Industrial GaInP/GaAs Power HBT MMIC Process

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ABSTRACT

UMS has developed an industrial power HBT process especially dedicated to power MMICs in the 10GHz frequency range. The process has been qualified and meets the very demanding specifications required for X-Band high power amplifiers. Aside from the obvious RF performances, this includes the demonstration of the necessary stability and reproducibility of the process, associated with state-of-art reliability. It is important to note that the later has been achieved without affecting the high frequency capability of the devices, and demonstrated directly on high power transistors. Thanks to its intrinsic qualities this process can naturally also be used for other applications, like low phase noise voltage controlled oscillators, and power amplifiers at lower frequencies (for mobile phones for instance).

INTRODUCTION

UMS HB20P process is based on the developments performed at the research centers of both mother companies [1,2]. It integrates all standard passives elements available for the other existing UMS process. The latest developments have been mainly focused on improving the reliability without jeopardizing the power performances of the devices.

PROCESS

The process is based on commercially available GaInP-emitter structures, and to guaranty availability two different material suppliers have been qualified. The technology is currently running on 3-inch wafers. Transfer to 4-inch wafers is underway, and will be available around the end of the year. The layer structure has been especially optimized to allow maximum reliability without negative impact on the performances of the devices. Selective etching is extensively used in the fabrication process, resulting in excellent uniformity, and reproducibility of the critical parameters. This is especially important for the etching of the emitter, and can be controlled on the base sheet resistance measured on TLM modules (Fig 2). The intrinsic and extrinsic values correspond to results obtained respectively before and after etching the emitter. The spread observed in both cases is almost identical, indicating the negligeable impact of the process. The result is therefore mainly conditioned by the epitaxy, yielding values better than 3%. The current gain measured on test transistors also shows very good uniformity and reproducibility. This is true for large surface as well as for single-finger devices (Fig 1 and 3). The transistors have a ledge passivation guarantying high current gain and excellent reliability. The higher current gain measured on small-dimension transistors compared to jumbo (100x100µm2) is a confirmation of the effectiveness of the

passivation. During the process, more than 15 PCM modules are measured, and over 100 parameters extracted, to monitor and guaranty its stability and reproducibility. S-parameters of a coplanar single-finger transistor are measured at the end of the process, for final acceptance of the wafers. Again, like on the DC data, the trend-chart of the equivalent circuit parameters show the excellent reproducibility of the process. In particular, Fig-4 shows the evolution of the base-collector capacitance and the base resistance.
The power transistors feature integrated ballast resistors and a thermal drain (Fig. 5), which allow for a maximum output power and an excellent thermal stability. Different basic cell topologies are available with output power exceeding 1W at 10GHz with a power added efficiency over 60% (Fig. 6). For non-power applications, or for low-voltage operation, a second version of the process is available without integrated ballast resistors. All passive elements necessary for monolithic integration are realized using standard process blocks already available at UMS.
Based on the qualified process, other versions are being specifically optimized for high-speed optical communication, as well as low-cost low-voltage mobicom applications.

RELIABILITY

In order to achieve the very demanding reliability objective for power applications at X-Band, the complete process has been thoroughly optimized. After identification of the degradation mechanisms the corresponding steps have been modified. In order to have a rapid feed-back, and therefore reduce to a minimum the optimization period, simple test devices were first stressed on-wafer, in some cases directly during the process. The final results have then been confirmed on real RF power transistors (typically 800mW to 1W cells) mounted in special carriers. Over 100 power transistors have been or are still being stressed at accelerated conditions (elevated junction temperatures and current densities). Fig. 7 and 8 show the evolution of the current gain of several 8-finger devices under stress at a current density of 40kA.cm-2 and junction temperatures of 200 and 250°C respectively. In both cases, all devices have reached 5000 hours without showing any catastrophic degradation. The test are still running, and up to now no activation energy could be estimated. However, based on these results, a very conservative extrapolation with an activation energy of 1eV gives an MTF exceeding 10^6 hours at 125°C and 25kA.cm-2. To our knowledge, these tests show the best lifetime results obtained on similar devices.

MMIC

X-band as well as wide-band power amplifiers have been fabricated using this process [3], showing state-of-the-art performances. Voltage controlled oscillators have also been fabricated using the ballast-free version of the process [4].

CONCLUSION

To our knowledge this is the first demonstration of a fully qualified GaInP/GaAs HBT process suitable for high power applications at X-Band, associating at the same time state-of-the-art power performances and best lifetime results. Conservative life-time estimation based on stress tests of X-band power cells exceeds 10^6 hours at 125°C and 25kA.cm-2.

