RELIABILITY OF GAAS PROCESSES FOR SPACE APPLICATIONS

J.F PERAY, C.FIERS, P.CRUDO, C.JACOBELLI
THOMSON COMPOSANTS MICROONDES
91401 ORSAY Cedex

ABSTRACT

This paper reviews the reliability of GaAs MMICs processes for low noise and power applications in future space systems. Each technology and library element were evaluated in terms of reliability. Results present main data of each process and an understanding of the causes of each failure modes. Improvements methodology is explained and first results are showed.

INTRODUCTION

First developed mainly for military purpose, the real growth of GaAs use is now boosted by civil applications. Mass production of GaAs MMICs has led to huge progresses in terms of cost, reliability, noise and power performances- in other words: GaAs is now mature technology. This, combined with the basic advantages of solid state devices over electronic tubes (life time, compactness, light weight, low voltage,...), will enable future space systems to use phased array active antennas for the numerous advantages they offer in radars and telecommunications: multi beam capability, beam pointing agility, increased performances, soft degradations....
Thomson Composants Microondes has developed a reliability programme to evaluate the quality of its microwave processes and to demonstrate their capability to be space qualified.
Four processes have been evaluated, two for discrete MESFETs , low noise up to 40GHz (EC1840) and high power up to 18GHz (HP05D), and two for MMICs , low noise up to 18GHz (LN05) and power up to 10GHz(HP07).

THE RELIABILITY PLAN

The reliability plan is attached to the developement steps of the process. The first step is to identify the failure modes associated with each process step and each discrete element constituing a GaAs integrated circuit such as resistors, capacitors, diodes, transistors, interconnections lines, interconnections between two metals levels , interdigital isolation cells, via holes and air bridges . For this purpose, process control monitor cells , microwave evaluation MESFETs or test MMICs are used either on wafer or test packages.

Storage or life tests are made for three high temperatures in order to determine the degradation mechanisms and the associated activation energy, (250 to 300°C for storage temperature and 175 to 225°C junction temperature for life tests). Reproducibility is evaluated by a minimum three test serie for each element or failure mode.

For microwave frequency evaluation, MMICs and MESFETs were tested in different carriers such T-PAK, chip carrier, or BMH package.

FAILURE MODE RESULTS

OHMIC CONTACTS

Many studies concern the stability of ohmic contacts during last years. Their stability is highly necessary especialy for power components. The increasing contact resistance was first evaluated with a 0.7eV activation energy . The explanation of this increasing is an exodiffusion of Gallium from the substrate and the ohmic contact layer through the barrier of the top metal level . A good choice in thichness and nature of this barrier increase the activation from 0.7 eV to 1.9eV . These value is the state of the art, but recent improvements in the barrier show no ohmic contact resistance variation after 500h at 300°C storage. In these conditions no activation is measured. Whenever ohmic contacts degradations are current dependant, these progresses must improve life time of power components.

TIPTAU GATE SINKING OF THE SCHOTTKY BARRIER

The main indicator of the stability of the MESFET is drain source current Idss. The now well known phenomenon of TiPtAu gate sinking was evaluated with a 1.45eV activation energy on the LN05 process for a 20% Idss current drift on MESFETs in high temperature storage tests. (figure 1). The same phenomenon is observed in high temperature life test with a 1.21eV activation energy.In the two cases, two mechanisms are observed: on one hand a Pt outdiffusion followed by a gold indiffusion through the Platinum barrier; on the other hand a gold diffusion along the gate edges This second phenomenon depends on the lithography and recess technology. The difference between storage and life test is attributed to a field effect acceleration and depends on the breakdown voltage of the process. A good thickness adjustment improve the median life associated to the gate sinking by a factor of ten (figure 2).

ALUMINUM SCHOTTKY GATE INSTABILITY

As earlier reported , a gate barrier variation of 0.3eV is observed. This decreasing is attributed to Al3Ti formation in the first decreasing step ; an AlGaAs formation in a succesive step increases the barrier height for long time . The associated Idss current or threshold variations are very low and then cannot be considered as failures.

ELECTROMIGRATION

Electromigration due high direct current density in Al Schottky gate could a possible failure mode for high power MESFETs . For a gate current density of $3\ 10^7$ A/cm2, electromigration appears after 336 hours. This phenomenon can be neglected in first time when maximum current density tested are 1.10^6 A/cm2 .

PURPLE PLAGUE

Aluminum gold interaction produces purple plague (Kirdendall voids) . Its effect can be measured through gate resistance variation. The corrosion increases the contact resistance between Aluminum gate level and the gold metal level. A good choice in the barrier layer increases the median life to 1000h at 300°C storage test .

