AN INVESTIGATION ON THE RELIABILITY OF AlGaAs/GaAs HEMTs

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ABSTRACT

The results of an investigation concerning reliability of AlGaAs/GaAs High Electron Mobility Transistor devices are presented.
Such investigation, carried out on devices from two different manufacturers, has been performed under an ESA contract (CCN N. 2 to 6462/85/NL/JG(SC)) aimed at providing sufficient confidence in HEMT devices, so to allow their use in satellite low noise receivers.

1. INTRODUCTION

In the frame of a previous ESA contract (6462/85/NL/JG(SC)), two low noise amplifiers were developed, operating at Ka band and employing either GaAs MESFET or AlGaAs/GaAs HEMT devices.
The achieved results showed better performance of HEMT with respect to MESFET at least in terms of gain (1 dB per stage) and of noise figure (2 dB for the overall amplifier).
As a consequence, HEMT's were considered as the most suitable devices for low noise application, even if their reliability had still to be assessed.

Accordingly, an evaluation was planned consisting of two high temperature (250 and 300 °C) storage tests on packaged devices, and of a life test at 150 °C on 2-stage amplifier modules employing chip devices biased in the actual operating conditions.
Chip-form and packaged parts came from the same production lot and were delivered at "standard grade" quality level.
HEMT's from two suppliers were used for comparison purposes, which hereafter will be referred to as "A" and "B" devices.
The main technological features of these devices, obtained by SEM and X-ray EDS microanalysis, are summarized in the following table.

DIE ELEMENT	MATERIAL	
	TYPE A	TYPE B
Passivation	Si compound	Si compound
Gate	Al/Ti	Al/Ti
Ohmic Contact	Au/Ge/Ni	Au/Ge/Ni
Barrier Layer	Pt/Ti	Pt/Ti
Gate Length	0.3 um	0.28 um
Gate Width	200 um	190 um

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2. HIGH TEMPERATURE STORAGE TESTS

Ten devices from each supplier were submitted to the storage tests.
The devices were initially electrically characterized and submitted to 24 hours pre-storage at 250 °C.
The duration of the test at 250 °C was agreed to be 10,000 hours, whereas the 300 °C storage test was run for 600 hours.
The tests were performed with the packaged devices held in proper jigs and dry Nitrogen atmosphere in order to avoid lead oxidation and/or contamination.
Each device was periodically monitored, by recording a suitable set of DC parameters.

Rd, Rs and Rg were measured following the "Lee-Shur" [1][2] method based on the "end" resistance measurement concept.
Moreover, the active parameters (Gm, Vp and Idss) were measured in order to characterize the devices from the operating point of view.

2.1 Results of Storage Tests

The devices submitted to the 250 °C storage test show a decrease of the barrier height and an increase of the ohmic contact and gate resistance values, mainly due to Metal-Metal and Metal-Semiconductor interaction.
In particular, the behaviour of the forward gate diode characteristics, reported in Fig. 1 for type A devices, show a parallel drift of the curves, indicating the decrease in the barrier height.
Such effect can be deduced also from the curves reported in Fig. 2 and Fig. 3 which give Gm vs Vgs and Id vs Vgs characteristics respectively.
At increasing times, both drain current and transconductance characteristics show an almost parallel shift towards more negative values.
Consequently, due to the bell shape of the transconductance curve, Gm decreases if measured at Vgs values less than the peak of the curve and increases if measured after the peak.
Drain current, conversely, exhibits an increase in all cases.

Type B devices show a similar behaviour of the barrier height (Fig. 4).
In this case, however, Gm and Idss characteristics present a small shift of opposite sign towards positive voltages (Figures 5 & 6).
These effects are probably related to the increase of parasitic source/drain resistances, resulting to be larger in "B" devices.

Significant data were obtained by comparing the results of the storage tests at 250 and 300 °C.
For type A devices, Fig. 7 shows that the barrier height ϕ decreases linearly with the square root of time; the slope of the two curves depends on the test temperature and allows to evaluate an activation energy of the phenomenon of 1.2 eV.
The ϕ modifications could be related to the built in of an intermetallic phase Al/Ti in contact with the semiconductor substrate [3].

