GaN Reliability Enhancement and Technology Transfer Initiative (GREAT^2)

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***Abstract* - This document summarises the work of the "GaN Reliability Enhancement and Technology Transfer Initiative" (GREAT^2 project, ESTEC contract. no. 21.499/08/NL/PA). The reliability of investigated GaN HEMT and GaN MMIC processes has been enhanced by orders of magnitude compared to the status at the beginning of GREAT^2. Reliability now exceeds 20 years at 230 °C peak channel temperatures for the UMS GH50-10 power bar and GH25-10 MMIC processes respectively. European GaN technology is now ready for space evaluation and first insertion in space.**

***Index Terms* – AlGaN/GaN, GaN-HEMT, GaN-MMIC, reliability, RF life test, radiation, SEE, SEB, hydrogen sensitivity, space**

I. INTRODUCTION

The wide bandgap semiconductor Gallium-Nitride (GaN) is a key strategic enabling technology for space that has the potential to provide an order of magnitude improvement in RF output power compared to conventional semiconductor technologies. GaN is inherently radiation hard and tolerates higher bus-voltages as well as higher operational temperatures. These characteristics promise to disrupt today's state of the art design for space affecting Telecommunications, Navigation, Earth Observation and Science missions. However, prior to the start of this project there was no GaN component supply chain existing in Europe to satisfy the needs of space industry. Manufacturing processes were not mature and little information on reliability limits and radiation effects was available. Therefore, in 2008, ESA launched the "GaN Reliability Enhancement and Technology Transfer Initiative" (GREAT^2) to address these issues.

The main objective of GREAT^2 has been to undertake space focused optimisation, reliability enhancement and validation of GaN HEMT and MMIC technology, addressing specific space related issues (e.g. radiation environment, hydrogen sensitivity) and the establishment of space compatible GaN HEMT and GaN MMIC foundry processes at United Monolithic Semiconductors (UMS).

The following processes were considered:

- UMS GH50-10, 3-inch diameter wafer, 0.5 µm gate length, GaN-on-SiC HEMT process (operation < 6 GHz, for L-, S- and C-band operation)
- UMS GH25-10, 4-inch diameter wafer, 0.25 µm gate length GaN-on-SiC MMIC process (operation < 20 GHz, for C-, X- and Ku-band)

The GREAT^2 project started on 01 June 2008 with completion of all tests by 31 December 2014. The GREAT^2 consortium comprised:

- Tesat-Spacecom, as space equipment supplier
- United Monolithic Semiconductors (UMS), as industrial component manufacturer

research institutes leading European GaN device development:

- Ferdinand-Braun-Institut für Hoechstfrequenztechnik (FBH)
- Fraunhofer Institute for Applied Solid State Physics (Fraunhofer-IAF)
- imec

and universities:

- University of Rome "Tor Vergata"
- University of Bristol, Center for Device Thermography and Reliability (CDTR)

The universities were responsible for providing support to the process development in terms of performing physical device simulation and thermal characterisation work respectively.

Results of the University of Rome's work package is summarised in section VI [4], while the University of Bristol's channel temperature determination work using micro Raman thermography [5] is described in section VII.

The research institutes were responsible for providing epitaxial material to be used for processing and for undertaking device and process development work to assist the industrial foundry supplier (UMS) in establishing its processes. In particular the following specific tasks were undertaken:

i. FBH developed in the frame of the “FBH Technology and Device Support” work package a new gate module with sputtered iridium [1], as described in section II.

ii. SiC substrates were procured and characterised by IAF and imec, prior to being accepted for device processing. Epitaxy wafers were grown by imec (GaN-on-Si and GaN-on-SiC) and by IAF (GaN-on-SiC) in respective work packages.

iii. IAF developed high efficiency X-band AlGaN/GaN-MMICs in their work package “IAF Technology and Device Support”. These MMICs were assembled into packages by Tesat and space operational robustness tests performed [2], as described in section III. Due to successful results obtained from these tests ESA initiated the first in-orbit demonstration of European GaN-MMIC technology on-board the PROBA-V mission [8].

iv. imec work packages were targeted towards development of GaN-on-Si HEMT technology for operation in L-band and benchmarking GaN-on-Si vs. GaN-on-SiC technology [3], section V.

v. Industrial entities UMS and Tesat were responsible for process development and space robustness validation respectively. The UMS work package “GaN-on-SiC L- and X-band process development” directed towards the establishment of space compatible UMS processes is summarised in section VIII. Tesat performed RF packaging and characterisation of the devices and this work is summarised in section IX.

There have been 3 major milestones in GREAT^2 comprising performance, reliability, yield and space environmental (i.e. radiation and hydrogen sensitivity) related targets. As an example the targets used for the UMS GH50 process validation for the final project milestone are shown in Table 1. Similar targets were also used for the IAF GaN25/UMS GH25 process, but with RF operation in X-band as shown in Table 2.

