X-BAND TECHNOLOGIES AND MMICS COMPARISON FOR ACTIVE PHASED ARRAY RADAR

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ABSTRACT

During the last 3 years, the French MOD has supported Technologies developments or Specific MMICs design for power amplification from S-Band to Ku-Band (i.e. 18 GHz), for radar and electronic warfare applications. In this paper, we aim at presenting and analysing the results obtained on three X-Band power amplifiers using different GaAs technologies and designs to answer to the same specifications target. This comparison was conducted from a technological and measurement point of view and according to an exhaustive test plan suited to T/R module evaluation. State of the Art results are promising and able to fulfil military needs in the near future.

INTRODUCTION

X-Band power amplifier is a key component for active phased array radar considering the radiated power, total consumption and cost issues of the T/R modules. Typical specifications of the related MMICs were defined initially in order to meet airborne radar applications, aiming at fulfilling, for instance, the European Radar program requirements called AMSAR (Airborne Multi-role Solid-state Active array Radar). The following technologies were chosen on the basis of the demonstrated results in similar applications and their industrial maturity. In this frame of mind, we have benchmarked Infineon DIOM 20 process and Triquint Power PHEMT. For the HBT, the French MOD has supported the development of the so-called HB20P process within United Monolithic Semiconductors Company. Designs were under the responsibility of Thales Airborne Systems for the first one and Thales Microwave for the two others. The Centre d'ELectronique de l'ARmement laboratories conducted characterisation, technology assessments and microwave measurements.

TECHNOLOGY ASSESSMENT

The DIOM 20 process (Double contact implantation, one Ohmic/gate metal step) which is a self aligned gate process, presents a process simplicity with only 12 levels of masks, a single metallization step for both ohmic and Schottky contacts (Cr/Au/W/Au), no gate recess, and a truly planar 0.5 micron gate lithography performed by an I line stepper. Adding different passivation layers, two interconnection metallizations complete the process, and finally a back side process module including wet etched, plated via holes and a 100 micron wafer thinning.

During the project, INFINEON successfully switched from 3 inches to 4 inches (now in 6 inches) and optimized the process parameters.

No defects were found on the 4-in delivered wafer and the process revealed consistent with the literature. Only one discrepancy was pointed out concerning the gate length which was a little bit too large (550 nm, see fig.1) This was directly correlated with a lower IDSS (185 mA/mm instead of a 230 mA/mm nominal value).

The Power Amplifier using TriQuint "Ku-PwrPHEMT" 0.25µm technology was, for its active part, an AlGaAs/InGaAs/GaAs double recess process (0.4 µm/1.4 µm) between a source-drain spacing of 2.9 µm. A typical cross section is presented in fig 2.

A T-shape gate with a classical Ti/Pt/Au metallurgy (300 nm length instead of a 250 drawn value), certainly patterned by electron beam lithography, as well as a double heterojunction were used.
The gate was shifted of about 125 nm towards the source but the double recess structure was symmetrical. The process also included AuGeNi ohmic contacts, nitride passivation layers, MIM capacitors airbridges and via holes through a 100 µm thinned substrate.
Two discrepancies were found (discontinuity into the Titanium gate barrier and deep ohmic contact interdiffusion) but further reliability works should be necessary to assure that such findings are really a reliability concern and not a cosmetic issue.

Initially designed with AlGaAs emitter, the HBT process, especially optimized for X-band high power applications, has been shifted to InGaP structure like many competitors [1, 2] for a better reliability and for larger process margins. The production was carried out on 3-in epitaxial wafers grown by MOCVD and transferred into 4 inches.
The processed wafers incorporated an InGaAs cap and a highly carbon-doped base layer with a thickness of 100 nm. A 1-µm-thick GaAs collector layer was used to obtain high breakdown voltages. The process utilized a conventional mesa approach and a non self-aligned base contact (see fig 3).
To enhance the reliability, an emitter-base ledge and non-alloyed contacts, except for sub-collector, were introduced. Stepper performed all lithography steps. Selective dry etching and a deep, high dose, proton isolation were also applied. The HB20P option of UMS HBT technologies also included gold plated thermal drain, integrated emitter ballast and standard passive components. A great number of technological splits (material, doping concentration, thickness) were conducted during the programs.

