RESULTS FROM ELECTRICAL CARACTERIZATION AND RELIABILITY TESTS OF GaAs/GaAlAs HEMT's

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Abstract

GaAs/GaAlAs HEMT's are rapidly replacing conventional FET's for applications where high gain and low noise figure at high frequencies are needed; for this reason we began a qualification program on them, with the goal of evaluating the possible criticalities that could affect long term performances. The program includes electrical characterization, thermal storages and operating life-tests on commercially available devices, coming from four different manufacturers.

During the electrical characterization we especially focused on "kink" effect, concluding that it should be ascribed to trapping/detrapping mechanisms in the AlGaAs layer; even if this phenomenon is peculiar of HEMT's, we found no evidence of any possible detrimental effect on reliability.

Thermal storage at 250 °C caused Schottky barrier degradation in the devices with Ni or Ti used as interdiffusion barrier between Al and GaAs; these degradations affect devices performances but cannot be considered peculiar of HEMT's technology, as they were found in low noise FET's too.

During biased life-test at Tch = 175 °C, no significant parametric degradation was found up to 2500 test hours.

INTRODUCTION

In recent years, High Electron Mobility Transistor (HEMT) has emerged to be a very promising device for both high-speed digital circuits and high frequency low-noise amplifiers, becoming a possible replacement for conventional GaAs MESFETs. These devices take advantage of the enhanced electron gas formed at selectively doped GaAs-AlGaAs heterojunction and show a high transconductance with best results in the range 300/400 ms/mm [1].

Up to now, the reliability of this device has not been thoroughly studied and very few data are available concerning failure mechanisms.

Reported reliability problems include ohmic contact degradation [2,3], changes in the 2DEG concentration [4], surface effects [5], soft drain breakdown phenomena (kink effect) [6] and burn-out phemomena [4]. Other problems, like I-V collapse in the dark and persistent photoconductivity, seem to be more closely related to control of fabbrication processes than to devices long-term stability.

In this paper we report results obtained during qualification tests on GaAs/GaAlAs HEMTs from four different suppliers, with standard low noise GaAs FETs used for comparison.

Tab. I reports some technological characteristics of the tested devices which mainly differ in gate metallization; C devices are also characterized by the so called "mushroom " gate, which allows to reduce gate lentgh without affecting

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parasitic resistance. Low noise FETs come from the same supplier of B HEMTs.

Tab. I : Technological characteristics of the tested HEMTs and low noise FETs.

TYPE	PASSIV.	GATE lenght/width um	OHMIC CONTACT
A	SiN/SiO	Al .35/200	AuGeNi
B	SiN	Al/Ni .40/200	AuGeNi
C	SiN	WSi/Ti/Pt/Au .25/200	AuGeNi
E	UNPASS.	Al/Ti .40/200	AuGeNi
LOW NOISE	SiN	Al/Ni .50/300	AuGeNi

First of all, an accurate DC and low frequency electrical characterization was performed, particularly addressed to evaluate the so called "kink effect"; afterwards high temperature storages were begun, with the purpose to evaluate thermally activated failure mechanisms, and finally operating life tests were performed. The results reported here are related to the storage test at 250 °C and to the life-test at Tch = 175 °C.

EXPERIMENTAL RESULTS

a) Electrical characterization

Kink effect is described as a sudden rise of Ids vs Vds at constant Vgs; output conductance (gds) shows a clear peak corresponding to Vds values where kink takes place; Fig. 1 reports two examples of gds vs Vds curves, showing the clear difference between devices with (supplier B) and without (supplier E) kink effect.

Analyzing the possible explanations of this phenomenon, we decided to evaluate the Ids response to a large square wave signal applied to the gate, with the measurement conditions and the results reported in Fig. 2, for the same previous devices: a correlation was found between kink and the presence of overshoots during turn-off and turn-on transients.

Small signal behaviour is different too, for devices with and without kink, as reported in Fig. 3 where gm dependence on frequency is shown: this kind of measurements, with the devices biased in the linear region, is extensively used to characterize surface states in standard FETs, where gm generally decreases with frequency; in HEMTs, surface states don't influence transistor characteristics, but nevertheless a strong dependence on frequency exists, with a clear influence of drain bias.

