Microelectronics Reliability 68 (2017) 13–20

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Commercial-off-the-shelf algan/gan hemt device reliability study after exposure to heavy ion radiation

B.S. Poling [a,*], G.D. Via [a], K.D. Bole [c], E.E. Johnson [c], J.M. McDermott [b]

[a] *Air Force Research Laboratory, Sensors Directorate, Wright-Patterson, AFB, OH, United States*
[b] *Wyle, Dayton, OH, United States*
[c] *Air Force Research Laboratory, Space Vehicles Directorate, Kirtland, AFB, NM, United States*

ARTICLE INFO

Article history:
Received 15 July 2016
Received in revised form 26 September 2016
Accepted 27 September 2016
Available online 1 October 2016

Keywords:
Gallium Nitride (GaN)
High Electron Mobility Transistors (HEMTs)
Reliability
Heavy Ion

ABSTRACT

The reliability of commercial-off-the-shelf (COTS) GaN HEMTs was studied after irradiation using heavy ions of Neon (Ne), Silicon (Si), and Argon (Ar). Devices were exposed to heavy ions at a flux of ~$1.8e^4$ ions/cm^2-*sec* to a fluence of $1.5e^5$ ions/cm^2 and DC characterization measurements taken immediately after exposure exhibited no change. Additionally, no change in device performance was observed in DC or RF characterization taken prior to RF stress testing. Infrared (IR) and electroluminescence (EL) characterization was conducted before irradiation, post irradiation, and following stress testing to assess changes in emissions. After heavy ion exposure, irradiated devices and non-irradiated devices were subjected to an RF stress test at an elevated baseplate temperature. Results imply the irradiated devices degraded at a different rate than the non-irradiated device which suggests potential for confounding effects on long term reliability from heavy ion exposure. Future studies should be conducted using larger sample sizes and different radiation sources to determine if additional stress testing is required for GaN HEMT space qualification.

Published by Elsevier Ltd.

1. Introduction

GaN high electron mobility transistors (HEMTs) have advantages over competing RF amplifier technologies in output power, bandwidth, and efficiency [1]. GaN HEMTs show promise to replace GaAs technology in microwave applications due to their higher power densities and better efficiency in a smaller periphery than GaAs devices [2]. Satellite communications [1], satellite broadcasting, weather forecasting [3], and the global positioning system (GPS) utilize microwave circuits. With multiple applications and performance improvements over leading alternatives, GaN technology is an ideal candidate for space-based system insertion. Investigations are being conducted to explore if GaN HEMTs can be used in space environments [3]. This adaptation of GaN into space-based systems requires qualification methods for space applications.

Preliminary research into radiation effects on GaN technology suggest GaN is very radiation tolerant and requires high levels of exposure to effect changes [4–7]. In one study, the devices were subjected to proton irradiation at fluences up to 6×10^{14} cm^{-2} that resulted in a decrease in mobility and decrease carrier concentration from charged traps [4]. In another study [5], GaN HEMTs were subjected to proton irradiation at fluences up to 1.2×10^{14} cm^{-2} that resulted in a shift in threshold voltage (V_{th}) and increased 1/f noise. In [6], heavy ion testing utilizing Xenon (Xe) was performed to compare different indications of single event effects (SEE) and single event burn-out (SEB) between DC and RF bias at targeted flux of 15 ions/cm^2-*sec* up to a fluence of $5e^5$ ions/cm^2. The resulting specific drain bias for performance degradation was > 100 V higher than what would typically be seen in RF applications. In [7], heavy ion testing using Neon (Ne), Argon (Ar), Krypton (Kr), and Xenon (Xe) at energy levels ranging from 74 to 443 MeV [7] were conducted that resulted in higher drain-gate leakage and higher drain-source leakage. The published works highlight the high levels of radiation required to induce changes in device performance. However, given there are changes in device performance due to radiation, an assessment of the impact on long term reliability of devices exposed to typical earth orbit radiation levels should be considered.

Recent articles, such as [8] highlight the potential for commercially available GaN devices to be space qualified and ready for insertion into space-based systems. This report highlights the use of NASA EEE-INST-002 Level 1 reliability and performance standards as the guideline for testing and qualification. Level 1 dictates that radiation hardness should be reviewed and radiation testing performed if data is not available [9]. The instructions detail that a part can be qualified if it follows specific testing, or has a history of performance in the field, or is similar to a part that is qualified with manufacturer defined “minor differences” [9]. Testing defined for transistor qualification is specified as

---

[*] Corresponding author.
E-mail address: brian.poling.2@us.af.mil (B.S. Poling).

http://dx.doi.org/10.1016/j.microrel.2016.09.017
0026-2714/Published by Elsevier Ltd.

Table 1
Heavy Ions and energy used during radiation exposure.

Device	Ion	LET (MeV-cm^2/mg(Si))	Flux ions/cm^2-sec	Fluence ions/cm^2
1, 5	Neon	3.49	$1.87e^4$,$1.75e^4$	$1.0e^5$
2, 4	Silicon	6.09	$1.1e^4$,$1.8e^4$	$1.0e^5$
3	Argon	9.74	$1.6e^4$	$1.0e^5$

intermittent operation life testing, accelerated steady-state life testing, and steady-state life testing [9]. The document does not specifically state qualification methods for GaN HEMTs nor does it discuss the potential of long term studies after radiation exposure. This highlights the need to research qualification methods covering reliability after or during exposure to radiation.

