InGaP Power HBTs : Basic power cells for High Power Transistors

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Abstract –Power HBT Technology offers today the best compromise for high power – high efficiency amplifiers up to Ku band. Many improvements have been published in the past to offer a better behaviour in terms of thermal heating and microwave performances. Since the reliability limiting factors have been solved, significant improvements could be proposed to get more power. In this paper, we report on the proposal of new elementary cells used in multi-finger transistors. Based on these, compact very high power amplifiers could be considered.

I – Introduction

GaAs based power HBT technology offers today the best compromise in terms of efficiency / power / linearity and cost depending on the application addressed. A large part of the manufactured devices or opened foundry services are proposed for communications based applications in which medium power and high linearity are required. The power handling capabilities and maximum frequency of use is thus limited to oriented mobile phone applications. For high power applications (>3W/mm) where reliability becomes the relevant factor due to high junction temperature (>150°C) [1-2-3], a lot of work has been done in the past to raise the MTF value. Successful developments and results have been obtained in C & X bands in pulsed and CW modes. Defence and Spatial applications are in these cases , the main consumers. However, the recent emerging of very high power amplifiers for base stations offer an attractive civil application in L band [4] to the HBT community. As it has been many times stressed in the past, the thermal management is the key limiting factor of this technology. State of the art multi-finger HBT delivers 1.2 W at 10 GHz with 50% min. of PAE. The design is based on a parallel topology combining up to 8 fingers of 40µm length spaced roughly by the same number. For L to C bands, the fishbone topology offers the best compromise between performance and compactness. In this case, the finger length could be upgraded to 100 and 70µm respectively.

To increase the power density of these transistors, we have developed a new power cell (Bi-Cell), basically designed by the combination of 2 fingers. More details on this will be given in part II. The first results given in this summary assess this solution to demonstrate a 2.5 W power X band transistor. An equivalent doubling of the output power is expected for L band application with output power ranging from 10 to 20 W by transistor. Notice that improved thermal management has been developed to sustain the increase in dissipated power. Depending on the mode of operation (CW or pulsed) and the final application, different solutions could be used.

II – New basic power cells

In figure (1a), we give a schematic cross section of a classical one finger HBT transistor in comparison to the new power cells developed in this study (b) & (c). In Fig. (1b), we observe the combination of 2 fingers sharing only one central base stripe. Note that the surface is unchanged in comparison to the surface of 2 independent fingers. In Fig. (1c), a more common combination is used. The width of the central base stripe is adjusted to homogenise the input base signal (RF and DC) between the two fingers. Significant improvement are expected with this structure. First, a drastic reduction of the output parasitic collector capacitance should be obtained. The main contribution of this parameter comes from the common surface shared between the extrinsic n- collector layer and the thick metal used to support the thermal spreader. The distance d (Fig. 1a) multiplied by the emitter length L gives the surface of an equivalent MIM parallel plate capacitance. In Fig. (1b) & (1c), this effect disappears. Moreover, the base-collector capacitance should present a lower value due to reduced border effects. Fig (1c) would be more suitable for high frequency operation due to a lower base access resistance. From a technological processing point of view, the width of the window used to etched the BCB layer (BenzoCycloButhene) is increased in comparison to Fig. (1a). Better uniformity and yield are expected. This enlarged access on the emitter contacts would also make easier the thermal cooling of the active layer. Different multi- finger transistors have been designed to test the potentialities of these new basic cells. In figures 2 (a) and 2 (b), we make a comparison between a 8 finger transistor of 2x40 μm^2 (320 µm of total emitter length) and a 8 Bi-cell transistor (640 µm of total emitter length). Note that the scale is the same for the 2 photos.