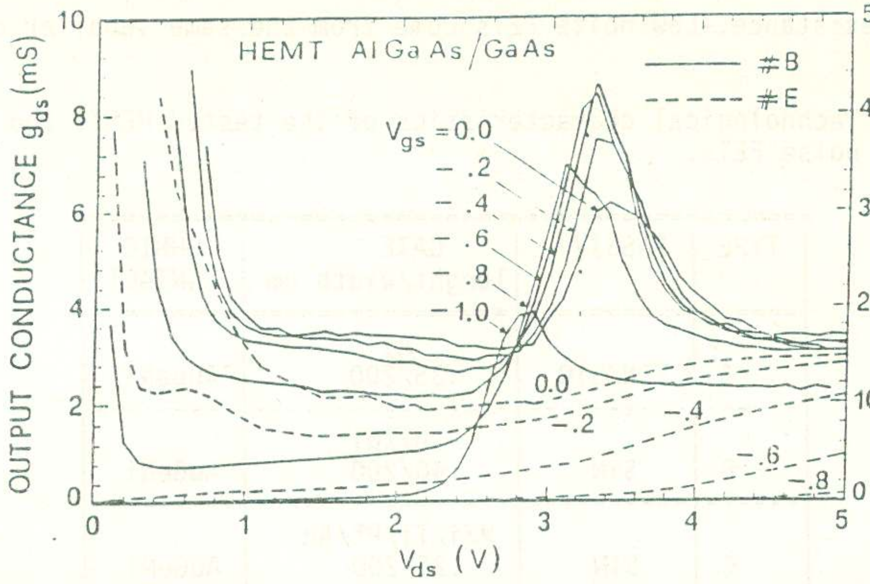

Fig. 1 : Drain conductance for devices with (B) and without (E) kink effect.

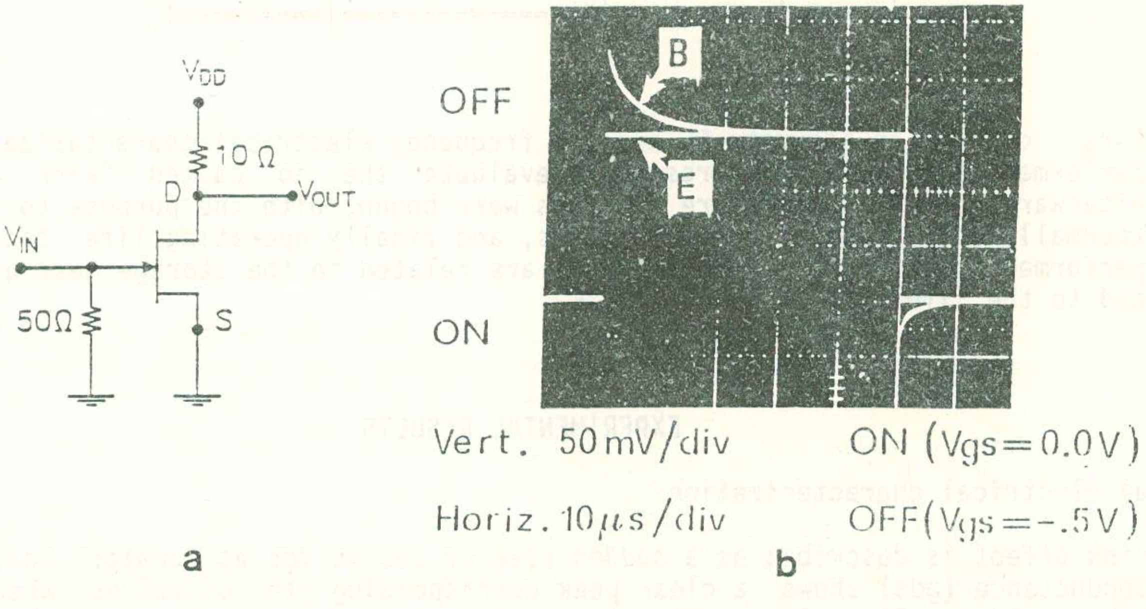

Fig. 2 : a) Schematic of measurement set-up for square wave modulation.
b) Response of B and E devices.