This paper describes the execution of heavy ion testing on COTS GaN devices, stress testing of both irradiated and non-irradiated devices, and investigation of any synergistic effects on GaN HEMT reliability from heavy ion exposure. This research attempts to begin answering questions about whether or not heavy ion radiation exposure induces different degradation modes than what has been observed in non-irradiated devices and can this methodology be used as a possible step towards defining space qualification procedures for GaN HEMTs.

2. Test Setup and Devices

The devices used were COTS GaN HEMTs purchased from a third party distributor. The GaN HEMTs chosen were S-band 10 W RF power devices utilizing a 28 V quiescent drain voltage and source connected field plate. A total of 10 parts were tested (5 irradiated and 5 non-irradiated). The devices were grown on a SiC substrate with an AlGaN barrier and a GaN buffer utilizing a commercial process. Each die was packaged in a 2 flange, screw-down package using eutectic die attach. Since the devices were purchased from a third party distributor, no knowledge is available regarding if the HEMTs are from the same wafer lot or even the same wafer. This implies that the devices are picked at random and only meet the spec sheet data requirements; ensuring a complete blind test.

Each device was electrically characterized by measuring a suite of current-voltage family of curves (IV-FOC), transfer curves, gate and drain leakage curves, static on resistance (Ron), and large signal RF gain compression characteristics all at a $T_{bp} = 60C$. A subset of devices received EL and IR characterization utilizing a Quantum Focus Instruments (QFI) test unit.

Heavy ion testing was conducted at the Lawrence Berkley National Laboratory's (LBNL) Berkeley Accelerator Space Effects (BASE) facility; more information can be located here [10]. Heavy ions used were Ne, Si, and Ar in a 10 MeV/nucleon energy "cocktail" and their respective Linear Energy Transfer (LET) [Table 1]. Devices were exposed while under DC and RF bias inside a vacuum chamber pumped down to 1 mTorr and held at a baseplate (T_{bp}) = 22C.

Stress testing was conducted on an Accel-RF Automated Accelerated Reliability Test Stand (AARTS) at an elevated $T_{bp} = 200C$ under RF biased at Vdq = 28 V, Idq = 55.6 mA/mm, $P_{in} = 26dBm$, and frequency = 3.5GHz. The test duration was 1000 h or parametric failure (a change in output power by 1 dB or a change in drain current of 20%). All DC, RF, and stress testing was performed in a dark enclosure with dry nitrogen being fed in to control the environment.

Below is a list of each step of operation during the testing process:

- Pre DC/RF characterization at AFRL.
- De-lidding of devices to be irradiated.
- Additional DC/RF characterization.
- Subset of de-lidded devices received IR and EL characterization.
- LBNL onsite DC characterization before irradiation.
- Heavy Ion Exposure [Table 1].
- LBNL onsite DC characterization after irradiation.
- Post irradiated device DC and RF characterization at AFRL.
- Same subset of de-lidded devices received post IR and EL characterization.
- Pre stress DC and RF characterization.

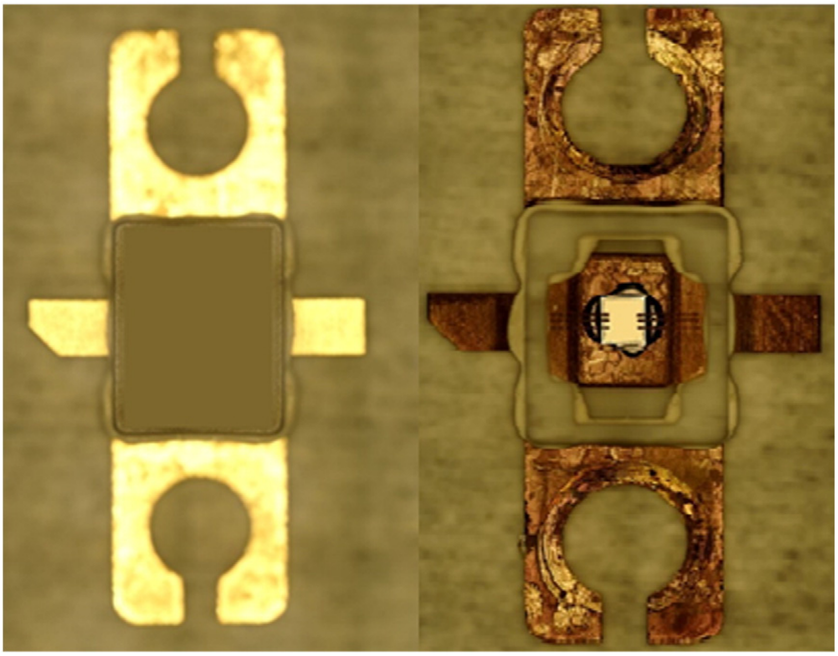

Fig. 1. Before and after delidding of heavy ion exposed devices. Color difference of package is from different light settings on camera used.