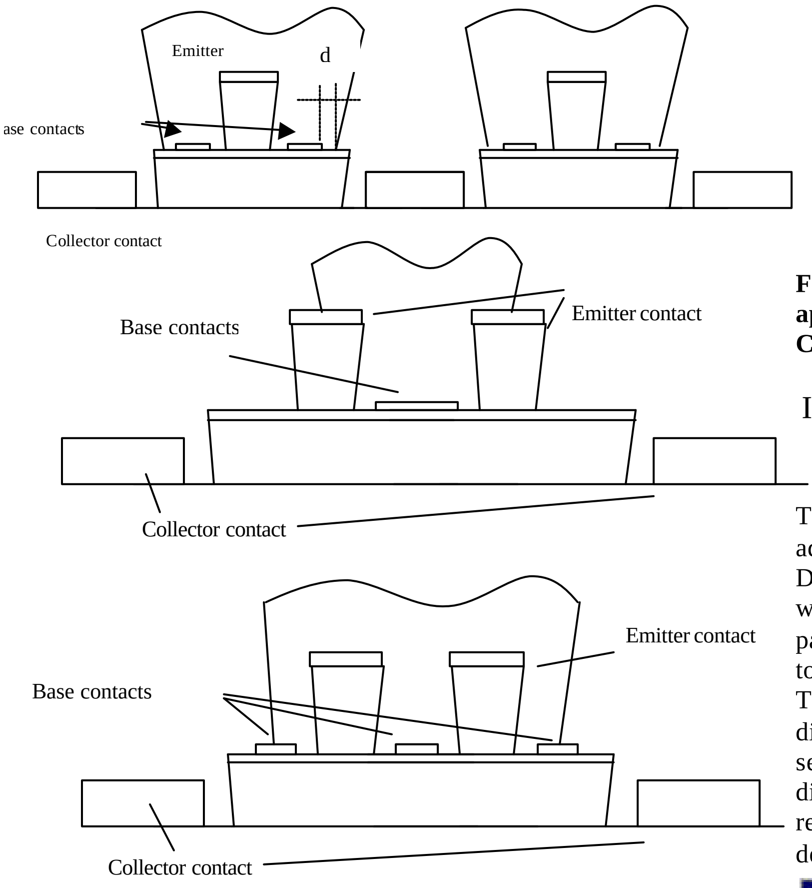

Figure 1 : From top to bottom (a) : schematic view of 2 cells. (b) : BiCell concept with one base stripe. (1c) : Bi-Cell concept with 3 base stripes

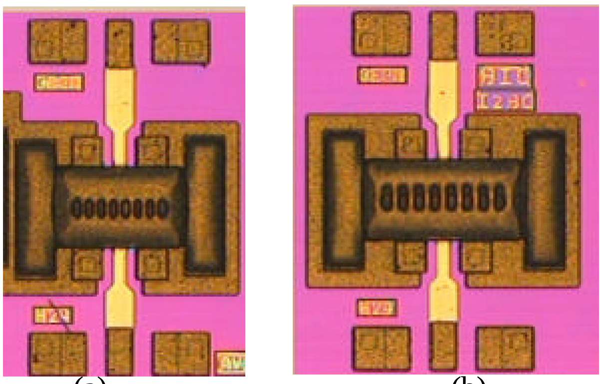
(a) (b)

Figure 2 : Comparison between a 8 finger HBT of 2x40µm^2 (0.32mm) and a 8 Bi-Cell HBT (0.64mm). Chip size : 1.0x0.6mm^2

We make the same comparison for a fishbone topology for which we present in Fig (3), a 20 Bi-cell of 2x2x100 µm^2 (4.0 mm). Fig 2b corresponds to an expected 2.5 W X- Band transistor and Fig 3b to a 20 W L- Band transistor. The surfaces of the chips are mentioned in comments under the photos.

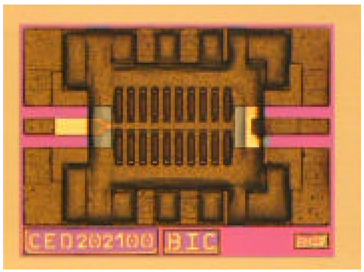

Figure 3 : Very high power design for L band application : 20 Bi-Cell of 2x2x100µm^2 (4 mm). Chip size : 1.3x0.6mm^2.

