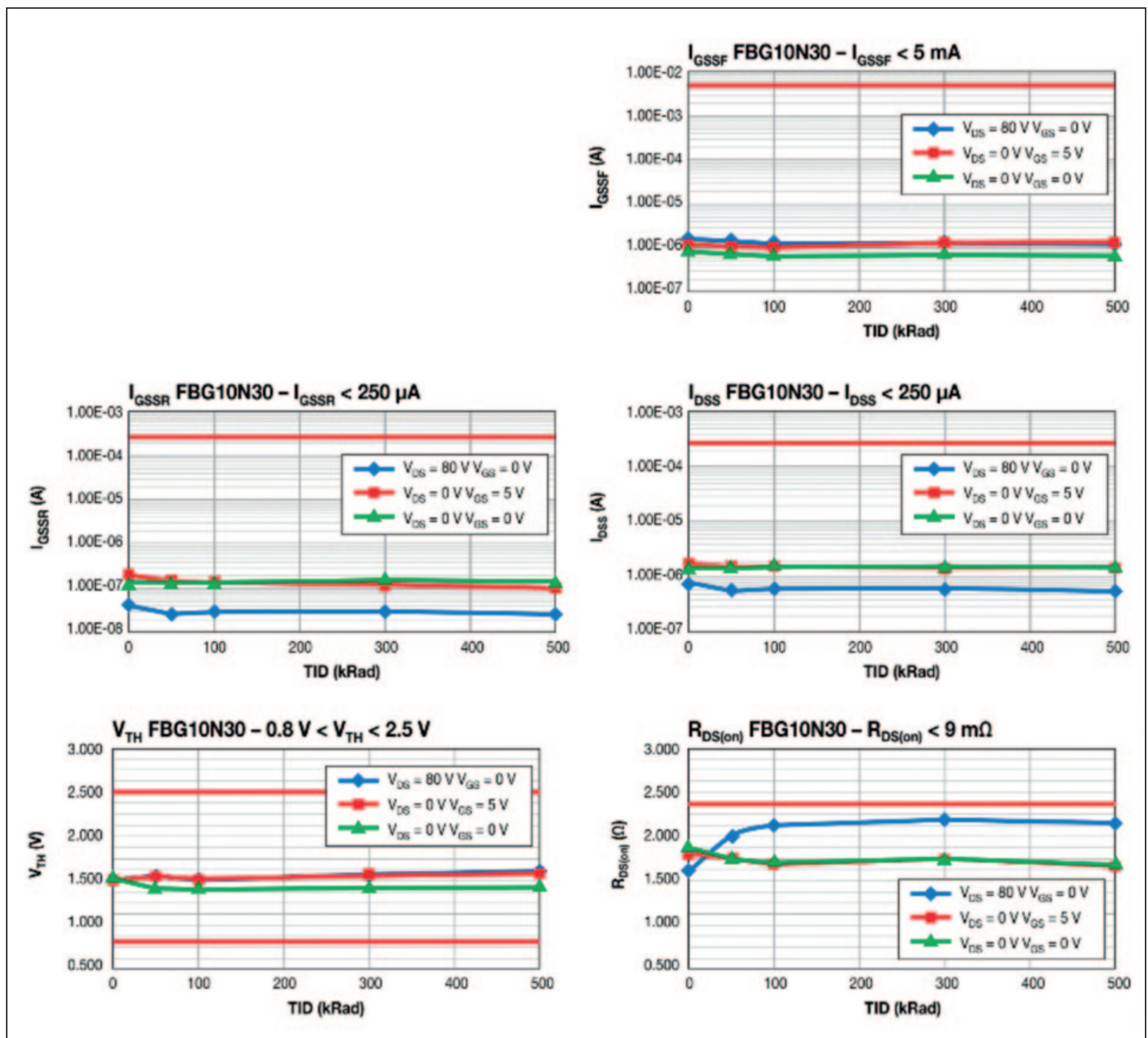


Figure 2: Results of gamma radiation testing of eGaN devices to 500 kRads

Silicon MOSFET, conduction between source and drain is modulated by biasing the gate electrode from zero volts to a positive voltage – usually 5 V. In enhancement mode GaN devices the gate is separated from the underlying channel by an aluminum gallium nitride layer. This layer does not accumulate charge when subjected to gamma radiation.