b) Storage test

This test was run for 3000 hours at least, on 3-5 samples for each supplier, including low noise FETs; the results are summarized in Fig. 4, where mean degradations for Idss and source resistance are reported: it seems that some short time phenomenon initially affect Idss while at longer times degradation of ohmic contact takes place.
The degradation of B type HEMTs is reported in Fig. 5 (a), where a shift in Ids and gm curve versus Vgs can be seen; almost the same shift can be observed in

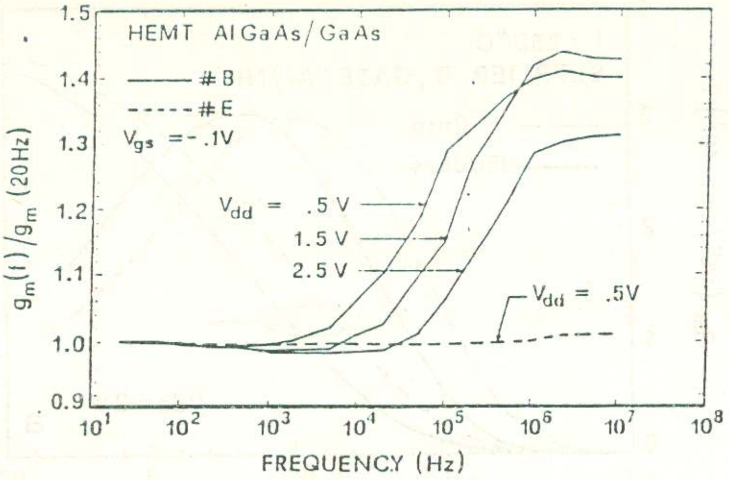

Fig. 3 : Transconductance vs frequency at different bias levels.

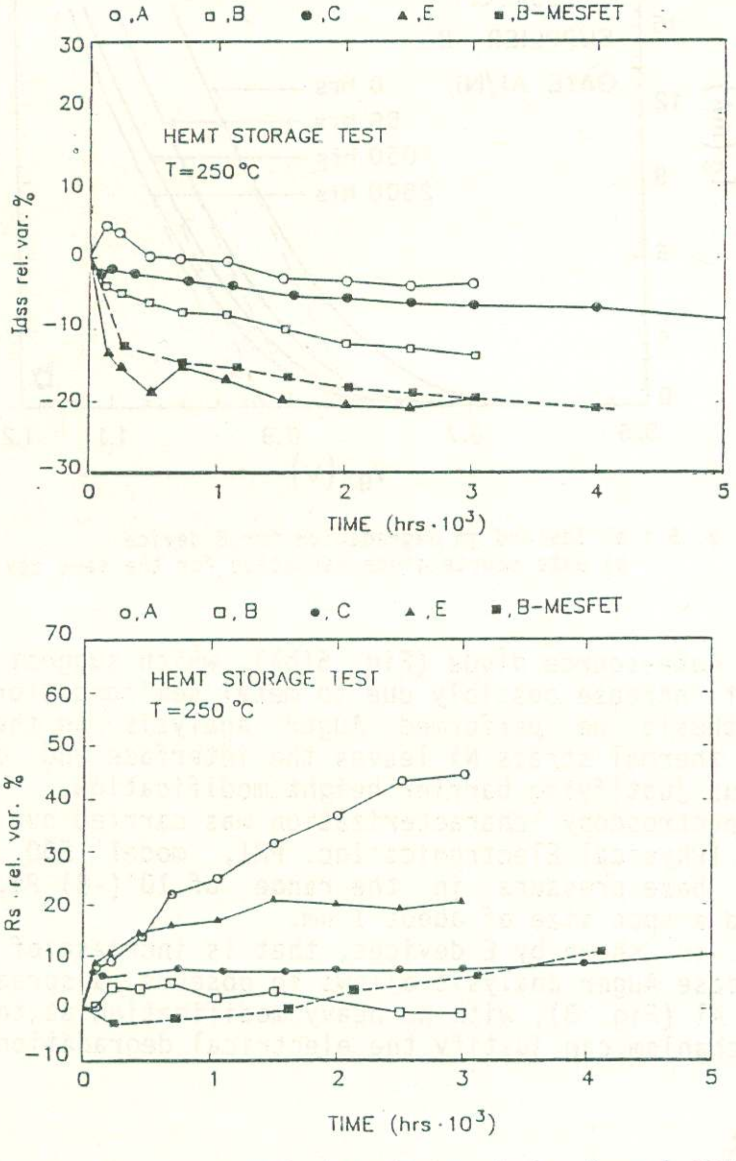

Fig. 4 : Mean parametric degradations during thermal storage.

