MANUFACTURABILITY OF 0.1-µm MILLIMETERWAVE LOW-NOISE InP HEMTs

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ABSTRACT

We report on the manufacturability of state-of-the-art passivated 0.1-µm low-noise InP HEMTs. These HEMTs offer an attractive, cost-effective solution to millimeter-wave satellite communications. We will discuss their yield and reproducibility, as well as typical performance at V- and W-bands.

INTRODUCTION

Since its introduction in the mid-1980s, the InP HEMT (also known as the AlInAs/GaInAs HEMT) has been widely regarded as the most promising device for millimeterwave low-noise applications. It presently exhibits the lowest noise figures (~1.0 dB at 60 GHz) and highest cutoff frequencies (>300 GHz) among all 3-terminal semiconductor devices [1, 2], and is also the only type of transistor that has demonstrated useful gain at frequencies much above 100 GHz (7.3 dB at 140 GHz) [3].

Despite these impressive results, the InP HEMT technology has not gained wide acceptance in the microwave and millimeterwave community. It is often perceived as an immature technology or, worse yet, one which is too expensive to manufacture. In this paper, we report for the first time a state-of-the-art passivated 0.1-µm InP HEMT technology, which offers high performance, high reproducibility, and adequate yield. We will describe the major features of our technology and discuss its present status below.

PROCESS DESCRIPTION

Our baseline InP HEMT consists of a 250-nm undoped AlInAs buffer, a 40-nm GaInAs channel, a 1.5-nm undoped spacer, an 8-nm AlInAs donor layer doped to approximately 7×10^{18} cm^{-3}, and, finally, a 7-nm GaInAs doped cap, all grown lattice-matched to InP on a 2-inch semi-insulating substrate. Because of its simplicity, this particular HEMT structure has been chosen for most of our low-noise work in the past several years. It typically exhibits an electron sheet density of 2.5 to 2.8×10^{12} cm^{-2} and a room-temperature mobility of 10,000 to 11,000 cm^2/Vs.

The transition of InP HEMT technology from research and development to manufacturing requires a passivation layer to protect the HEMT from particulates and moisture. We have recently incorporated a silicon nitride passivation layer into our baseline process. This layer is 100 nm thick and can also be used as a dielectric for the MIM capacitor in a MMIC process. Its added capacitance, however, degrades the minimum noise figure of the HEMT by approximately 0.2 dB at 60 GHz.

The latest addition to our InP HEMT process is a novel double-exposure electron-beam lithography process. As shown in Figs. 1(a) and (b), this process requires two separate exposures and developments: the first exposure creates a large opening in the top resist layer through which the second exposure takes place [4], [5]. It has demonstrated the highest dc yield thus far, up to 91%, and is now the baseline process for our 0.1-µm InP HEMTs.

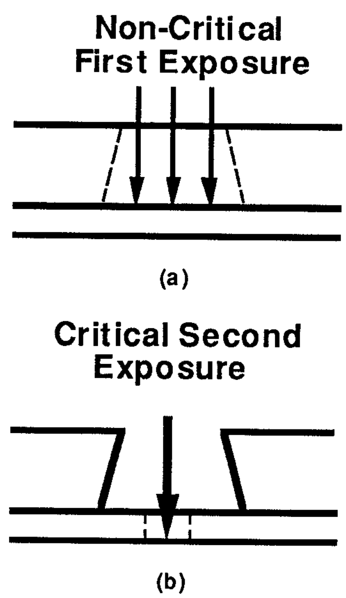

Fig. 1. A double-exposure electron-beam lithography process: (a) non-critical first exposure and (b) critical second exposure.

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DEVICE AND AMPLIFIER RESULTS

Figure 2 compares the dc yield of a conventional single-exposure process and the new double-exposure process. While the former shows an oscillatory behavior around a mean value of 60%, the latter exhibits a clear trend of improving with time, reaching a dc yield as high as 80% to 91% for the last three wafers. We are monitoring this process closely and will update our results at the time of the conference.

The reproducibility of our process, as measured by the transconductance at a drain-source current of 100 mA/mm (g_m@LN), is also excellent. As shown in Fig. 3, the median value of g_m@LN is 560 mS/mm for 14 wafers and its variation from wafer to wafer is less than 10%.

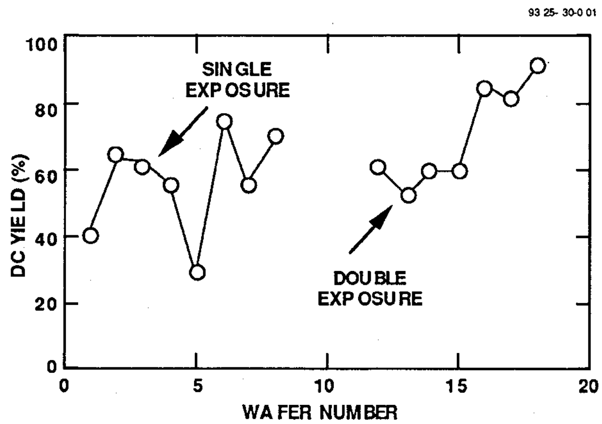

Fig. 2. A preliminary comparison of the dc yield of 0.1-µm InP HEMTs using a single-exposure and a double-exposure process.