As an example of the performance of Rad Hard GaN devices, 100 V GaN-on-Si transistors were subjected to 500 kRad of gamma radiation. Throughout the testing, leakage currents from drain to source and gate to source, as well as the threshold voltage and on-resistance of the devices at various checkpoints along the way were measured, confirming that there are no significant changes in device performance. Since the initial testing, these same GaN devices have been subjected to 50 MRads, confirming that enhancement mode GaN devices built as in Figure 1(b) will not be the first part to fail due to gamma radiation in any space system. Testing results are shown in Figure 2.

Neutron radiation

The primary failure mechanism for devices under neutron bombardment is displacement damage. High energy neutrons will scatter off atoms in the crystal lattice and leave behind lattice defects. Figure 3 shows the impact of neutron radiation at doses up to 1 x 10^{15} per cm^2 impact of neutrons on the GaN crystal and the entire device structure is minimal.

The reason for GaN's superior performance under neutron radiation is that GaN has a much higher displacement threshold energy compared with Silicon. The displacement energy of a crystal is proportional to the bond strength of the crystalline elements. The bond energy between gallium and nitrogen is significantly higher than the bond energy between Silicon atoms in a Silicon power MOSFET.

Single Event Effects in Si MOSFETs

Single Event Effects (SEE) are caused by heavy ions generated by the impact of galactic cosmic rays, solar particles or energetic neutrons and protons. This can be simulated terrestrially by using a cyclotron to create beams of different ions. Two of the most common ions used to evaluate radiation tolerance of electronics components are Xenon, with a linear energy transfer (LET) of about 50 MeV·cm^2/mg, and gold, with an LET of about 85 MeV·cm^2/mg.

In a Silicon MOSFET there are two primary failure mechanisms caused by these heavy ions, single event gate rupture (SEGR) and single event burnout (SEB). SEGR is caused by the energetic atom causing such a high transient electric field across the gate oxide that the gate oxide ruptures. Whereas SEB is caused when the energetic particle transverses the drift region of the device where there are relatively high electric

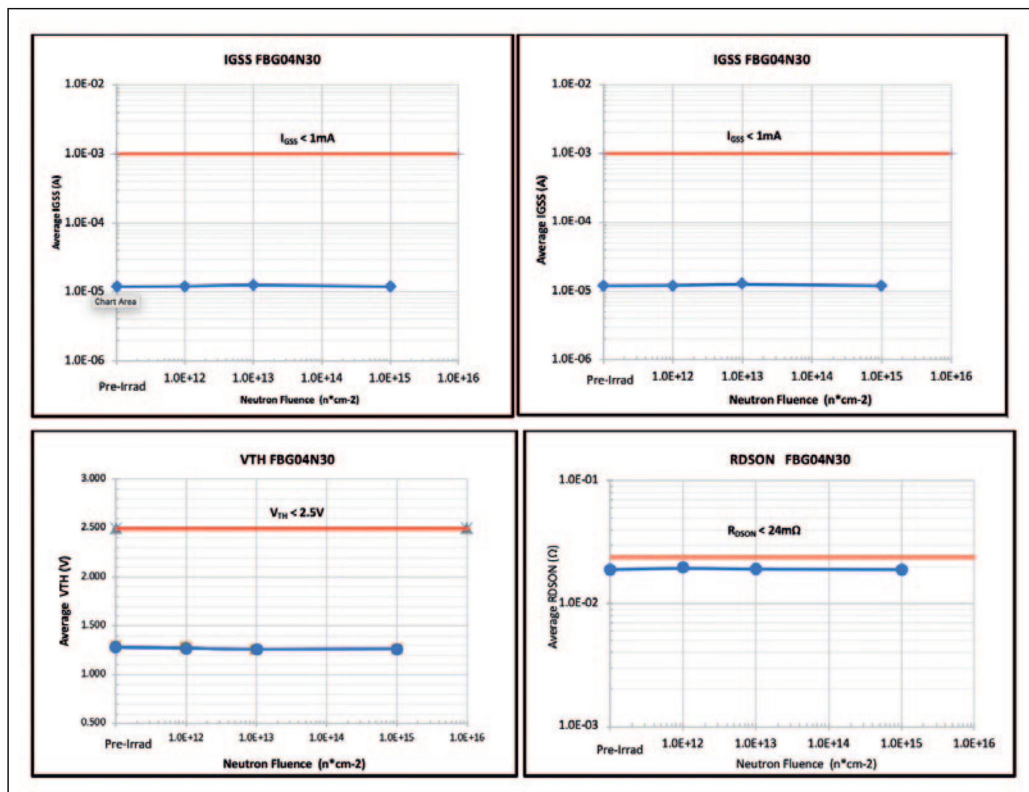


Figure 3: Impact of neutron radiation on eGaN devices at doses up to 1 x 10^{15} per cm^2

fields. The energetic particle loses its energy while generating a large number of hole electron pairs.