Intrinsic advantages and drawbacks of MESFET, HEMT and HBT have been already described [3, 4, 5] however the real performance of the X-band MMICs, is strongly affected by design options, passive elements and thermal management. In our case, the 3 designs exhibit roughly the same size.
Table 1 summarizes technology comparison. If we transfer MURPHY laws [6] from silicon field to gallium arsenide technologies, yield appears to be the product of process complexity (related to intrinsic defect density for each level) and die area. In fact, as the three processes exhibit a similar BEOL technology (post transistor manufacturing), we take into account only the active field of which two major contributors, which are process complexity and active area, vary in an opposite way.
So, this present methodology is purely indicative. Is HBT technology more difficult to produce than FET ones? On the one hand, lithography is less aggressive but, on the other hand, misalignment tolerance is pretty tough as 0.2 µm lithography requirements to achieve high reliability performance for X-bands application.
In conclusion, the most important criteria are the manufacturer process stability and quality, rather than intrinsic technological parameters.

MMICS SPECIFICATIONS AND TEST PLAN

In order to fulfil T/R modules requirements, and subsequently phased array antenna specifications, the MMICs have been designed with the targeted characteristics stated in Tab 2.
The three MMICs exhibit 2 stages structure (see Tab 3) and were obtained in one technology run. A fishbone-FET structure has been chosen for the MESFET devices (instead of comb-FET one), non-linear stability analysis needed for the HBT one, and complementary non-linear models performed for the PHEMT.
The three devices have been soldered in metallic test fixture including capacitors and SMA connectors.
A test plan with three types of waveform and two temperatures in a 20% bandwidth around 10GHz, have been implemented in order to assess the operational capability of each technology regarding the relevant measurements which are, for instance, the output power, the consumption, the AM/AM and AM/PM behaviour [7].
The test bench, previously developed for AMSAR program, included a vector network analyser (VNA) Wiltron 360B and a pulsed power supply. The “Fixed Profile“ of the VNA mode got the scattering of the device under test in amplitude and phase versus frequency for different input power values, so that the output power was obtaining by calculation. In the same way, pulse droop was obtained with the “Pulse Profile” mode, which allowed getting the [S21] parameter in amplitude and phase, at different time values in the pulse and different input power values.

MEASUREMENT RESULTS

The maximum output power at the 2dB compression point (Fig. 4-A) was 39dBm, 38dBm and 37dBm respectively for PHEMT, HBT and MESFET HPAs. In the same conditions, and at 10 GHz and 25°c, the associated Power Added Efficiency, was respectively 45%, 30% and 40%. As a matter of fact, the maximum PAE for the HBT was achieved at more compressed level (up to 40%) and MESFET results have to be corrected by the probably need of a driver stage in order to compensate the lower linear gain on the whole bandwidth.
As can be seen from the AM/AM curve (Fig. 4-B), the lower gain and output power of the MESFET devices, as well as the 2 dB added gain of the PHEMT HPA compared to the HBT one, were confirmed at 10 GHz.
The pulse profile test, with a pulsed VNA, allowed us to quantify the phase variation with the input power (Fig. 4-B) which is a crucial parameter regarding the dispersion between T/R modules. From this point of view, the 40° deviation phase presented by the PHEMT HPA (instead of the less than 10° for the HBT and MESFET devices), could be a concern for the radar calibration complexity management.
The impact of temperature on the output power and phase behaviour was quite the same for the 3 amplifiers (the output power variation at the 2dB compression point around 0,02dB/°C)
The pulse profile measurement, performed on the MESFET and HBT devices for the two temperatures and the three waveforms, has revealed that, for both devices and at the 2dB compression point, the pulse droop was near 3dB, whereas 10° variation was achieved for the phase droop. Especially for pulse droop, we have noted sensitivity between the different waveform configuration (2 dB difference); these phenomena are under investigations by the mean of simulation tools.

SUMMARY

MMICs developed and manufactured for the French MOD during the last 3 years, using three technologies, exhibit state of the art performances for X-Band radar applications. These technologies are now very mature and present some similar behaviours and also different trade-off for our MMICs solutions and needs. Considering the power capability and potential future improvements (in term of design especially), GaAs-based technologies will be able to fulfil the main defence requirements (i.e. radar applications) for the next 5 years. Further works aim at assessing the operational capability of each technology regarding the operational use (intra pulse behaviour, pulse to pulse stability and extrinsic reliability). We are also currently promoting wide bandgap technologies in order to build the next systems breakthroughs.