Table 1: Final milestone targets for UMS GH50 evaluation test structure

Operating frequency (GHz)	1.7
Gate width (mm)	2.4
Drain Bias (V)	≥ 50
Output power P_{out} (dBm) at max. PAE	≥ 37
PAE (%)	≥ 55
Associated Gain at P_{out} (dB)	> 15
Device Median-time-to-failure (MTF) performance for ΔP ≤ 1dB @ T_j ≥ 230°C	≥ 1*10^6 h
RF output power variation (dB)	± 1
RF small signal gain uniformity (dB)	1
Wafer RF yield (%)	≥ 70
Radiation displacement damage / TID radiation insensitivity drift	≤ 15 %
Hydrogen poisoning drift	≤ 15 %

Table 2: Final milestone targets for UMS GH25 evaluation test structure

Operating frequency (GHz)	8.0 to 8.5
Drain Bias (V)	≥ 30
Output power P_{out} (dBm) at max. PAE	≥ 37
PAE (%)	≥ 40
Associated Gain at P_{out} (dB)	> 20
Input and output return loss (dB)	> 15
Device MTF performance for ΔP ≤ 1dB @ T_j ≥ 230°C	≥ 2*10^5 h
RF output power variation (dB)	± 0.5
RF small signal gain uniformity (dB)	1
Wafer RF yield (%)	≥ 70
Radiation displacement damage / TID radiation insensitivity (drift)	≤ 15 %
Hydrogen poisoning drift	≤ 15 %

Intensive accelerated reliability testing of GaN HEMTs and MMICs has been performed by UMS and Tesat. At each major milestone, independent testing was also performed by ESA to validate the results obtained. These results are described in section X.

vi. Radiation and hydrogen sensitivity testing has been undertaken in the work package “Space Assessment of GaN-HEMT Technology” by Tesat, as described in section XI and XII.

II. GAN HEMTS WITH SPUTTERED IRIDIUM GATE MODULE (FBH)

A new gate module providing high reliability operation using iridium to prevent degradation of the GaN HEMT Schottky contact has been developed by FBH, Figure 1 [1].

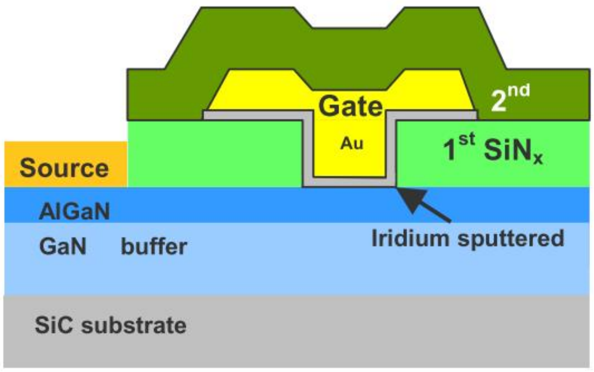

Figure 1: Sketch of FBH gate module with sputtered Schottky gate

Conformal deposition of Schottky and barrier metal in the gate trench ensures sealing of the semiconductor. Sputtering is the enabling technology that yields low mechanical stress of the iridium contact. Patterning of the gate contact is achieved by a subtractive method. An order of magnitude improvement in reliability compared to evaporated Schottky metal reference devices at FBH has been demonstrated. However, the output power levels demonstrated with an iridium gate have been approximately 20 % lower compared to the standard gate metal approach. For sputtered iridium devices, this work allowed demonstration of a life time of > 10^8 hours for a peak simulated channel temperature of 175 °C with improved conformal coverage of the gate contact.

III. HIGH EFFICIENCY X-BAND ALGAN/GAN MMICS (IAF)

The IAF GaN25 quarter-micron gate length HEMT process has demonstrated breakdown voltages beyond 150 V and an output power density of 5 W/mm (30 V drain bias) with 50% PAE at 10 GHz operating frequency [2].

Packaged and hermetically sealed two-stage MMICs with 8 W output power, operating over the 8 to 8.5 GHz frequency range, have a PAE exceeding 40% with a lifetime above 10^5 hours at a channel temperature of 200 °C. Figure 2 shows the IAF GaN25-MMIC used for reliability validation tests within GREAT^2.

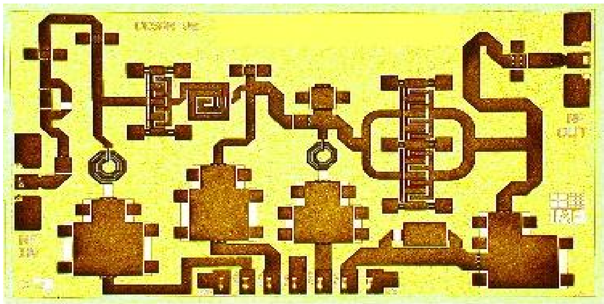

Figure 2: IAF GaN25-MMIC (3 x 2 mm^2)

Initial space evaluation tests indicated a suitable reliability and robustness of IAF devices to be considered for an early in-orbit demonstration using this technology.