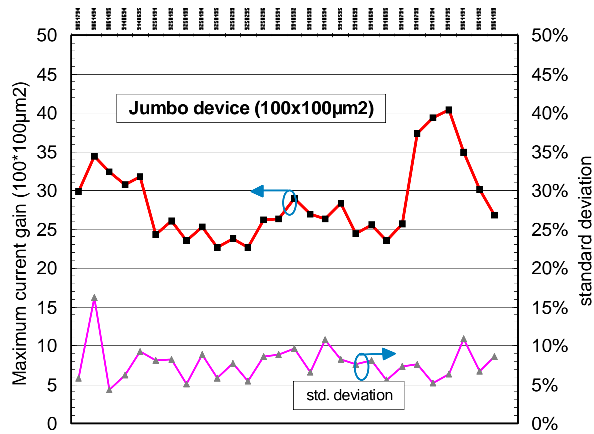

Fig. 1: Trend-chart of the current gain measured on a jumbo device (100x100µm2).

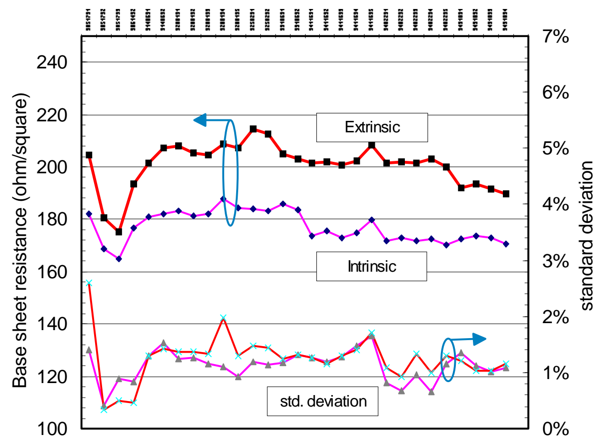

Fig. 2: Trend-chart of the intrinsic and extrinsic base sheet resistance.

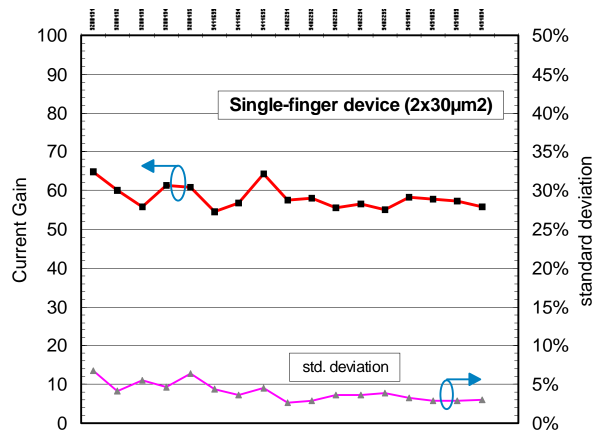

Fig. 3: Trend-chart of the current gain measured on a single-finger device (2x30µm2).

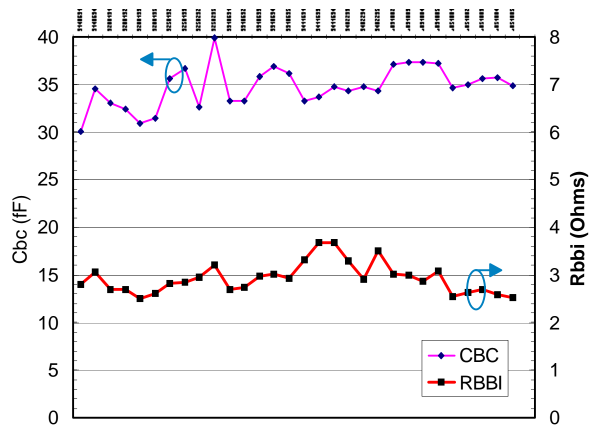

Fig. 4: Trend-chart of Cbc and Rbbi extracted from S-parameter measurement of a single-finger device (2x30µm2).

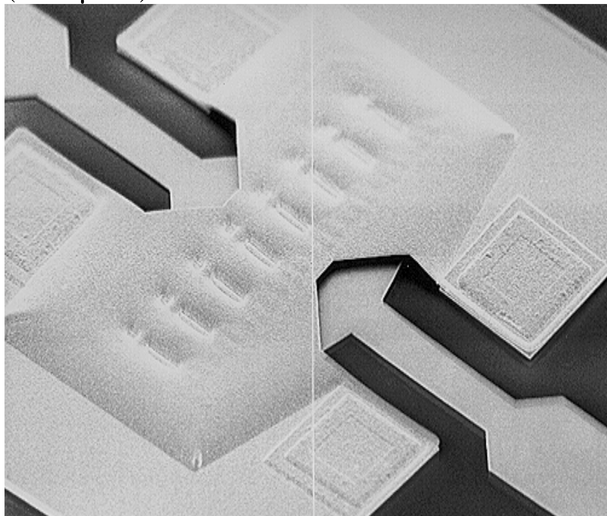

Fig. 5: SEM picture of a 8-finger power HBT.