Another widely reported degradation mode of HEMT's was the increase of ohmic contact resistance.
Figure 8 reports the percent variation of the source contact resistance, Rs, as a function of the square root of time for type A devices.
Experimental data follow a linear dependance on the square root of time, represented by the dashed lines. For this phenomenon, an activation energy of 1.8 eV was calculated from the slopes of the curves.

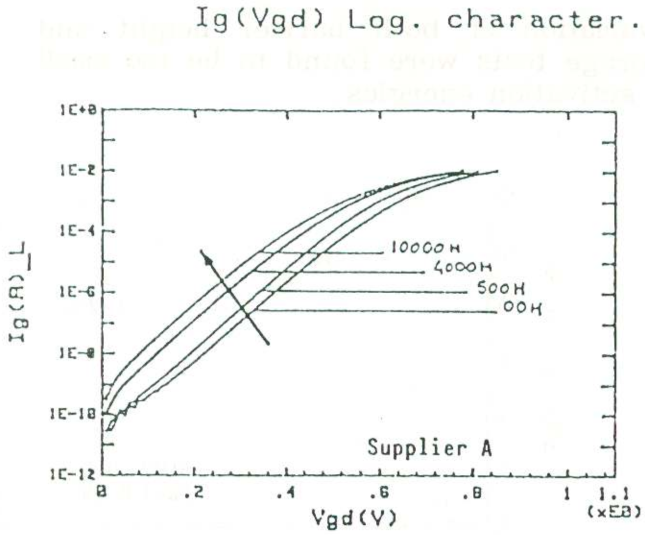