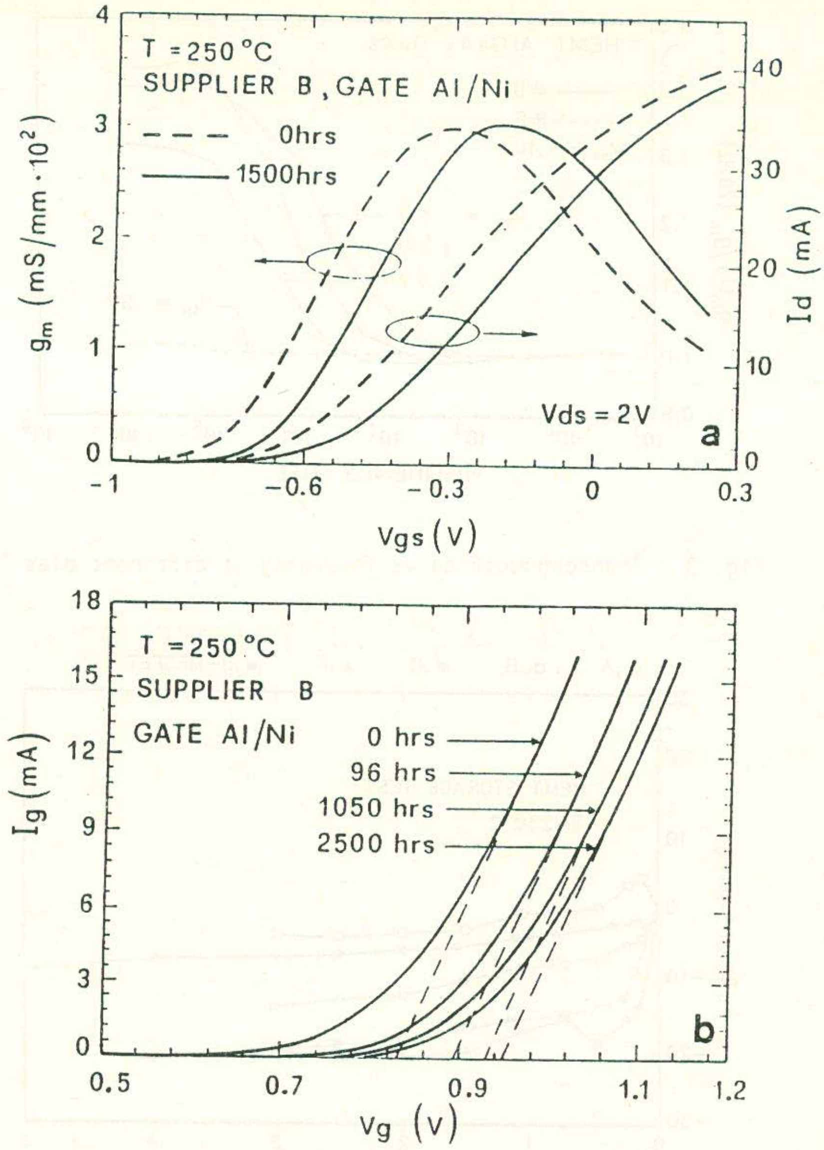

Fig. 5 : a) Ids and gm degradation for B device.
b) Gate source diode variation for the same device.

the I-V curve of Gate-source diode (Fig. 5(b)), which suggest the possibility of a barrier height increase possibly due to metal semiconductor reaction; to verify this hypothesis we performed Auger analysis on the gate (Fig. 6), finding that after thermal stress Ni leaves the interface and deeply migrates in the Al gate, thus justifying barrier height modification.

Auger electron spectroscopy characterization was carried out on a commercial Auger spectrometer (Physical Electronics Inc. PHI, model 590 Scanning Auger Microprobe) with a base pressure in the range of 10^(-8) Pa, a primary beam energy of 5 KeV and a spot size of about 1 um.

