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InP HEMT:An Emerging Technology for Millimeterwave Applications

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1. ABSTRACT

The indium phosphide High Electron Mobility Transistor (InP HEMT) is the most advanced member of the HEMT family, offering low noise and high gain at millimeterwave frequencies. In this article, I will review the status of the InP HEMT technology and discuss its potential impact on the emerging millimeterwave markets.

1. INTRODUCTION

Near-future millimeterwave communications and automotive collision warning systems will require low cost, high performance Monolithic Microwave Integrated Circuits (MMICs) operating in frequency bands around 30, 44, 60, 77, and 94 GHz. These emerging systems have fueled the developments of a new class of GaAs and InP HEMT MMICs capable of delivering low noise and high gain up to 100 GHz.[1-6] The GaAs pseudomorphic HEMT (or pHEMT) is clearly the more mature technology, although the InP HEMT is unmistakably the more capable at the higher frequencies.

The Hughes Research Laboratory, in a quest to develop a super low-noise HEMT at 60 GHz, has embraced the InP HEMT technology early on. Its pioneering work in this area has led to a series of world record results for millimeterwave low-noise HEMTs and MMICs, as well as the establishment of one of the first 3-in. InP HEMT fabrication lines. Thanks to its super low noise and high gain, the InP HEMT has displaced the GaAs pHEMT as the device of choice for advanced satellite communications and radio astronomy systems.

Future commercial millimeterwave markets, however, will present many challenges for InP HEMT technology. Over the past several years, Hughes has been investing a significant amount of resources at its Research Laboratories to develop a cost competitive InP HEMT capability. We have recently upgraded our wafer fab from 2-in. to 3-in., and are now putting in place the necessary infrastructure to support a 0.1-μm InP HEMT MMIC process for low to moderate-volume requirements (<1000 wafers/year).

3. InP HEMT MMIC TECHNOLOGY

The commercial millimeterwave markets consist primarily of three segments: broadband wireless communications at 20, 30, and 38 GHz; short-range wireless communications at 60 GHz; and automotive collision warning systems at 77 and/or 94 GHz. At the lower frequencies, the 0.25-μm GaAs pHEMT is the most mature technology and will probably get the lion share of the market, which includes vehicular communications, digital radios, and satellite communications systems. For the intermediate frequency bands, say from 40 to 60 GHz, there has been strong evidence that a 0.25-μm GaAs pHEMT will not be competitive due to its lack of performance and adequate process margins. A 0.25-μm GaAs pHEMT MMIC requires at least 4 or more stages to meet the typical 20-dB gain requirements of many applications in this frequency band,[7] rendering it too cumbersome and expensive; whereas the same job could be accomplished with a 3-stage design in a 0.1-μm GaAs pHEMT or InP HEMT process.[8-9] At the highest frequency bands, say from 60 to 94 GHz, the 0.1-μm InP HEMT could potentially be the more attractive technology because it offers higher process margins. Figure 1 shows the various HEMT technologies and their respective frequency bands of operation.

The Hughes' 0.1-μm InP HEMT MMIC process was designed for high reliability and manufacturability, while meeting the aggressive performance goals of near-future millimeterwave systems. It is a 150 GHz f_T and 230 GHz

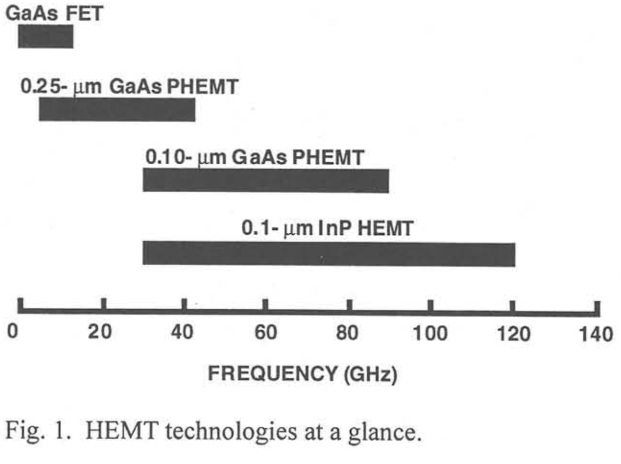

Fig. 1. HEMT technologies at a glance.

f_{max} process, capable of delivering 1.5 dB noise figure and 8.0 dB associated gain at 60 GHz. A summary of the process capability is given in Figure 2 below.