These hole electron pairs crossing the drift region cause the device to momentarily short circuit between drain and source. This short circuit can either destroy the device, which is a single event burnout, or the device can survive, appearing as a momentary short circuit that can cause damage to other components in the system. This latter case is call single event upset, or SEU.

Single Event in GaN devices

Since enhancement mode GaN devices built as in Figure 1 do not have a gate oxide, they are not prone to single event gate rupture. Also, since eGaN devices do not have the ability to conduct large numbers of holes very efficiently, they are not prone to single event upset.

The primary failure mechanism for enhancement mode GaN devices under heavy ion bombardment is caused by energetic particles crossing the drift region of the device where there are relatively high electric fields. The conditions are about the maximum conditions possible, with an 85 LET beam of gold atoms pummeling the device biased at the maximum data sheet limit. In testing, the gate leakage does not go up during bombardment. The drain-source leakage, however, does start to rise as the displacement damage from the heavy ions increases.

SEE Safe Operating Areas

Many specially produced enha ncement mode GaN transistors have been tested for SEE under varied conditions. 40 V and 100 V product did not fail under any conditions up to full rated voltage and 87 LET. Figure 4 shows the results from several commercially available FBG20N18 200 V products and FBG30N04 300 V products. For the 200 V products, the first failures occurred at 85 LET and 190 V, as

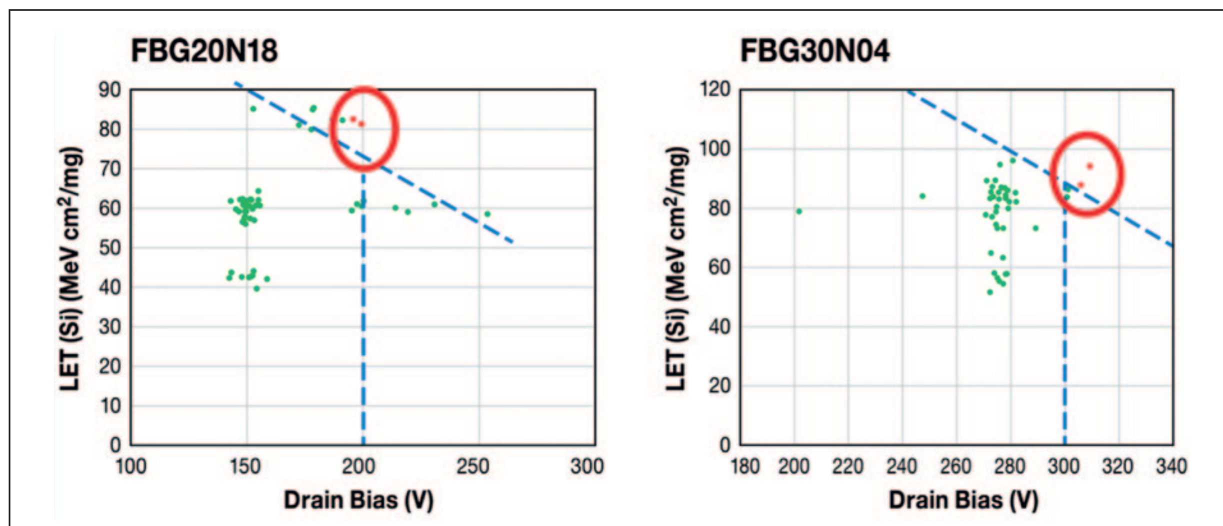


Figure 4: Results from several FBG20N18 200 V products (left) and FBG30N04 300 V products (right)