Another behaviour is shown by E devices, that is increase of gate resistance (Fig. 7); in this case Auger analysis allows to observe a spread of Ti layer towards the top of Al (Fig. 8), with no heavy modification at the interface: we think that this mechanism can justify the electrical degradation.

c) Biased Life-test

This test required a special test fixture [7] designed to eliminate external

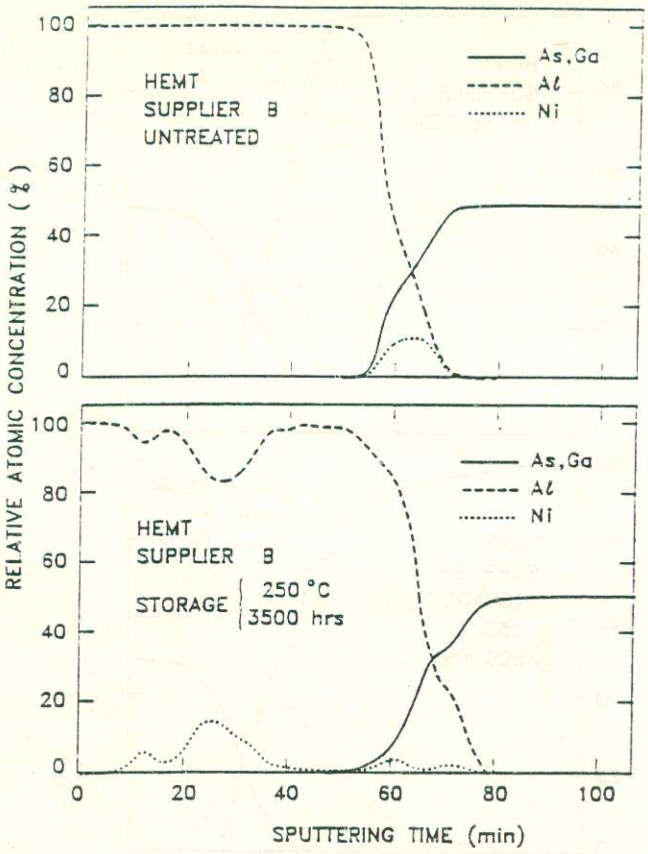

Fig. 6 : Auger analysis results on a virgin (up) and degraded B device.

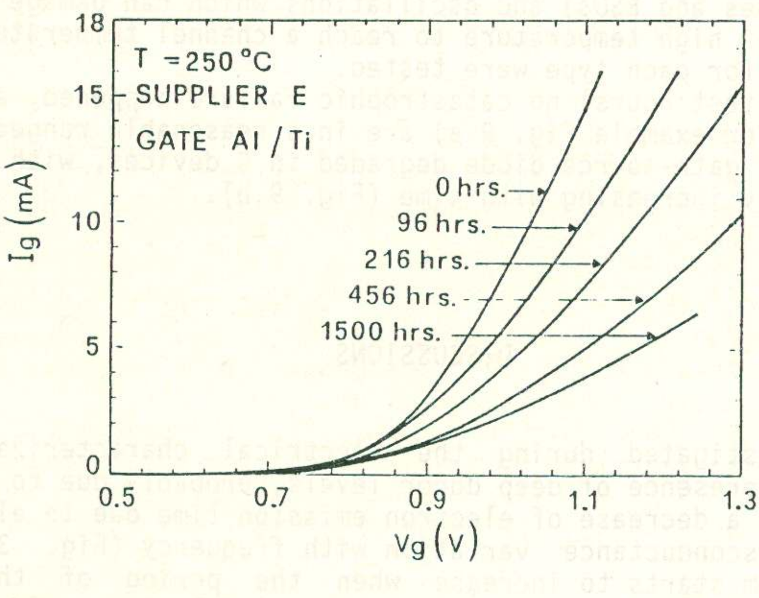

Fig. 7 : Gate source diode degradation for an E device.