IV. PROBA-V IN-ORBIT DEMONSTRATION (ESA)

This work enabled the first in-orbit demonstration of European GaN-MMIC technology on-board the PROBA-V mission of the European Space Agency, Figure 3 [7]. IAF GaN-MMICs were assembled, hermetically sealed and tested by Tesat. Syrlinks (F) made the design, assembly, testing and qualification of the GaN X-band transmitter for PROBA-V.

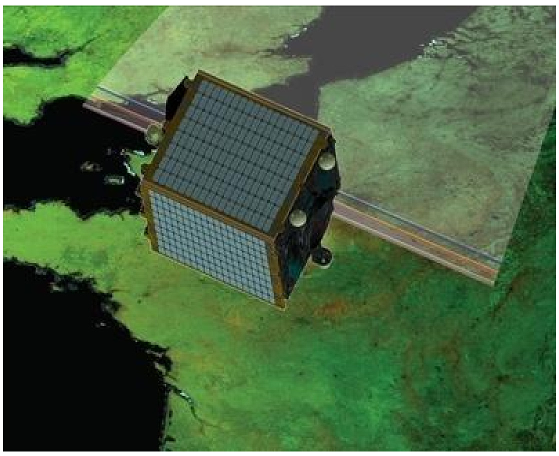

Figure 3: PROBA-V satellite (picture courtesy of ESA)

The PROBA-V GaN X-band transmitter has now been successfully operating in space for image and data transmission for more than 24 months with zero drift in MMIC telemetry operating parameters observed [8].

V. GAN-ON-SIC AND GAN-ON-SI HEMTS (IMEC)

Imec development and benchmarking of GaN-on-SiC and GaN-on-Si L-band RF device technology led to a major improvement of reliability and performance. Towards the end of the project, imec's GaN-on-Si process technology was demonstrated with a median time to failure (MTF) of $2*10^6$ hours for a channel temperature of 175 °C [3]. Figure 4 shows a schematic cross-section of imec's latest GaN RF device generation developed within GREAT^2.

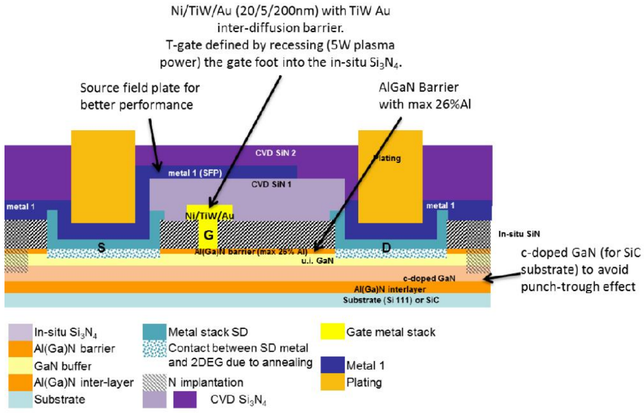

Figure 4: Schematic cross-section of the latest imec GaN RF device generation developed within GREAT^2

VI. GAN HEMT RELIABILITY PHYSICS MODELING AND DEVICE OPTIMISATION (UNIVERSITY OF ROME TOR VERGATA)

The University of Rome Tor Vergata worked on theoretical understanding of device degradation by simulation of electronic transport, simulations of transient behaviour and optimisation of a fully coupled electro-thermo-mechanical model [4]. This model has been used to simulate the electro-mechanical stress state in a GaN-HEMT under DC operating conditions in order to assess the importance and implications of the inverse piezoelectric effect, the aluminium (Al) content and thermally induced stress.

VII. CHANNEL TEMPERATURE DETERMINATION AND DEFINITION (UNIVERSITY OF BRISTOL)

Channel temperature determination is crucial for the interpretation of accelerated life tests, i.e. for correct extrapolation of life time from high test temperatures to lower use temperatures.

Presently, the best spatial resolution and temperature measurement accuracy is offered by micro Raman thermography, a method developed by the University of Bristol CTDR [5]. Channel temperature measurement and thermal resistance extraction was performed by the University of Bristol using Raman thermography both under DC and RF operation.

Micro-Raman thermography, utilizing the Raman scattering phenomena, overcomes the spatial resolution limitations of conventional electrical and IR thermography.

This method is non-invasive and achieves a sub-micron lateral spatial resolution, adequate to resolve the 0.5 µm-long heat generation region in GaN-HEMTs. The incident light is partially inelastically scattered by quantized lattice vibrations in the material (phonons). The scattered light is collected by the same focusing objective lens. Because each material has distinct phonon energies, the GaN and SiC temperatures can be probed selectively, as shown in Figure 5.