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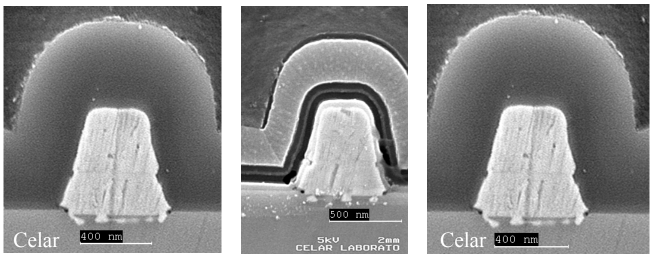

Fig 1 : MESFET gate structure with different staining delineations. We can also observe a special sintering process for Schottky contacts

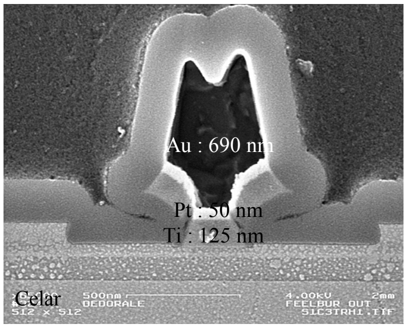

Fig 2 : PHEMT Mushroom Gate (after staining).

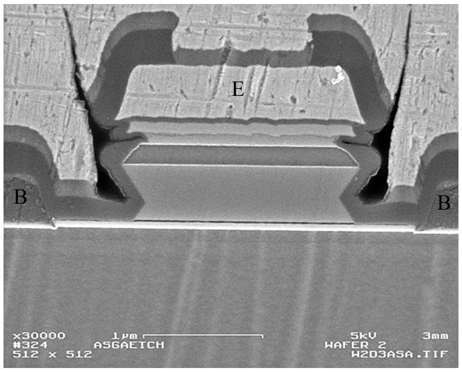

Fig 3: HB 20P structure.

	MESFET	**PHEMT**	**HBT**
Process complexity (related to mask levels)	12	16	20
Chip area (mm^2)	19	18	20
Active Area (transistor) (reference : HBT= 1X)	2x	1.2x	1x
Lithography (µm)	0.5	0.2	2
Passive elements number (reference : HBT= 1X)	1x	1x	1x
Substrate thickness (µm)	100	100	100
SPC deployment	Yes	Yes	In progress

Tab 1: Process Comparison

	Specifications
Fc / bandwidth	10GHz / 10%
Waveforms (pulse/duty cycle)	WF1: 1µs@10%, WF2: 10µs@10%, WF3: 10µs@30%
Output power at max. PAE (-2 dBc)	39 dBm
PAE (%)	35%
Power Gain (max. PAE)	30 dB
Temperatures (T case)	25 and 50°C

Tab 2: Specifications and associated waveforms

	MESFET	PHEMT	HBT
Manufacturer	Infineon	Triquint	UMS
Process	DIOM20	PPHEMT	HB20P
Chip area (mm²)	19	18	20
Nb of stages	2	2	2
1° stage	6.4mm	2.7mm	0.96mm
2° stage	16mm	13.4mm	2.6mm

Tab 3: Design statement

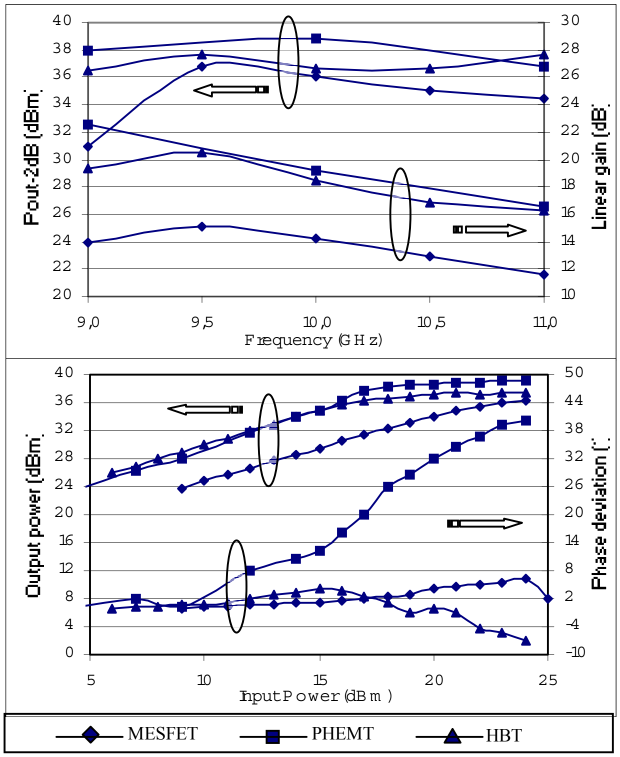

Fig. 4 (WF1, @ 25°c):
A (up): Output power and linear gain Vs frequency,
B (down): AM/AM and AM/PM curves @10 GHz