RESISTOR DEGRADATION

Passive metal resistors drifts are evaluated on TaN with a 1.18eV activation energy and a MTF of 10 000 h at 200°C . The mecanism is an oxidation phenomenon. No specific failure mode was observed in life test with a 1.10^5 A/cm2 current density. Note that the test conditions were recorded in the worst case (Nitrogen atmosphere storage).

CAPACITORS

Silicon nitride capacitors have a 130V static breakdown voltage. No shift is observed for good quality Capacitors. The quality of capacitors is determined by leakage current or by pulsed voltage stress.

EARLY DEFECTS ON LOW NOISE AND POWER MESFETS

Life tests on MESFETS show early catastrophic defects . The catastrophic failure rate was evaluated to over than 10 % at the beginning of the study for low noise LN05 process and high power HP05D discrete MESFET process . The main causes were Schottky gate current breakdown due to technological inhomogeneity in the gate or ohmic contact definition. Optical process control and final increasing in optical screening decrease this early defects failure rate below 0.9 % at 200°C burn-in during 168 hours. Figures 3 and 4 show infant defects progresses for these two processes during the the last years.

MICROWAVE EVALUATION

Evaluation of LN05 process

The microwave evaluation was made on two MMIC amplifiers. The first is a 8-12GHz amplifier. Static operating life test at 125°C were made during two years without any shift on 14 MMICs. The second tested MMIC is a 2-18GHz amplifier operating at 110°C in T-PAK Package during 4000h . The MTTF measured is 38000 hours. 2-18 Ghz amplifiers were stored at 225°C and 275°C on wafer. The S parameters shift are similar to Idss shift on MESFETs . S21 parameter drift is associated to a gm transconductance or Idss current drift due to gate sinking. No other failure mode is observed.

Evaluation of HP07 process

MESFETS (8x140µm gate width) were tested in static operation at Vds=8V, Idss/2 for 200 to 250°C junction temperature.MTTF is evaluated to 36,000h at Tj=250°C. For this test the MTF associated with gain et power decreasing of more than 1 dB is evaluated to 10,000h .
The second life test is made with a driver amplifier operating in static conditions at 225°C junction temperature. 40,000hours without any defect.

Evaluation of HP05D process

The EC4790 high power MESFET issued from this process is evaluated in life test at a 175°C junction temperature with more than 20,000component hours. The MTTF is greater than 20,000 hours. No specific failure mode was attributed to epitaxy buffer type.

Evaluation of EC1840 process

Previous results were obtained for this low noise MESFET . 1,130,000h component hours with a 100,000h MTTF for storage test at 150°C and 958,000 components hours with a 20,000h MTTF for 150°C junction temperature operating.

CONCLUSION

Reliability evaluation methodology of Thomson Composants Microondes 2 inch processes has been tested. Understanding of failure mechanisms procuced great improvements. The evaluation of the 3 inch process is running with continuous reliability and yield improvement. These processes are now ready to be space qualified .