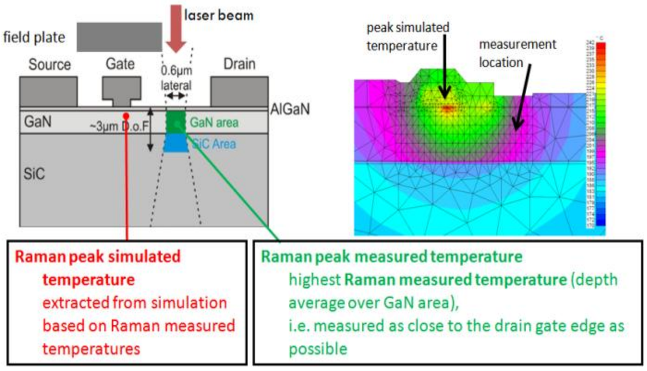

Figure 5: Raman thermography and temperature definitions used for GREAT²

The following temperature definitions have been used in GREAT², cf. to Figure 5:

- Raman peak measured temperature. This is the peak temperature that is accessible for measurement (depth average over GaN area marked green in Figure 5). This temperature is measured as close to the drain gate edge as possible.
- Raman peak simulated temperature. The peak simulated temperature extracted by finite element simulation (Figure 5, right-hand side) based on the Raman thermography measurement temperature data

For lifetime extraction Raman peak simulated temperatures have been used.

VIII. PROCESS DESCRIPTIONS

A. UMS GH50-10 process

The GH50-10 process is based on a 0.5 µm gate length gallium nitride high electron mobility transistor (HEMT) technology useable for frequencies up to 6 GHz. Figure 6 shows the schematic cross section of the active region of a GH50-10 transistor.

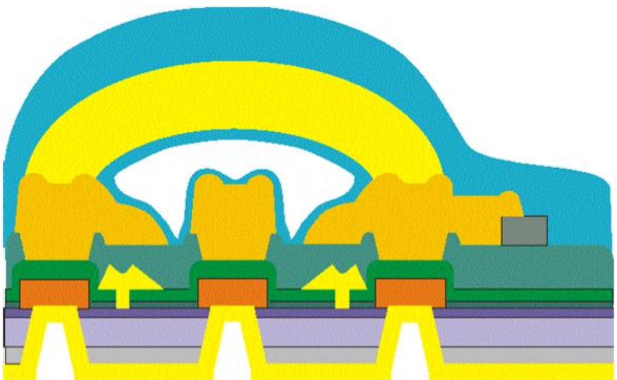

Figure 6: Schematic cross section of the active region of a GH50-10 transistor

The major features of this process are the following:

- HEMT MOCVD active layer on 3-inch semi-insulating SiC substrate with high sheet-resistance uniformity
- Isolation by ion implantation
- 0.5 µm T and Γ shaped gold gate with diffusion barriers with low resistance suitable for high frequency operation. The gate foot lithography is made with e-beam whereas the gate head lithography is made with an I-line stepper.
- 30Ω/sq TaN resistors, 640Ω/sq Semiconductor resistors and 1000Ω/sq TiWSi resistors
- Thick gold electroplating for interconnects and line reinforcement
- Air bridges to overcome device topography
- SiN-protection of the wafer front side
- 100 µm substrate thickness with via interconnects for source contacting / connection to ground pads
- Power density 5 W/mm @ 2 GHz
- Operating voltage Vds = 50 V
- Maximum voltage Vdsmax = 150 V
- Pinch-off voltage Vp = -2.2 V
- Drain saturation current Idss = 420 mA/mm
- Transconductance Gm= 190 mS/mm @ Vgs = 0V
- Gate and Drain leakage currents Igl, Idl < 200 µA/mm @ Vds = 50 V, Vgs = -7 V

B. UMS GH25-10 process

The GH25-10 technology is based on AlGaN / GaN high electron mobility transistors of 250 nm gate length with slanted profile. Figure 7 shows a schematic cross section.

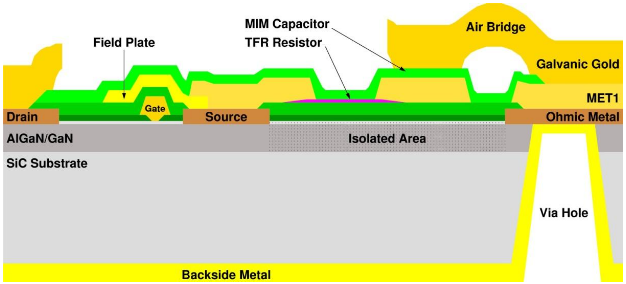

Figure 7: GH25-10 process schematic cross section

The major features of this process are the following:

- MOCVD active layer on 4-inch semi-insulating SiC substrate with high uniformity
- Isolation by Ar-implantation
- GaN HEMT with Lg = 250 nm and slanting shape gate foot
- Source terminated field plate topology
- Recommended operating value Vds = 30 V
- Idss = 825 mA/mm (average value)
- Power density 4 W/mm @ 10 GHz CW
- Diodes
- MIM capacitors (255 pF/mm²)
- 1.8 µm evaporated and 7 µm electroplated gold layers for interconnects and lines
- Air bridges to overcome device topography and realization of integrated inductors
- SiN protection of the wafer front side
- 100 µm thick substrate and via interconnects to access the backside metallization

Optional:

- 30 Ohm/sq. TaN thin film resistors
- 1000 Ohm/sq. TiWSi thin film resistors

The technology is suitable for realising robust low noise amplifier MMICs, switching and power applications, robust low power MMICs and multi-stage, high power, high efficiency amplifiers up to 20 GHz.

