Preliminary reliability data from accelerated RF life tests on European GaN HEMTs

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Abstract

This paper gives an overview of the preliminary reliability findings obtained through performing independent accelerated RF life testing as part of the European Space Agency GREAT^2 project.

INTRODUCTION

GaN has attractive material properties making it very interesting for use in space. The material can operate at much higher voltages and temperatures than widely-used semiconductors such as silicon or gallium arsenide (GaAs), and is also inherently radiation-hard. However, to begin using GaN in space it was clear that more focus should be given towards improving component reliability. To address this situation ESA launched its GaN Reliability And Technology Transfer Initiative (GREAT^2) in 2008 [1], with the aim of establishing a European supply chain for the manufacture of high reliability, space compatible, GaN-based microwave transistors and integrated circuits. Project success is judged through achieving specific performance related milestone targets denoted M3, M5 and M7 where the aim is to pass all space related operational environment tests and achieve operating lifetimes of 1000hrs, 10,000hrs and greater than 20 years for a junction temperature >230°C. This paper describes the preliminary findings for the accelerated reliability tests performed at ESA laboratories for the M3 milestone.

TEST VALIDATION STRUCTURES

Within GREAT^2 two technology validation structures are being used to evaluate and better understand the intrinsic performance capabilities for operation in space, an L-band discrete transistor and a two stage X-band MMIC. These devices are fabricated using the United Monolithic Semiconductors production foundry processes, GH50 and the IAF GaN25 process using 0.5µm and 0.25µm gate lengths respectively. The typical test structure RF performance at a 50 °C baseplate temperature is illustrated in Figure 1. The L-band device operates at 50V and delivers approximately 10W of output power for >15dB associated gain and a power added efficiency (PAE) >40% at a frequency of 1.7GHz. The PAE performance was not optimised for the reliability test campaign, but with appropriate matching and a deep class AB quiescent bias point the typical PAE value easily exceeds 60% with the UMS GH50 process. The X-band evaluation vehicle is a two stage MMIC with an operating voltage of 30V that delivers greater than 6W of RF output power over the 8 to 8.5GHz frequency band, with ≈18dB associated gain and a PAE of typically 30-40% depending upon the quiescent bias condition.

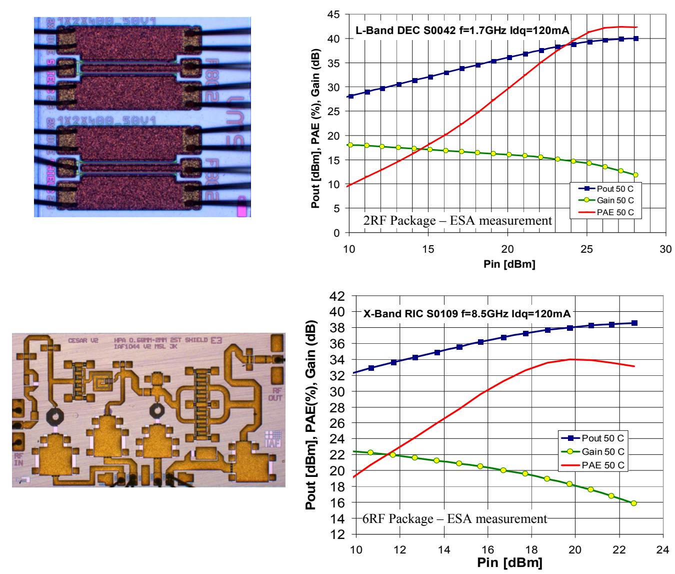

Figure 1:RF performance for L, X-band validation structures

ACCELERATED RF LIFE TEST

Over 168 parts (68 L-Band, 67 X-band) have been assembled in hermetic packages as part of the M3 milestone RF reliability validation. Figure 2 shows the measured change in RF output power for 11 packaged L-Band test vehicles and demonstrates that over 1400 hours of operation was achieved for a peak channel temperature >230°C, with operation at 4dB of gain compression and 6dB of RF gain compression (maximum PAE) using two baseplate temperature groups (125°C and 150°C). For this test the maximum drift in RF output power is ≤0.5dB, except for one device that showed a rapid degradation at the start of the test. Intermediate measurements (base plate at 50°C) were performed every 48 hours in order to monitor DC parameter changes with RF stress. For the L-Band devices, we noticed the following parameter changes: Idss reduction of 15% and a positive threshold voltage shift of approx 200mV.