Energy activation for Idss drift (-20%)and early defects
Low noise LN05 process

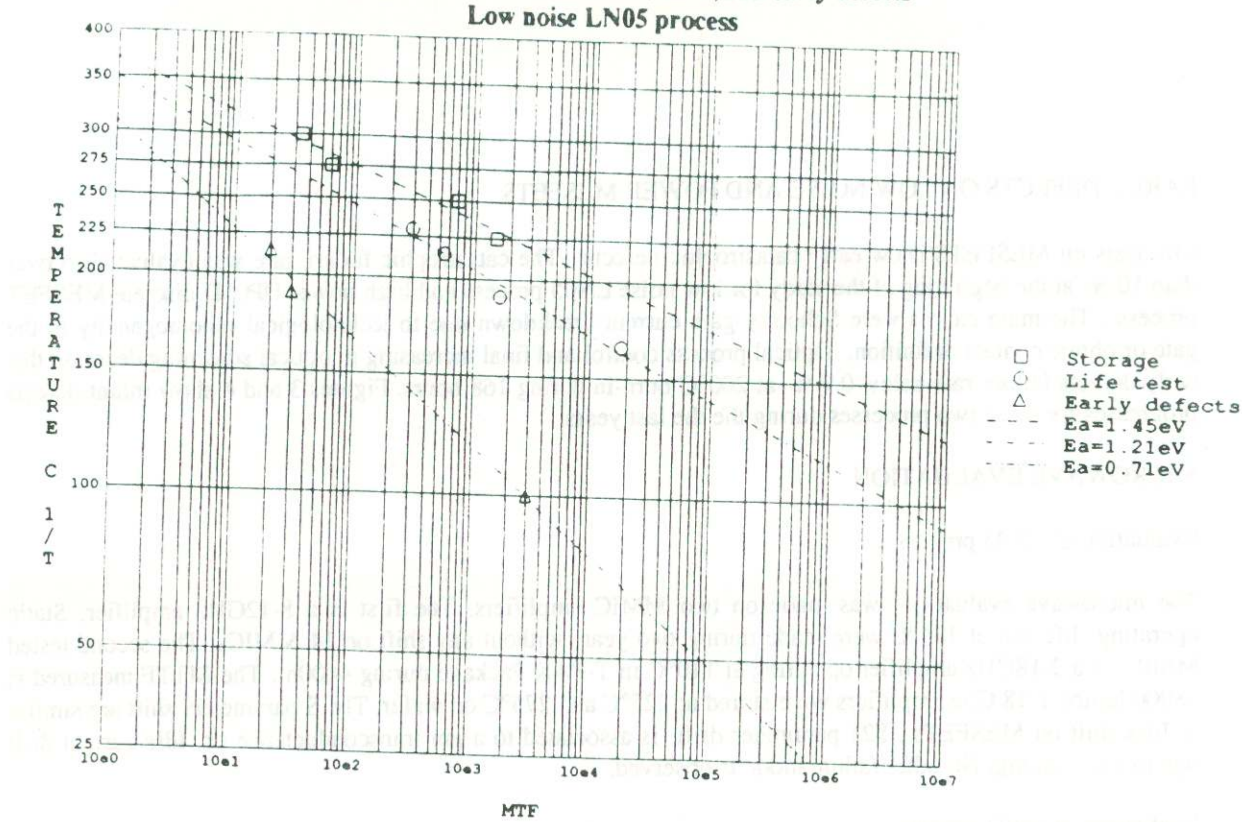

FIGURE1.