Fig. 1

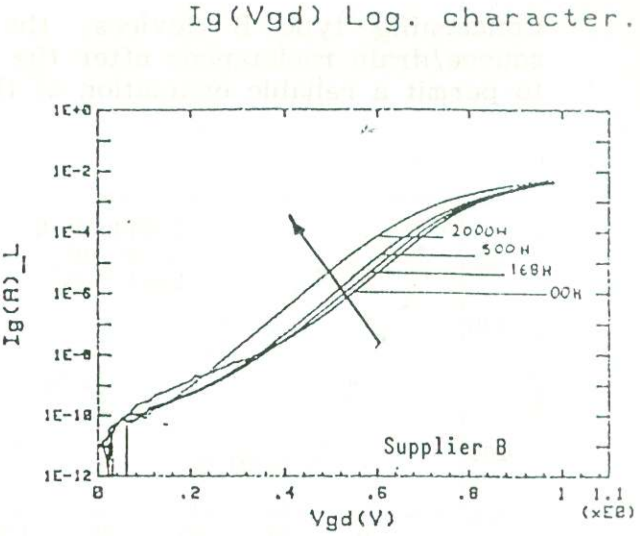

Fig. 4

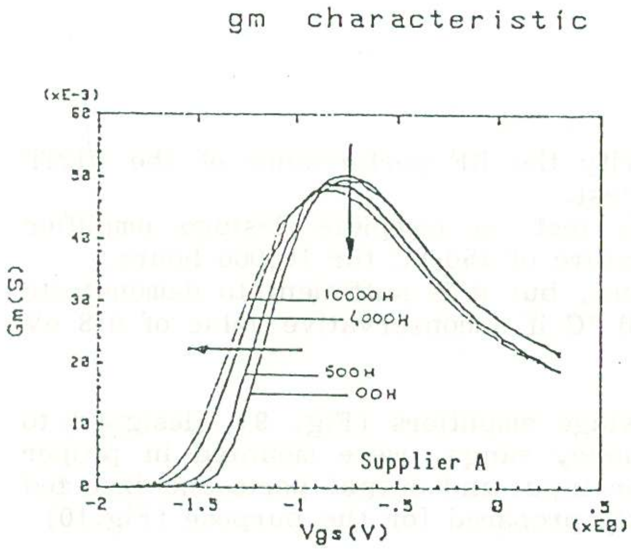

Fig. 2

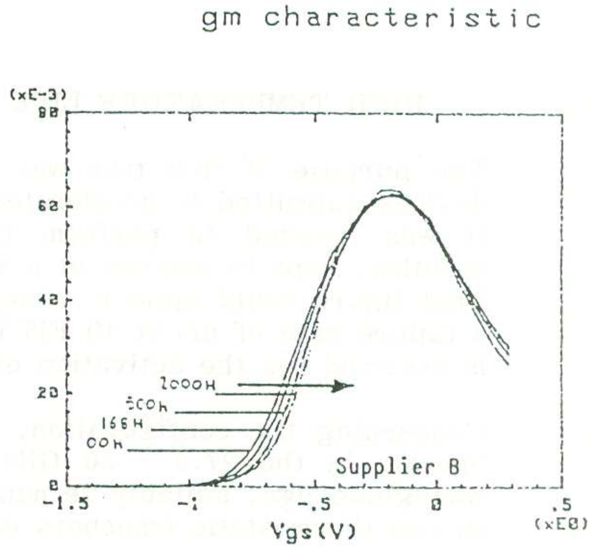

Fig. 5

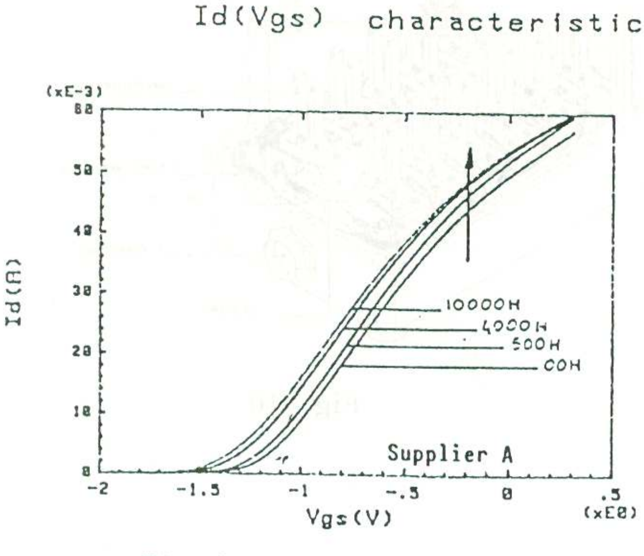

Fig. 3

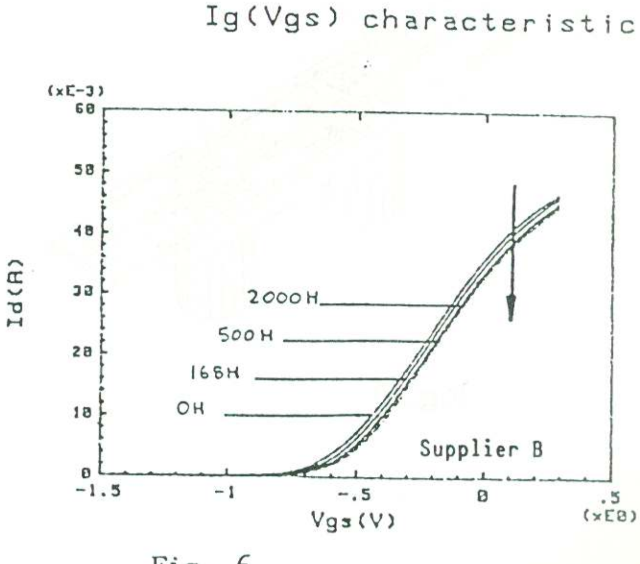

Fig. 6

Concerning type B devices, the variation of both barrier height and source/drain resistances after the storage tests were found to be too small to permit a reliable evaluation of the activation energies.