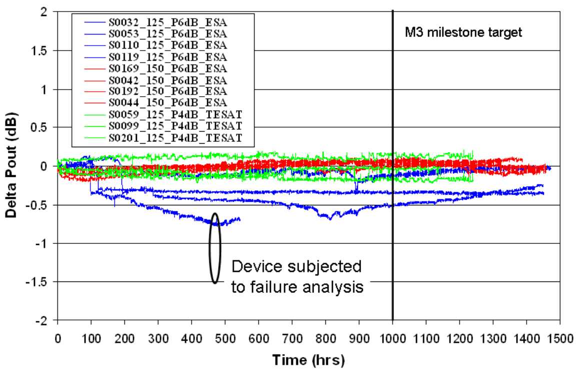

Figure 2: Relative change in RF output power during accelerated RF life test for L-band test structure

The peak gm, gate and drain current in pinch off conditions (Vg=-4V, Vds=10V) were constant. A possible explanation of the Idss and Vth change might be related to the Schottky gate stability with combined RF and temperature stress. In order to verify this statement we performed a failure analysis on the device which showed the largest Pout drift to identify physical changes and to better understand any underlying failure mechanisms. Figure 3 shows a plan view of the channel region after delayering of the gate metallization and figure 4 shows a TEM cross section of the gate finger of the failed device. For the L-band device there were anomalous intermixing elements and defects present between the gate diffusion barrier metallization and the AlGaN semiconductor, not observed on unstressed reference devices. However, no gate-drain edge pit formation was observed for this device as reported by other groups [2]. After delayering, top and bottom section of Figure 3, it can be seen that there is physical damage with a continuous line of defects running along the path of the gate, most likely toward the drain side where the electric field is the highest.

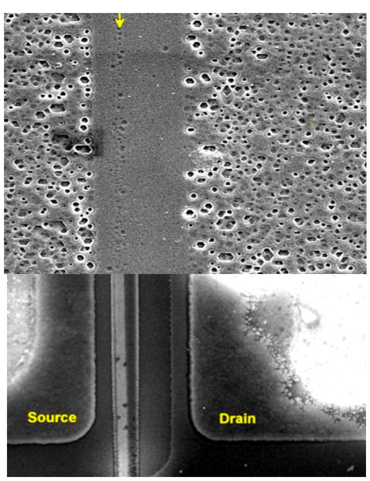

Figure 3: L-band device plan view overlay of gate delayering after RF stress testing

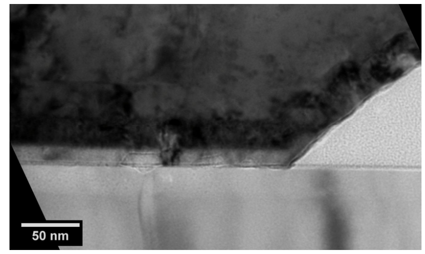

Figure 4: L-band TEM device cross section

A different failure signature (full paper) was observed after stressing the X-band device. This structure used a shorter gate length (0.25µm) and higher Al percentage in the channel (22%). For those devices that showed a rapid reduction in Pout, it was observed that there was a gradual increase in gate current towards positive values during RF stress, an increase in Ron and a 10-15% reduction in Idss1. Figure 5 shows evidence of etch pit formation at the drain edge of the gate that is believed to be responsible for the measured changes.

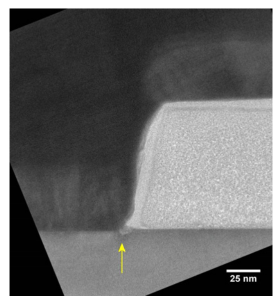

Figure 5: Failure analysis on X-band test structure after RF stress showing etch pit formation

CONCLUSIONS

Accelerated RF life tests have been undertaken on discrete L-band transistors and X-band MMICs as part of the ESA GREAT^2 project. Different failure mechanisms have been observed for these structures and are believed to be dependant upon multiple competing factors such as the epitaxial material quality, controlling strain in the epitaxial layer stack, the level of Al% in the AlGaN barrier and the shape of the gate profile in order to tailor electric field profiles. For the first time, similar failure mechanisms, as previously described for DC only step stress tests have been reported under RF stress. This shows that it is important to undertake RF accelerated life tests to obtain representative real life operating lifetimes rather than rely solely on DC, static bias point accelerated life tests.

REFERENCES

[1]ww.esa.int/esaCP/SEMKBBSTGOF_index_0.html
[2] Makaram et al., Evolution of structural defects associated with electrical degradation in AlGaN/GaN high electron mobility transistors, App Phys letters 2010.