This process has been successfully used to develop a chip set for near-future Q- and V-band satellite communications systems, including low-noise amplifiers (LNAs), IF amplifiers, mixers, and downconverters.[9] Figure 3 compares the performance of the Hughes' InP HEMT LNAs with published results from 1992 to 1995. At Q- and V-bands, it is clear that the InP HEMT offers significantly lower noise figure with comparable or higher gain than the GaAs pHEMT technology. At W band, howver, the dominant MMIC technology is now the TRW's 0.10-μm GaAs pHEMT. At the 1994 GaAs IC symposium, TRW reported a 3-stage MMIC LNA with 5.0 dB noise figure and 18 dB gain, as well as a very impressive W-band Monolithic Transceiver for automotive radar applications.[10-11]

Frequency	Device Size	NF (typ.)	Gain (typ.)	P_{out} * (typ.)
10 to 30 GHz	0.1 x 300 μm	0.9 dB @ 18 GHz	10 dB @ 18 GHz	13 dbm
30 to 60 GHz	0.1 x 150 μm	1.3 dB @ 35 GHz	9 dB @ 35 GHz	10 dbm
40 to 100 GHz	0.1 x 50 μm	1.5 dB @ 60 GHz	8 dB @ 60 GHz	5 dbm

* Saturated power under low-noise bias conditions

Fig. 2. Hughes' 0.1-μm InP HEMT process capability.

4. COPLANAR WAVEGUIDE TECHNOLOGY

Coplanar waveguide (CPW) is an attractive technology for millimeterwave MMICs, especially for low cost applications because it requires neither wafer thinning nor backside vias. In recent years, the CPW technology has emerged as a leading candidate for the commercial millimeterwave markets. As shown in Figure 4, CPW MMICs have demonstrated state-of-the-art gain-bandwidth products, reasonably low noise figures, and adequate output power. In addition, they can be realized in very small sizes: both the Fraunhofer's 5 to 80 GHz distributed amplifier and the HP/Hughes' 0.1 to 70 GHz shunt feedback amplifier occupy less than 1.0 mm^2. In contrast, conventional MMIC LNAs typically require 3.0 to 9.0 mm^2 of expensive GaAs or InP real estate.

5. SUMMARY

It is clear that both GaAs and InP HEMT MMICs are capable of delivering high performance up to 100 GHz. Cost, however, will be the key to success. CPW MMICs provide a promising approach to solving this performance/cost puzzle, and is potentially an enabling technology for near-future millimeterwave markets.

		Noise Figure (dB)		Gain (dB)					
f (GHz)	Technology	Min.	Max.	Min.	Max.	Gain/ Stage (dB)	Size (mm^2)	Company	Ref.
41-45	0.15 μm GaAs pHEMT	2.8	3.0	21	22	7	1.0 x 2.3	M.M.	8
42-46	0.20 μm GaAs pHEMT	3.2	3.3	19	22	5	n/a	TRW	7
43-45	0.12 μm InP HEMT	2.0	2.1	22	22	7	2.0 x 3.0	Hughes	9
58-63	0.20 μm GaAs pHEMT	4.2	5.2	10	11	5	3.0 x 3.0	TRW	12
58-62	0.15 μm GaAs HEMT	3.7	5.9	13	19	4	n/a	Fujitsu	13
56--64	0.10 μm InP pHEMT	2.5	3.0	24	25	8	n/a	TRW	14
58-62	0.12 μm InP HEMT	2.2	2.3	15	16	8	2.0 x 2.5	Hughes	9
70-77	0.15 μm GaAs pHEMT	6.2	6.2	21	26	4	1.0 x 2.8	Fraunhofer	15
91-95	0.10 μm GaAs pHEMT	5.5	5.8	13	17	8	n/a	TRW	16
91-97	0.10 μm GaAs pHEMT	3.5	3.8	21	23	7	1.2 x 3.2	TRW	17
92-96	0.10 μm GaAs pHEMT	5.0	(typ.)	18	(typ.)	6	n/a	TRW	10

Fig. 3. Recent published results of millimeterwave MMIC LNAs.

Technology / Topology	Bandwidth (GHz)	Gain (dB)	NF (dB)	P-1 dB (dbm)	Size (mm^2)	Company	Ref.
0.15 μm GaAs pHEMT (5-section distributed)	5 to 80	9	4.3 (@ 61 GHz)	11.6 (@ 50 GHz)	0.6 x 1.5	Fraunhofer	15
0.10 μm InP HEMT (8-section distributed)	dc to 47	16	5.0 (@ 30 GHz)	n/a	n/a	NTT	18
0.10 μm InP HEMT (3-stage shunt feedback)	0.1 to 70	17	5.8 (8-16 GHz)	6.0 (@ 8 GHz)	0.9 x 1.0	HP/ Hughes	19
0.10 μm InP HEMT (7-section distributed)	1 to 57	11	4.5 (8-16 GHz)	10.0 (@ 8 GHz)	1.0 x 1.5	HP/ Hughes	19
0.15 μm GaAs pHEMT (3-stage LNA)	70 to 77	21	n/a	n/a	1.0 x 2.8	Fraunhofer	15
0.10 μm InP HEMT (capacitive division)	1 to 96	11	n/a	n/a	0.7 x 2.0	UCSB/ Hughes	20

Fig. 4. Recent published results of CPW MMICs.

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