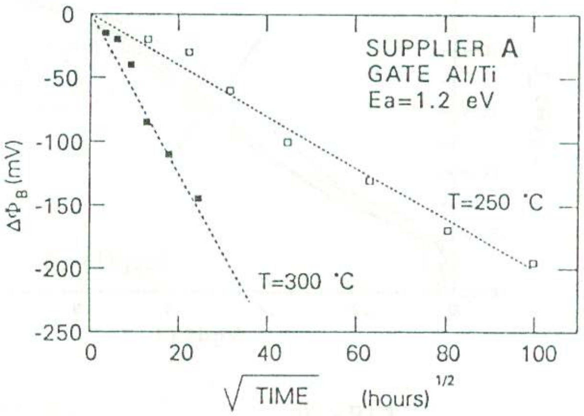

Fig. 7

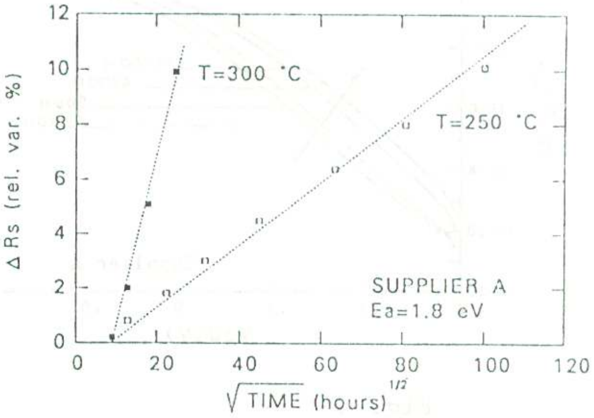

Fig. 8

3. HIGH TEMPERATURE LIFE TEST

The purpose of this test was to verify the RF performance of the HEMT devices submitted to accelerated life test.
It was decided to perform the life test on complete 2-stage amplifier modules, kept in vacuum at a temperature of 150 °C for 10,000 hours.
This figure could appear rather modest, but it is sufficient to demonstrate a failure rate of about 10 FIT's at 60 °C if a conservative value of 0.8 eV is assumed for the activation energy.

Concerning the configuration, 24 2-stage amplifiers (Fig. 9), designed to operate in the 27.5 - 30 GHz frequency range, were mounted in proper waveguide jigs, suitably terminated on input and output ports and inserted in two thermostatic chambers expressly prepared for the purpose (Fig.10).

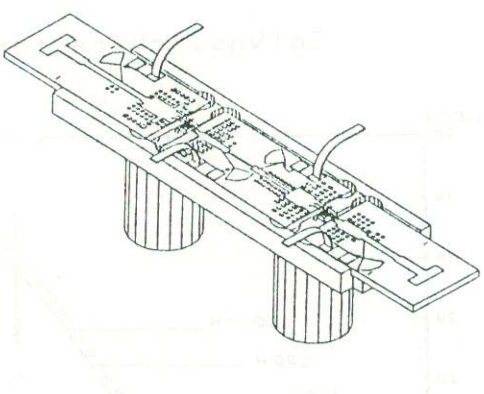

Fig. 9

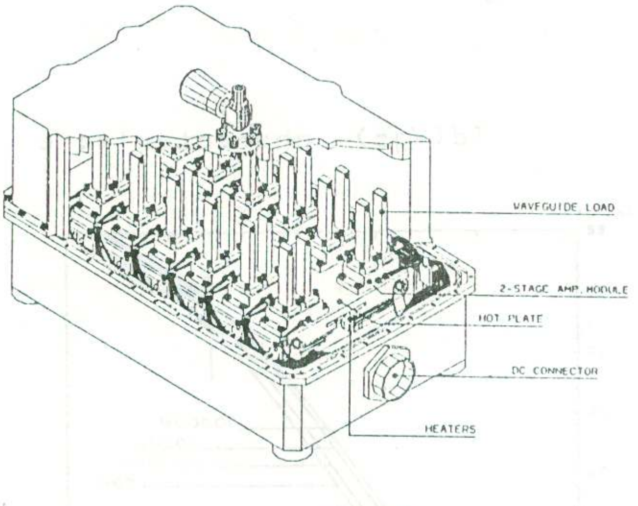

Fig. 10

This approach allows a direct evaluation of the amplifier performance in terms of gain, slope and noise figure, but it is clear that this solution focuses mainly on the application aspects, and represents a sort of preliminary qualification of the device as well as of the assembly.