Idss drift on for 90 and improved 92 LN05 processes

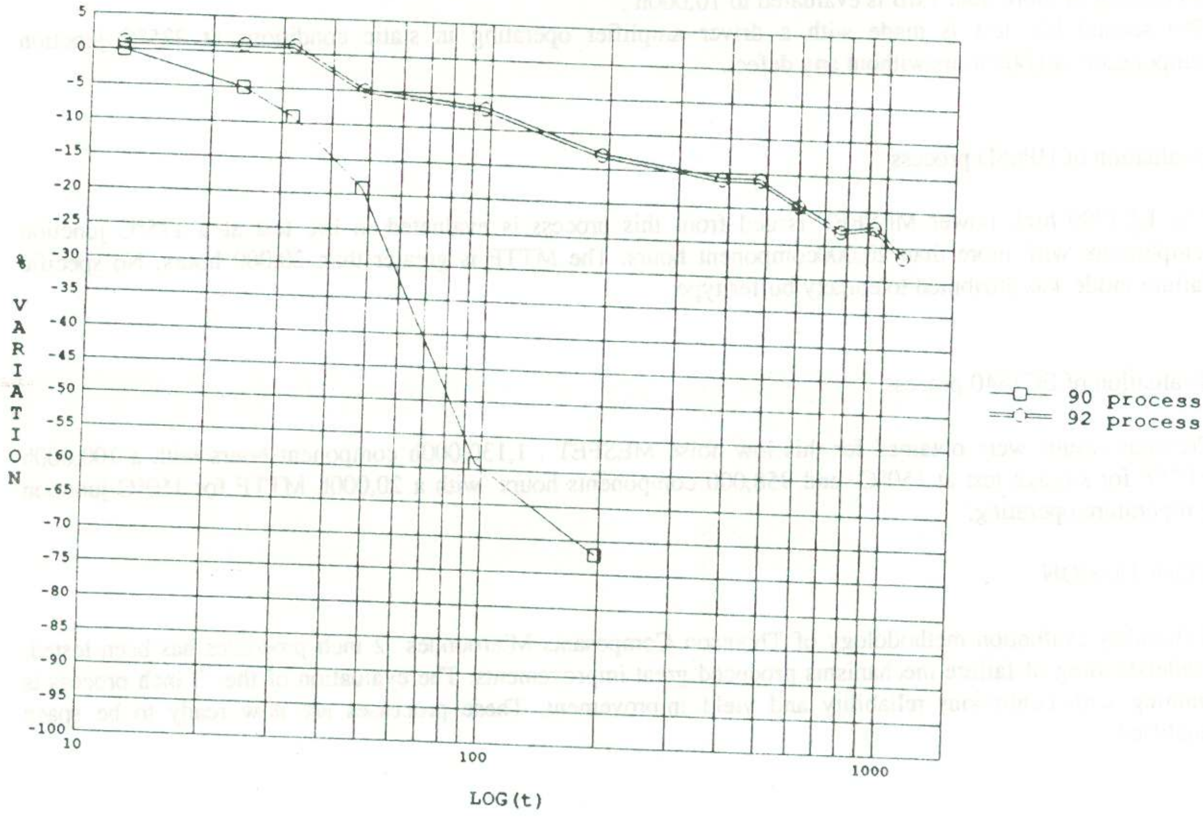

FIGURE2.

EARLY DEFECTS EVOLUTION ON LOW NOISE LN05 PROCESS
Burn-in of 246 MESFETs at 175 or 200°C

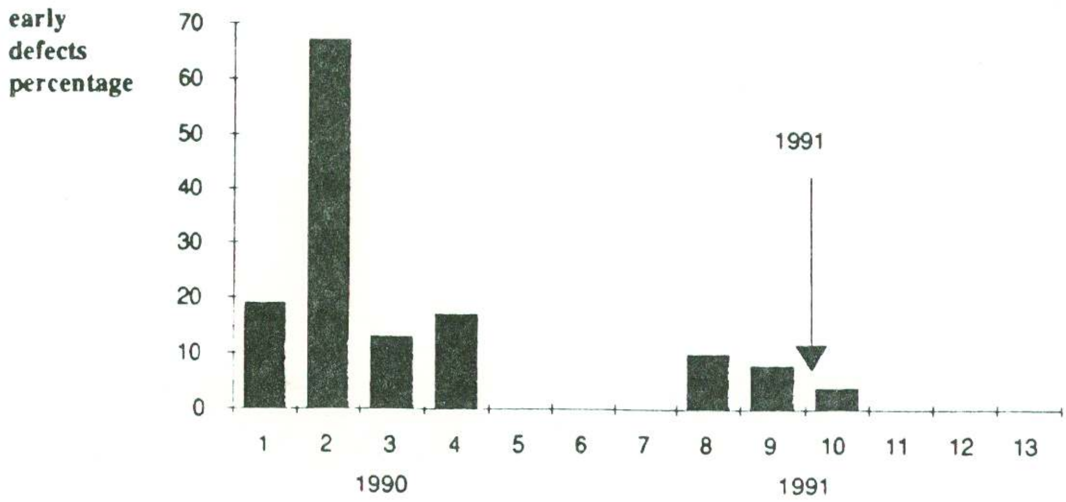

FIGURE 3

EARLY DEFECTS EVOLUTION ON HIGH POWER MESFET HP05D PROCESS

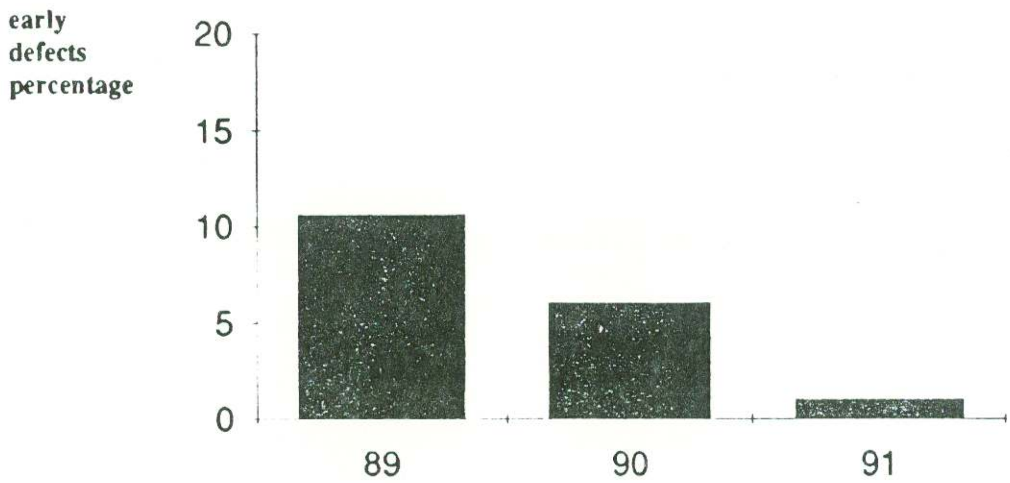

FIGURE 4