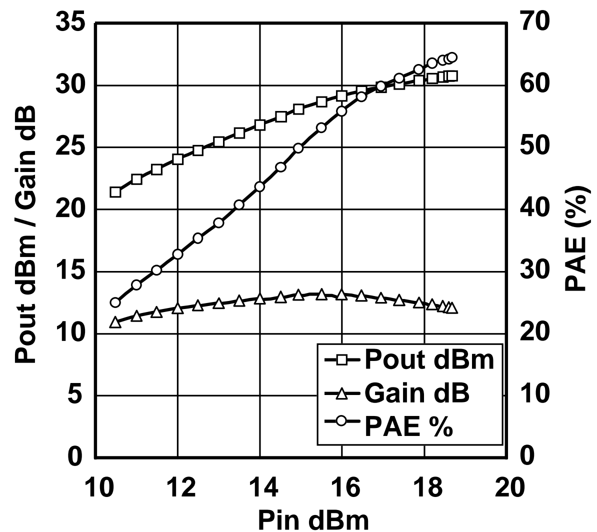

Fig. 6: Output power versus input power of a 10-finger power HBT at 10GHz. Vce = 8V

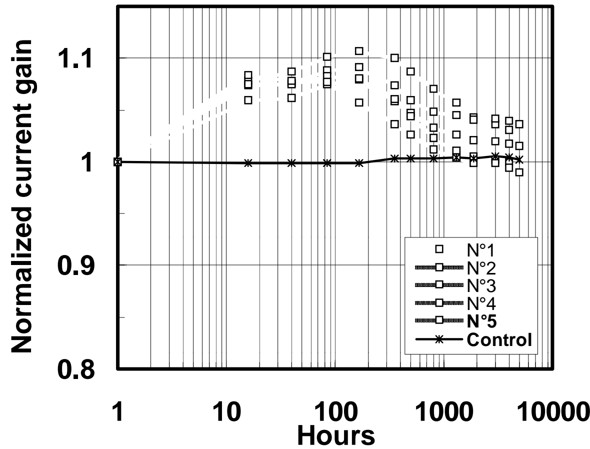

Fig. 7: Evolution of the current gain during the stress tests of 8-finger power transistors at Je=40kA.cm-2 and Tj = 200°C.

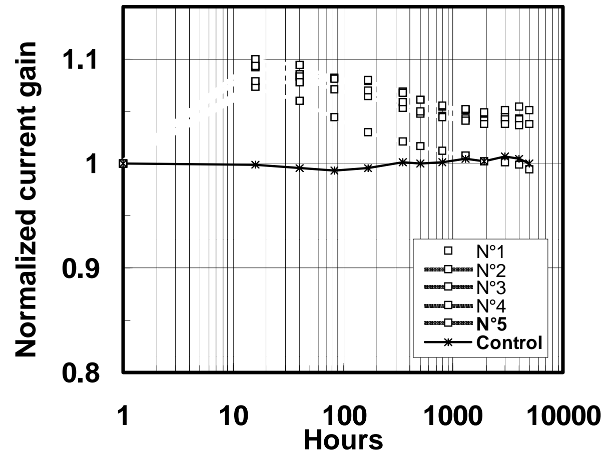

Fig. 8: Evolution of the current gain during the stress tests of 8-finger power transistors at Je=40kA.cm-2 and Tj = 250°C.

ACKNOWLEDGEMENT

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REFERENCES

[1] K. Riepe, H. Leier, U. Seiler, A. Marten and H. Sledzik; High-Efficiency GaInP/GaAs HBT MMIC Power Amplifier with up to 9W Output Power at 10GHz; 1996; IEEE Micr. And Guided wave letters, Vol. 6; No1; pp22-24.

[2] S.L. Delage, D. Floriot, H. Blanck, S. Cassette, E. Chartier, M.A. diForte-Poisson, C. Brylinski, D. Pons, P. Roux, P. Bourne, and P. Chaumas; Power GaInP/GaAs HBT MMICs; 24th European Microwave Conference Prc., September 1994, pp. 1143.

[3] J-P. Viaud et al.; GaInP/GaAs HBT power MMICs; 30th European Microwave Conference; October 2000.

[4] M. Camiade et al.; to be published.