Gain and noise figure vs frequency were periodically monitored together with HEMT's DC parameters in order to find, if possible, a correlation between storage and life tests.

3.1 Results of Life Test

Figures 11 and 12 show the midband gain drift and the noise figure vs elapsed time for both types of devices, whereas Fig. 13 gives the behaviour of Gm with time.
No practical drift in noise figure can be observed for both families, while a slight increase in gain exists for type A devices.
In addition, no appreciable gain slope variation is evidenced, thus implying small or negligible drifts in HEMT's reactive parameters.
Concerning DC measurements, no drift was observed on barrier height (Fig. 14), confirming the activation energy value found in storage test.

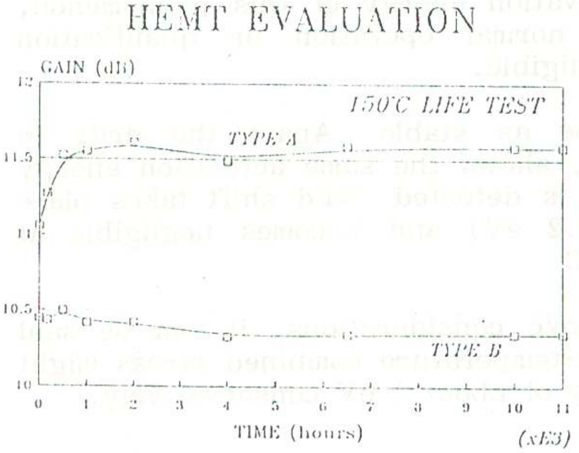

Fig. 11

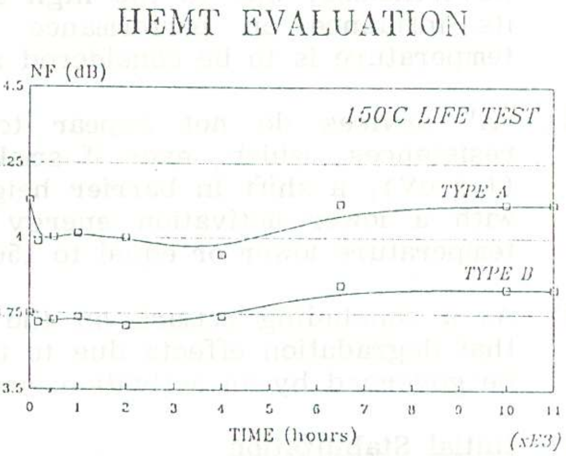

Fig. 12

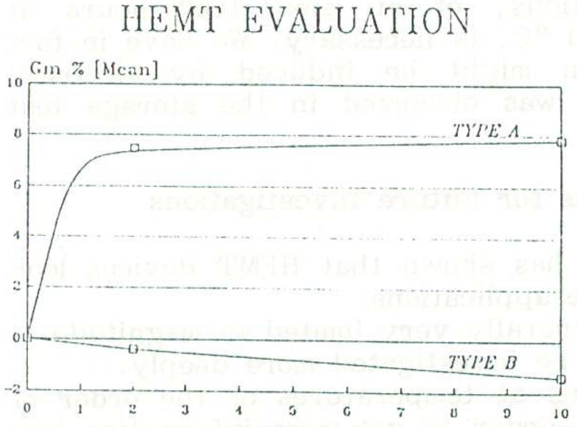

Fig. 13

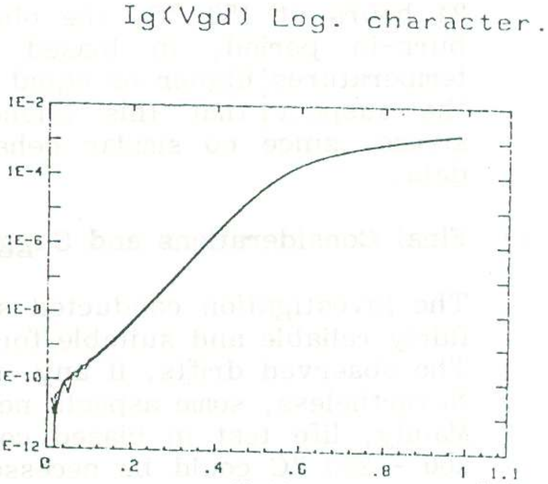

Fig. 14

Conversely, an initial increase of Gm was detected (Fig. 15), which stabilized after approximatively 1000 hours.
Said increase was found to be in good agreement with the corresponding changes in amplifier gain and noise figure (Fig. 11 & 12): this agreememt was also confirmed by a computer simulation by means of Academy (EEsof).

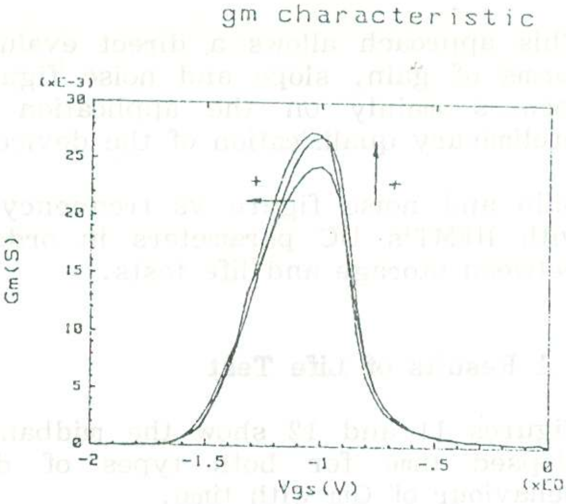

Fig. 15

4. COMMENTS AND PRELIMINARY CONCLUSIONS

1) "B" devices do not show any major drift, apart device resistances which present an increase larger than A devices.
Nevertheless, due to the high activation energy of this phenomenon, its influence on performance at normal operation or qualification temperature is to be considered negligible.

2) "A" devices do not appear to be as stable. Apart the drift in resistances, which, even if smaller, shows the same activation energy (1.8 eV), a shift in barrier height is detected. Said shift takes place with a lower activation energy (1.2 eV) and becomes negligible at temperature lower or equal to 150 °C.