III Thermal Analysis for a Transient Mode of Operation

The distance between the two emitters has to be adjusted in respect of the mode of operation. Depending on the pulse length and the duty cycle, we use thermal modelling to optimise this parameter in order to limit further thermal heating to 5 °C for short and long pulses applications Typically, we got a factor two between the 2 distances. The figure 4 gives an example of a cross section of one bi-cell for which 2 volumes of dissipated power have been defined in the collector regions corresponding to 4W/mm of RF power density.

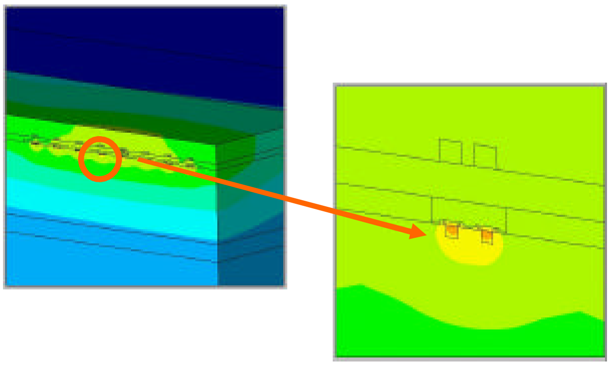

Figure 4 : Thermal simulation and cross section of a 8 bi- cell transistor. In short pulse (x10µs), the stabilised max. temperature is limited to 150°C.

IV – DC and RF Results

Several lots of wafers have been fabricated. The epitaxial structures of InGaP HBTs have already been detailed respectively in [1] and [2] for L and Ku band applications. Corresponding to Fig. (2a) & (2b), a very thick Gold radiator (>20µm) has been processed on top of the emitter fingers.

In this summary, we present a DC characteristic and S parameter on- wafer measurements corresponding to the schematic cross section (1b) and (1c). Fig. 5 gives the base- emitter voltage (Vbe) drift versus the collector current for different collector- emitter voltage (Vce). This presentation is very common to observe the thermal behaviour of power HBTs. From this characteristic, it appears that the trend is very similar between a 8 finger transistor of 2x40µm^2 and a 4 bi-cell transistor with the same total emitter length.

In X-Band, at 10GHz, a power gain (MSG) close to 12.5 dB is expected for a 2.5 W power transistor (8 bi-cells of 2x2x40µm^2). In Fig. 6, we present the RF gain versus frequency for transistors based on the Bi- cell concept shown in fig (1b) and (1c). The bias point is fixed at Vce=6.0V (Bvce0 = 18V – Ib=1µA) and Ic=130mA in order to limit the overheating.

Using a symmetrical base stripe like in Fig. 1c reduce the base resistance and increase this one by 2 dB in comparison to Fig. 1b. Note also a slight decreasing of the base- collector capacitance by unit length in comparison to a standard cell (fig 1a).

For L band application, we present in Fig. 7 the RF performances of a 16 Bi-cell transistors. The bias point is fixed at Vce=6.0V and Ic=260mA (Bvce0 = 31V – Ib=1µA). This last example is very promising and supports the idea that power HBT could challenged Si Bipolar and LDMOS technologies.

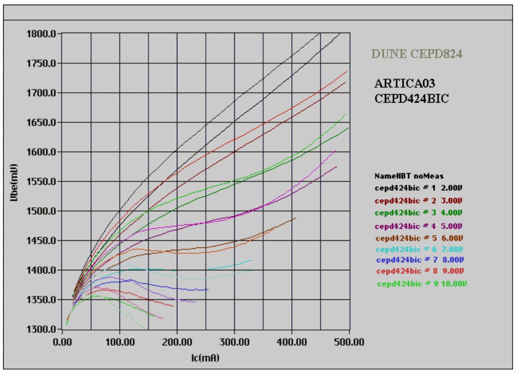

Fig 5 : Vbe versus collector current Ic for a set of Vce. Comparison between a 8 finger of 2x40µm^2 and a 4 Bi-Cell of 2x2x40µm^2 (same development).