IX. EVALUATION TEST VEHICLES AND PERFORMANCE

A. Radiation Test PCMs

For irradiation and hydrogen sensitivity testing, radiation process control monitors (PCMs) containing 6 off 1x50 µm GaN-HEMTs on each test chip were used. The radiation PCMs were assembled in DIL24 packages as shown in Figure 8.

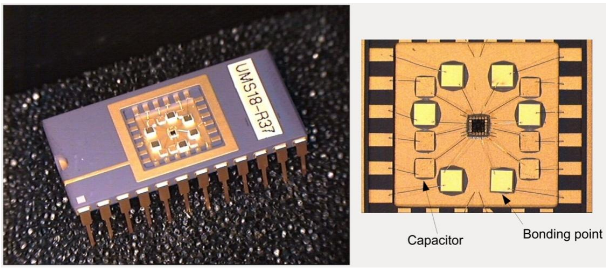

Figure 8: Radiation PCM assembled in DIL24 package

A. UMS GH50-10 power cell

For the GH50 reliability and radiation validation, 6x400 µm power cells with a total gate width of 2.4 mm were used. This transistor type shown in Figure 9 and is one of the UMS standard basic cells that is being used in several commercial GaN power transistor products. This power cell was chosen as a compromise between being representative of the process output power capability, but at the same time allowing a high number of test samples to be obtained from each wafer for yield analysis.

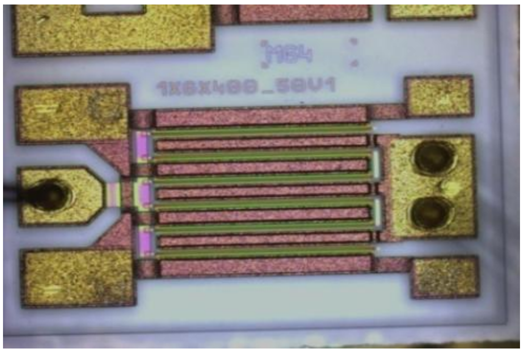

Figure 9: UMS GH50-10 6x400 µm power cell

More than 160 RF packages, similar to the package shown in Figure 11, have been assembled by Tesat using this power cell. Internal lumped element matching networks were used to provide a 50 ohm power match. Typical performance of the internally matched power cell operating at 1.7 GHz (CW) and with 50 V drain bias was:

- Output power > 12 W
- PAE > 60 %
- Associated gain > 17 dB

B. UMS GH25-10 MMIC (RIC)

For the GH25 reliability and radiation validation, a two-stage MMIC with 8 to 8.5 GHz bandwidth was designed by UMS. Figure 10 shows a photograph of the RIC. The gate width of the driver stage is 8x125 µm, the gate width of the power stage 2x8x150 µm.

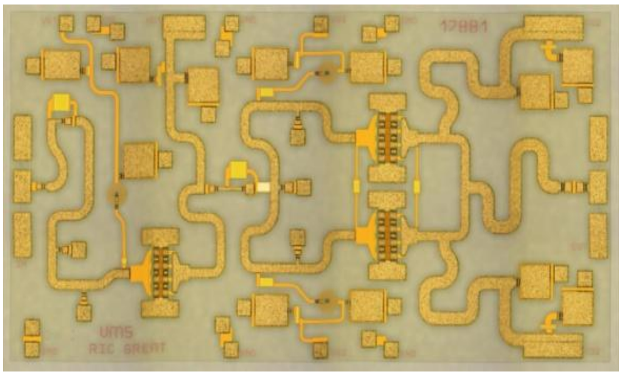

Figure 10: UMS GH25 GaN X-Band MMIC (4.1 x 2.2 mm^2)

More than 120 GH25 MMICs have been assembled by Tesat in hermetic packages, similar to that shown in Figure 11.

Figure 11: 6RF package with X-band GaN-MMIC

Typical measured performance of packaged GH25 MMICs was as follows:

- Bandwidth 8.0 to 8.5 GHz
- Drain-Source Voltage 30 V
- Output power > 10 W
- PAE > 40 %
- Associated gain > 20 dB

X. RELIABILITY VALIDATION RESULTS

A. Reliability of UMS GH50-10 power cells

Accelerated RF life testing was performed by Tesat with 25 packaged 6x400 µm power cells in 3 test campaigns with 3000 hours, 4250 hours and 4400 hours duration respectively. Peak simulated channel temperatures were in the range from 270 °C to 390 °C. These tests were complemented by DC and RF life tests at UMS and with independent life test validation and failure analysis performed by ESA.