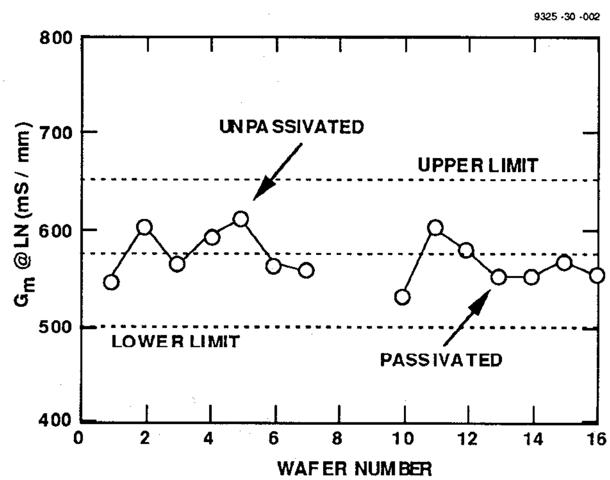

Fig. 3. Reproducibility of transconductance at low-noise bias from wafer to wafer. The median value is 560 mS/mm at a drain-source current of 100 mA/mm.

The excellent uniformity and reproducibility of our InP HEMTs have significantly reduced the need for device screening at the amplifier assembly step, which is a costly process. As an example, we showed in Fig. 4 the noise figure and associated gain of five V-band single-stage amplifiers using five randomly-picked devices. Their noise figures, including all fixture loss, all fall between 1.8 and 2.0 dB across a 4.0 GHz band from 59.5 GHz to 63.5 GHz. This high level of performance, achieved without rf screening, should meet the requirements of most low-noise applications and offers a cost-effective solution to millimeterwave satellite communications.

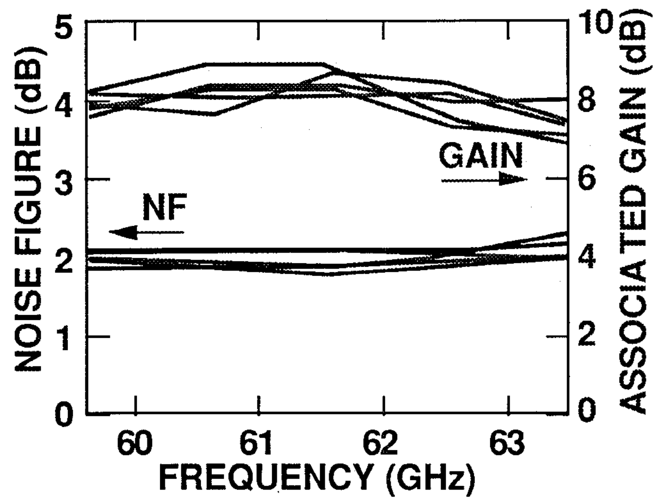

Fig. 4. Noise figure and associated gain of five V-band single-stage amplifiers using passivated InP HEMTs. The noise figure, including all fixture loss, varies from 1.8 dB to 2.0 dB from 59.5 GHz to 63.5 GHz.

These HEMTs are also capable of operating at W-band as well. Figure 5 shows the noise and gain performance of a W-band 2-stage amplifier using passivated InP HEMTs. Its average noise figure and associated gain, including all fixture loss, are 4.0 dB and 13 dB, respectively, across a 2.0 GHz band from 93.5 GHz to 95.5 GHz. This level of performance is highly competitive and presents an attractive alternative to other competing technologies, such as GaAs HEMT and Schottky diode, for near-future W-band applications.

SUMMARY

The 0.1-µm InP HEMT technology has reached a maturity level for near-future system insertion. Currently, it is an attractive, cost-effective solution to millimeterwave satellite communications. We believe that, with further improvements in yield and reproducibility, this technology will become an important technology for a wide range of low-noise applications in the near future.

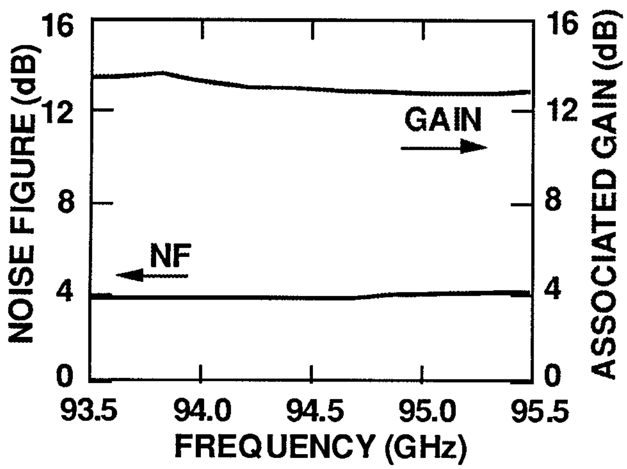

Fig. 5. Noise figure and associated gain of a W-band two-stage amplifier using passivated InP HEMTs. The average noise figure and associate gain, including all fixture loss, are 4.0 dB and 13.0 dB, respectively, from 93.5 GHz to 95.5 GHz.

REFERENCES

[1] Mishra et al., IEDM Tech. Dig., Dec 1988.
[2] Duh et al., IEEE Microwave and Guided Wave Lett., vol. 1, no. 5, 1991
[3] Tan et al., IEDM Tech. Dig., Dec 1991.
[4] Samoto et al., J. Vac. Sci. Techol. B, vol. 8, No. 6, Nov/Dec 1990.
[5] Le et al., GaAs Man Tech, 1993.