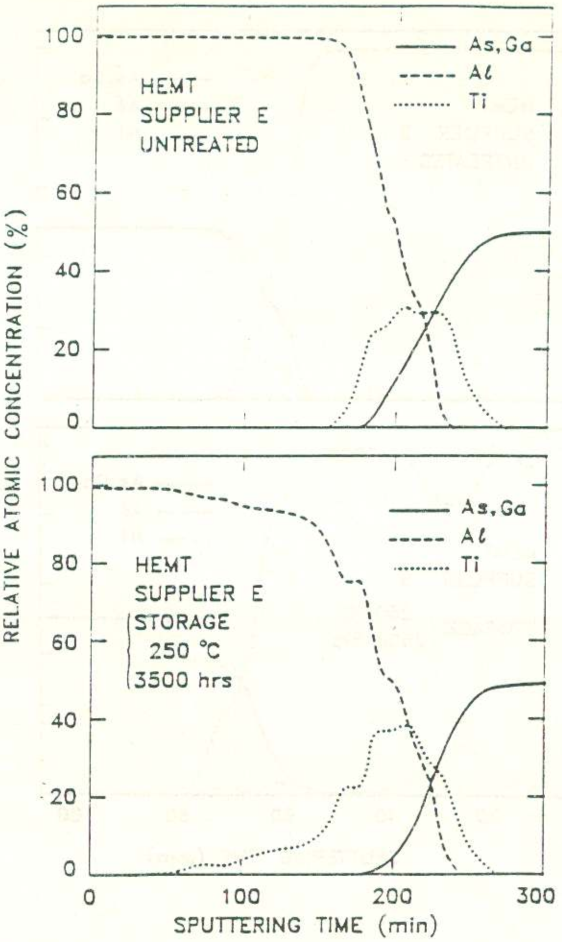

Fig. 8 : Auger analysis results on a virgin (up) and degraded E device.

effects (overstresses and ESDs) and oscillations which can damage the devices, that were biased at high temperature to reach a channel temperature around 175 °C; about 10 piece for each type were tested.
Up to now (2500 test hours) no catastrophic failure happened, and parametric degradations (see for example Fig. 9.a) are in a reasonable range; only reverse characteristics of gate-source diode degraded in C devices, with a degradation rate that is rapidly increasing with time (Fig. 9.b).

DISCUSSIONS

The effects investigated during the electrical characterization can be explained with the presence of deep donor levels, probably due to DX centers in AlGaAs, and with a decrease of electron emission time due to electric field. Referring to transconductance variation with frequency (Fig. 3), we can see that the value of gm starts to increase when the period of the sinusoidal signal applied to the gate becomes faster than the electron emission time from traps and gets its maximum when the period becomes even faster than the capture time.