For reliability tests, the devices were operated at Vds = 50V, 1.7 GHz under CW conditions using an output power corresponding to the output power at maximum PAE ($Pout_{PAEmax}$), which corresponded to ≈ 4 to 5 dB gain compression. Prior to stress testing, initial output power values were typically in the range of 39 to 40 dBm. No burn in or device screening, other than performance integrity checks, was performed.

The dominant failure mode of the devices was a gradual RF output power degradation (wear-out). A failure criterion of

1 dB reduction in output power was used. Based on this criterion, the time to failure (TTF) was determined and the mean-time-to failure (MTF) and activation energy (Ea) extracted.

Figure 12 shows an extrapolation of the GH50 accelerated RF life test results to operation at lower channel temperatures, i.e. as typically used for nominal operation. The light blue rectangles indicate the channel temperature (250 °C to 290 °C and 310 °C to 390 °C respectively) and time duration range (3000 hours to 4000 hours) where RF life tests have been performed within GREAT^2 for the GH50-10 process.

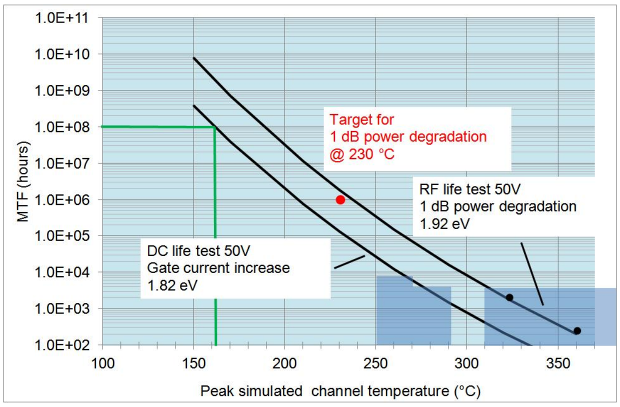

Figure 12: GH50-10 power cell life time extrapolation for wear-out failure mode (failure criterion: 1 dB RF output power degradation from RF life test and UMS DC life test data)

For a confidence level (CL) of 60 %, a median time to failure (MTF) > 1*10^6 hours at a channel temperature of 230 °C was achieved for 1 dB output power degradation. Activation energies of > 1.9 eV could be extracted. This data agrees well with RF life test results obtained by UMS

It is now assumed that for achieving a low failure rate (e.g. < 10 FIT) over a 20 years mission duration, a MTF requirement of ≥ 10^8 hours would be reasonable. Then a recommendation for derating can be made based on RF and DC life test results that the peak simulated channel temperature should not exceed 160 °C for GH50-10 (cf. green lines in Figure 12) for space operation.

Figure 13 shows combined data from ESA and Tesat RF life tests for output power degradation at channel temperatures from 250 °C to 290 °C for 13 devices.

The maximum output power degradation for 8000 hours operation was below 0.4 dB. It should be noted, that since no burn-in had been performed, the initial "burn-in" power degradation is also included in this data, i.e. prior to device stabilisation.

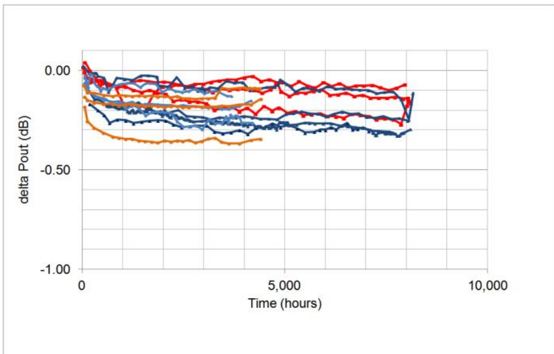

Figure 13: GH50-10 power cell output power degradation at 250 °C to 290 °C channel temperatures RF life test

B. Reliability of UMS GH25-10 MMIC process

Nine packaged UMS MMIC ("RIC") GH25-10 samples were subjected to accelerated RF life test at Tesat for 4000 hours.

Devices were divided into two channel temperature groups of 300 °C and 325 °C, respectively. The devices were continuously driven by a constant RF input power at 8.5 GHz such that they operated at $Pout_{PAEmax}$ at stress temperature. This corresponded to approximately 7 to 8 dB gain compression. During the tests the drain bias voltage was set at Vds=30 V and the initial starting output power was in the range of 39 to 40 dBm.

Figure 14 shows output power (alias power gain) degradation at stress temperature over the 4000 hours RF life test.