100 V

Parameter	FBG10N30	IRHNA67160	Units
I_D	30	35	A
I_{DM}	120	140	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	9	18	mΩ
Q_G	9	160	nC
Q_{GD}	2	65	nC
Q_{RR}	0	1.9	µC
$R_{θJC}$	2.12	0.5	°C/W
Radiation Level	>10 M	300 k	Rad (Si)
SEE at 85 LET	100	100	V
Size	23	236	mm²

Parameter	FBG10N05	IRHNJ67130	Units
I_D	5	22	A
I_{DM}	40	88	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	38	42	mΩ
Q_G	2.2	50	nC
Q_{GD}	0.6	20	nC
Q_{RR}	0	3	µC
$R_{θJC}$	3.6	1.67	°C/W
Radiation Level	>10 M	300 k	Rad (Si)
SEE at 85 LET	100	100	V
Size	12	78.5	mm²

200 V

Parameter	FBG20N18	IRHNA67260	Units
I_D	18	56	A
I_{DM}	72	224	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	26	28	mΩ
Q_G	6	240	nC
Q_{GD}	1.95	60	nC
Q_{RR}	0	11.7	µC
$R_{θJC}$	2.12	0.5	°C/W
Radiation Level	>10 M	300 k	Rad (Si)
SEE at 85 LET	175	170	V
Size	23	236	mm²

Parameter	FBG20N18	IRHNJ67230	Units
I_D	18	16	A
I_{DM}	72	64	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	26	130	mΩ
Q_G	6	50	nC
Q_{GD}	1.95	20	nC
Q_{RR}	0	3.5	µC
$R_{θJC}$	2.12	1.67	°C/W
Radiation Level	>10 M	300 k	Rad (Si)
SEE at 85 LET	175	170	V
Size	23	78.5	mm²

Table 1: Electrical performance comparisons of Rad Hard eGaN transistors against popular power MOSFETs

shown in the red circle on the left. The FBG30N04 300 V product failed at 85 LET and 310 V as shown in the red circle on the right.

Electrical performance comparison

In addition to the superior Rad Hard advantages of gallium nitride over Silicon, GaN has superior electrical performance as well. As an example, the electrical performance comparisons of 100 V and 200 V Rad Hard eGaN transistors against Rad Hard power MOSFETs are shown in Table 1.

The 100 V FBG10N30 packaged part has half the on-resistance compared to the Silicon MOSFET, yet is but one-tenth the size and has about one-twentieth the gate and gate-drain charges that determine switching speed. In addition, the radiation resistance is significantly higher.

At 200 V, the difference in electrical performance of the GaN transistors is even greater. Note that the GaN device listed on the left side of the 200 V section of Table 1 has similar on-resistance to its MOSFET counterpart, yet is one-tenth the size, and has about 30 times better switching performance while demonstrating superior radiation resistance.

Conclusion

In summary, GaN power transistors and ICs are the best choice for power conversion applications in spaceborne systems. Enhancement mode GaN devices have proven to be more rugged than Rad Hard MOSFETs when exposed to various forms of radiation. In addition, the electrical performance of GaN devices is many times superior to the aging Silicon power MOSFET.

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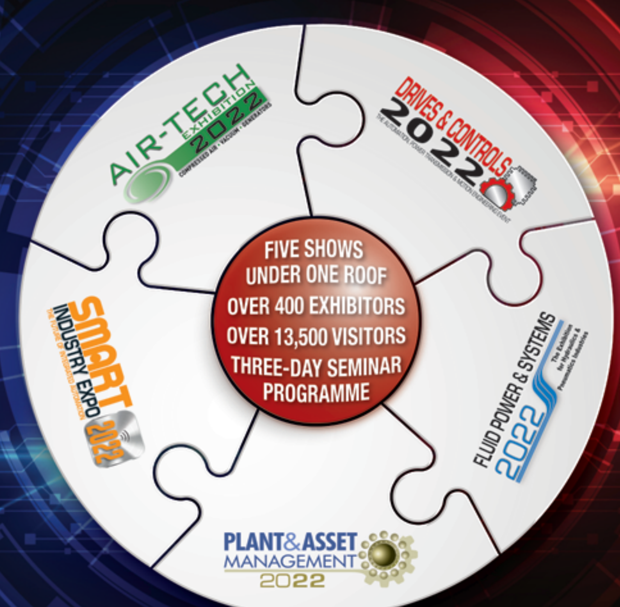

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