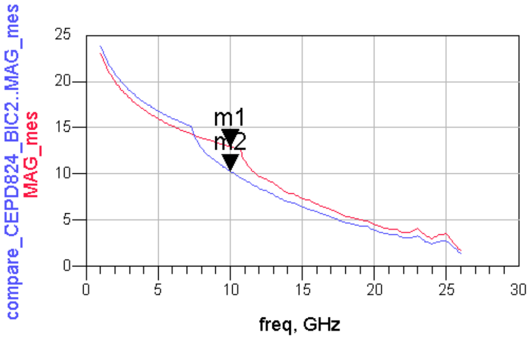

Fig 6 : RF gain of different 8 Bi-Cell transistors (0.64mm emitter length). Vce=6V – Ic=130mA. Blue curve corresponds to the fig 1b, red curve to the fig. 1c.

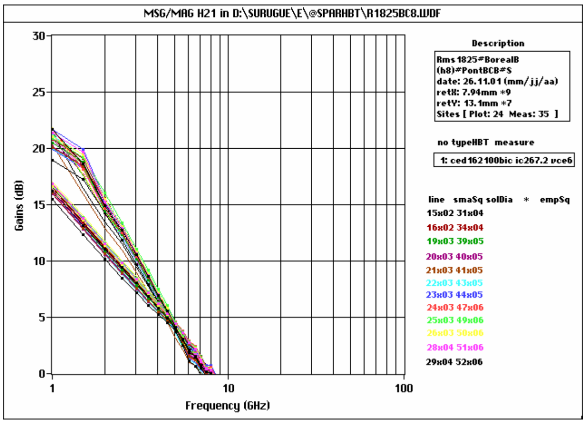

Fig 7 : RF gain of different 20 Bi-Cell L Band transistors (4mm of emitter length). Vce=6V – Ic=260mA.

RF large signal measurements are underway on X-band transistors and should be presented at the GaAs 2002 Symposium. Based on non linear fully electro-thermal model, with a special effort to fit tightly the thermal transient behaviour, we present in Fig 8 a non linear simulation from which a 2.45W at 10GHz with 55% PAE is expected on the transistor of the Fig. 2b.

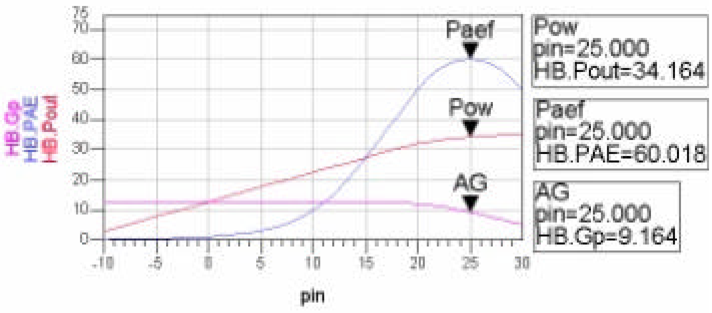

Fig.8 : Non linear simulations of a 8 Bi-cell transistor (0.64mm of emitter length). Vce=9.5V.

Similar results have been obtained for longer emitter finger (up to 100µm length). As it is well known, the power gain rapidly decrease in respect of the emitter length. Nevertheless, with a specific modification of the base stripes, we claim that this limit could be pushed from 40 to 80µm keeping safe the power gain. With this last evolution of the Bi-cell design, 4W X-Band power transistor could be achieved.

V – Conclusion

We have proposed in this summary a new basic cell used in multi finger power HBTs for application ranging from L to Ku bands. The basic power HBT transistor (1.2 to 1.5W as widespread value at 10

GHz) in now doubled for the same surface keeping constant a high PAE of 55%.

With this new topology, a significant improvement is expected in the design of very compact integrated or hybrid amplifiers. Non linear measurements would confirm the great advantages of this evolution for very high power applications.

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