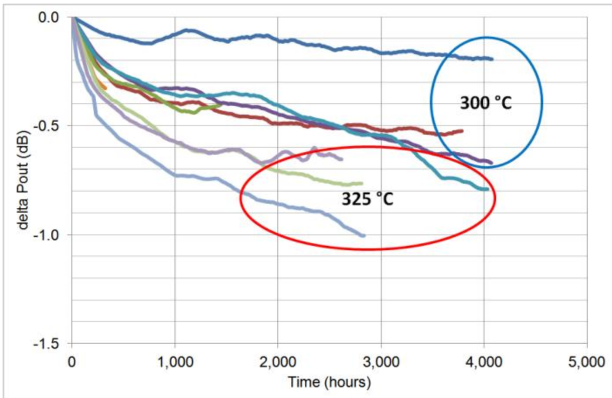

Figure 14: GH25-10 MMIC output power degradation at 300 °C and 325 °C channel temperatures

Figure 15 shows an extrapolation of the GH25 4000 hours RF life test result to lower channel temperatures used for nominal operation.

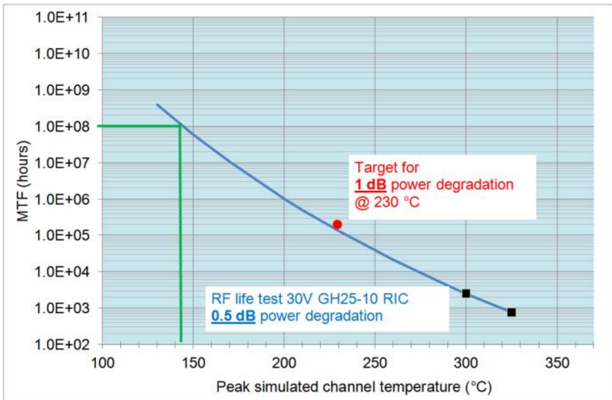

Figure 15: GH25-10 GaN-MMIC life time extrapolation for wear-out failure mode (failure criterion: 0.5 dB RF output power degradation)

For a confidence level (CL) of 60 %, a MTF > 2.3*10^4 hours at a channel temperature of 230 °C was achieved for 0.5 dB output power degradation. For this test an activation energy of 1.4 eV could be extracted. It should be noted that the blue curve in Figure 15 is based on a more demanding criterion of 0.5 dB output power degradation than the 1 dB specified in the GREAT^2 performance targets. For 1 dB output power degradation the estimated MTF is higher and exceeds 2*10^5 hours.

Based on similar arguments used for the GH50-10 process and a minimum MTF requirement of ≥ 10^8 hours, a preliminary space derating can be made for the GH25-10 process where it is recommended that the peak simulated channel temperature should not exceed 145 °C (cf. green lines in Figure 15).

XI. RADIATION SENSITIVITY

Total ionising dose (TID) effects and proton irradiation (displacement damage) effects were extensively tested on the radiation test PCMs (GH50 and GH25).

Protons with energy 35 MeV up to a fluence of 1.5 x 10^{12} protons/cm^2 have been used. The total dose applied was 1 Mrad, with a dose rate of 36 krad/h.

For both processes, the radiation test structures and GH50 power cells/GH25 MMICs, respectively, were irradiated with heavy ions Ar, Kr and Xe to test for single event effects (SEE) and single event burn-out (SEB) voltage threshold values.

A. UMS GH50-10 process

TID effects and proton irradiation resulted in less than 10 % change in key parameters like saturation current, maximum transconductance and threshold voltage. During irradiation, devices had been biased at 50 V drain voltage and with the gate voltage at pinch-off (Vgs = -7 V).

For the GH50-10 process, the SEB of 6x400 µm power cells under Xe irradiation, with a linear energy transfer (LET) 53 MeV/mg/cm², occurred above 125 V for a first lot, and between 110 V to 125 V for a second lot of test cells. Whereas, DC static burn-out for power cells occurred at 175 V for the first lot, and at 160 V for the second lot. Based on this information there seems to be a lot-to-lot dependence of SEB voltage and a correlation between SEB and DC breakdown voltage.

In addition to SEE testing under DC operation, RF operation was also examined in the presence of heavy ions. Three power cells from the first lot had been successfully tested (i.e. no failure) under Xe irradiation and RF operation both at 50 V and at 60 V drain bias, with an output power of more than 41.5 dBm, corresponding to more than 7 dB gain compression at maximum PAE output power operating point.

However, for devices from the second lot, SEB occurred already under nominal RF operation which was not expected. It was concluded that this failure can be attributed to the reduced SEB voltage of the GaN-HEMT from the second lot, as the simulated drain voltage under nominal RF operation reached 120 V peak voltage, i.e. a voltage region in which SEB can occur for the second lot [6].