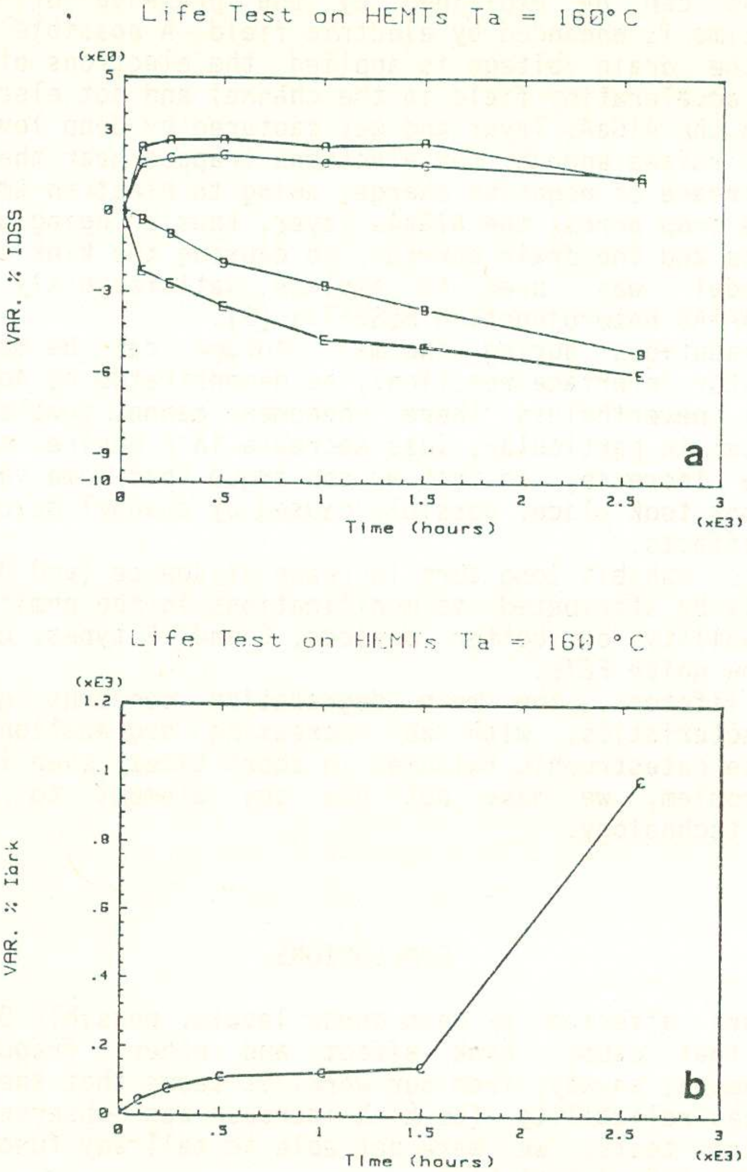

Fig. 9 : a) Mean Idss degradation during life-test.
b) Mean Ibrk degradation of C devices during life-test; Ibrk is the reverse gate-source current measured at a fixed voltage.

Increasing drain voltage, the electric field enhances the electrons emission and lowers their emission time; as a consequence, the increase of gm takes place at higher frequencies.
Emission and capture times of electrons from deep donor levels can be estimated directly from the decay time constant of the positive and negative overshoot of the output pulse reported in Fig. 2 (- 20 us and 2 us respectively for the reported bias conditions).
Emission time at 300 °K of the same order of magnitude have been already reported for deep donor levels in AlGaAs [8].

Kink effect also can be explained by the presence of deep donor levels whose emission time is enhanced by electric field. A possible explanation is as follows: when the drain voltage is applied, the electrons of the 2-D gas gain energy from the accelerating field in the channel and hot electrons starts to be injected into the AlGaAs layer and get captured by deep levels. However when drain voltage is raised enough, the electrons trapped near the drain side are emitted. The decrease of negative charge, owing to electron emission, increases the gate voltage drop across the AlGaAs layer, thus bringing up the density of channel electrons and the drain current, so causing the kink effect.

A similar model was used to explain satisfactorily kink effect in InAlAs/InGaAs/InAlAs heterojunction MESFET's [9].

Short-term degradations during thermal storage can be mainly explained by metal-semiconductor interface reactions, as demonstrated by Auger analysis on B and E devices; nevertheless there phenomena cannot completely justify some parametric drifts: in particular, Idss decrease in E devices cannot depend on gate resistance increase, so that we can argue that some variations in the 2 DEG concentrations took place, possibly caused by channel de-confinement and/or interdiffusion effects.

A and E devices exhibit long term increase of source (and drain) resistances that can probably be attributed to modifications in the ohmic contact region. Anyway the stability of better devices, C and B types, compare favourably with standard low noise FETs.

During biased lifetest, the main degradation concerns gate-source diode breakdown characteristics, with an increasing degradation rate which is expected to cause catastrophic failures in short times; even if this fact could be a serious problem, we have not now any element to attribute it to heterostructure technology.

CONCLUSIONS

HEMT devices are affected by deep donor levels, possibly DX centers, in the AlGaAs layer, that cause kink effect and other frequency and field dependent phenomena; anyway, from our work, it seems that these effects do not influence devices reliability (no kink increase was observed during aging) and, from system tests, we were not able to tell any functional difference among devices with and without kink.

The results of reliability tests (both biased and unbiased) show as a first conclusion that HEMTs compare favourably with standard low noise FETs, the main failure mechanisms not being peculiar of heterostructure technology; in particular Auger analysis demonstrated that high temperature causes metal-semiconductor interface degradation, with migration of the interdiffusion layers inside aluminum.

Applied bias seems to cause problems to C devices, even if we think that they could arise from the particular gate structure and the very critical dimensions; relevant informations from this test are expected in short times.

In general, to investigate acceleration factors of the different stresses and to deeply understand all the degradation phenomena, other tests in different conditions are required and will be carried on in the next future.

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