3) As a concluding remark on the above considerations, it can be said that degradation effects due to time-temperature combined stress might be governed by an activation energy of about 1 eV conservatively.

4) **Initial Stabilization**

Concerning "A" devices, a change of about + 7% in Gm ia appreciable during the first 1000 hours of operation at 150 °C.
Since all the devices were submitted to an initial stabilization of only 24 hours at 150 °C, the observed initial drift could suggest that a burn-in period, in biased conditions, of at least 1000 hours at temperatures higher or equal to 150 °C, is necessary. We have in fact the suspect that this phenomenon might be induced by electrical stress, since no similar behaviour was observed in the storage test data.

5) **Final Considerations and Suggestions for Future Investigations**

The investigation conducted so far has shown that HEMT devices look fairly reliable and suitable for space applications.
The observed drifts, if any, are generally very limited in magnitude.
Nevertheless, some aspects need to be investigated more deeply.
Mainly, life test in biased conditions at temperatures of the order of 200 - 250 °C could be necessary in order to get more information how electrical stress effects interract with temperature and time.

6) Incidentally, the life test is still going on.
Namely, one box (6+6 modules) is continuing its test in nominal conditions (see section 3), whereas the second box is kept at 150 °C in open air (controlled atmosphere according to fed. sts 209D, cleanliness class 10000), with the purpose to collect useful indications about the influence of environmental conditions during assembly, tuning and integration of hardware including HEMT's in chip form.
The results after 1000 hours life test still show no drift in gain and noise figure for both families of devices.

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