B. UMS GH25-10 MMIC process

TID effects and proton irradiation resulted in less than 10 % change in key parameters like saturation current, maximum transconductance and threshold voltage. During irradiation, devices had been biased at 50 V drain voltage and gate voltage at pinch-off. A second campaign for TID effects and neutron irradiation with energy 14 MeV up to a fluence of 1.0 x 10^{13} neutrons/cm^2 at 30 V drain voltage confirmed this result.

For the GH25-10 process SEB of GaN-HEMT radiation test structures under Xe irradiation, with a LET 53 MeV/mg/cm², occurred at 130 V to 140 V, whereas DC static burn-out occurred between 165 V and 205 V.

Ten GH25-MMICs were tested under RF operation (8.5 GHz CW, drain voltage 30 V, RF output power > 39 dBm and > 5 dB compression) under Xe-irradiation. One device failed due to a SEE weakness of integrated metal-insulator-metal (MIM) capacitors. Whereas, SEE results for GaN-HEMT from the radiation test structures resulted in significantly higher SEB voltages. SEE tests on isolated MIM capacitors revealed a SEB voltage in the range of 40 V to 45 V under Xe irradiation, only. This is a value that could be exceeded by RF voltage excursion in GaN-MMIC operating at a drain bias of 30 V. Investigations are ongoing to improve the radiation robustness of MIM capacitors used for the GH25 process.

XII. HYDROGEN SENSITIVITY

Hydrogen sensitivity was tested by a 1000 hour passive (no bias) storage of radiation test structures held at a temperature of 200 °C. Devices were hermetically sealed under 5 % H2 / 95 % N2 atmosphere. 24 devices (comprising reference devices) were included in each of the 1000 hour tests.

A. UMS GH50-10 process

Figure 16 shows no significant change of saturated current Idss for GH50-10 structures during 1000 hours.

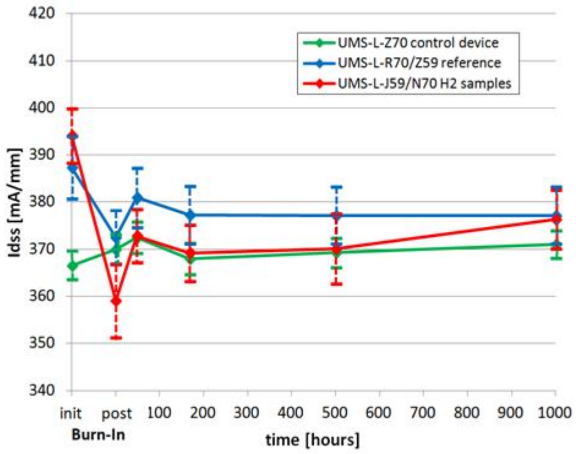

Figure 16: GH50-10 Idss evolution during 1000 hours hydrogen test (mean value of 12 devices +/- the standard deviation as error bar shown)

B. UMS GH25-10 MMIC process

Figure 17 demonstrates that no significant change of saturated current Idss for GH25-10 structures occurred.

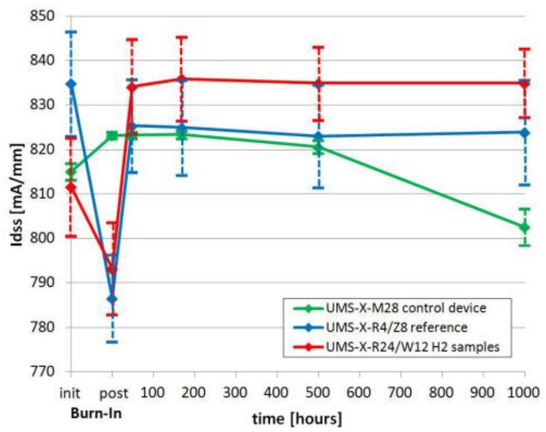

Figure 17: GH25-10 Idss evolution during 1000 hours hydrogen test (mean value of 12 samples +/- the standard deviation as error bar shown)

XIII. CONCLUSION

In summary, preliminary reliability and space robustness data, obtained as part of the ESA GREAT^2 project, has been presented for industrialised European GaN technology. Encouraging reliability figures of merit and radiation robustness data has been obtained for the UMS GH50-10 and GH25-10 GaN processes. For the GH50 process, breakdown voltage variation and the impact on SEB voltage still needs further optimisation. For the GH25 process, MMIC radiation hardening of the MIM capacitors is required.

In addition, the first use of European sourced GaN technology has been demonstrated on an ESA mission with stable performance demonstrated after 24 months operation in orbit. A critical milestone in the development of European GaN technology and its use in space has now been met giving confidence that there should be no major showstoppers for qualifying this technology. As a result of the results obtained from GREAT^2 and the flight heritage data from PROBA V, ESA project teams are now considering using GaN technology for future missions. The ESA BIOMASS mission will use UMS GH50-10 technology for realisation of a P-band SAR SSPA. Device assembly and qualification for BIOMASS is currently ongoing, along with space qualification of the GH50-20 process.

XIV. ACKNOWLEDGMENT

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