GaAs Power PHEMT Technology and Applications

Manfred J. Schindler
Raytheon Microelectronics, Research Laboratories
362 Lowell St., Andover, MA 01810

ABSTRACT

GaAs Pseudomorphic High Electron Mobility Transistor (PHEMT) technology provides excellent power performance from frequencies under 1 GHz up to 50 GHz and beyond. This technology is being applied to a wide range of applications, and as a result production volumes are large and costs a dropping rapidly. Thus far, powers of up to 18 watts have been achieved for a single transistor, and multiple transistors have been power combined for up to 50 watts of output power.

INTRODUCTION

GaAs Metal Semiconductor Field Effect Transistors (MESFET) have been produced since the 1970's. HEMT and PHEMT are a high performance variants of the MESFET. Although originally developed as a low noise transistor, techniques have been developed to provide exceptional power performance from PHEMTs [1], [2]. These properties are obtained by increasing the breakdown voltage to as high as 20 volts, allowing high efficiency operation with a 7 volt supply. Low noise properties are maintained.

Because the PHEMT is based on well established GaAs MESFET technology, transition from research demonstration to high volume production occurred quickly. At Raytheon, for example, the first research demonstration of the power PHEMT occurred in 1990 [1], and production began in 1992 [3]. Power PHEMTs are now being produced in very high volumes for a large number of applications ranging from solid-state microwave power generation to radar and communications amplifiers. The power PHEMT is attractive for these applications because of its exceptional efficiency, excellent reliability, and modest cost. For communications applications we have also found the PHEMT to provide and excellent combination of power and linearity.

PHEMT OPERATION

The cross-section of a power PHEMT is shown in figure 1. In a MESFET, carriers from n-type doping are transported through the channel under the gate. The gate potential modulates the carriers in the channel. The high mobility of GaAs allows high gain. Scattering due to dopants in the channel is one of the major performance limitations in a conventional MESFET. The PHEMT structure makes a number of improvements over the conventional MESFET. Referring to Figure 1, the channel is made of a layer of undoped InGaAs. The doping to provide the carriers is done in thin pulses above and below the channel. Energy band discontinuities ensure that most of the carriers transfer from the doping pulses into the channel. Since their is no dopant in the channel, scattering is minimized, resulting in excellent electron transport. The channel is grown with a significant percentage of Indium, typically 15 to 20%. Higher levels of Indium yield higher electron mobility in the channel. InGaAs is not lattice matched to GaAs, so InGaAs layers are strained (hence the device is pseudomorphic). This limits the amount of Indium that can be grown into the channel, and the thickness in the channel.

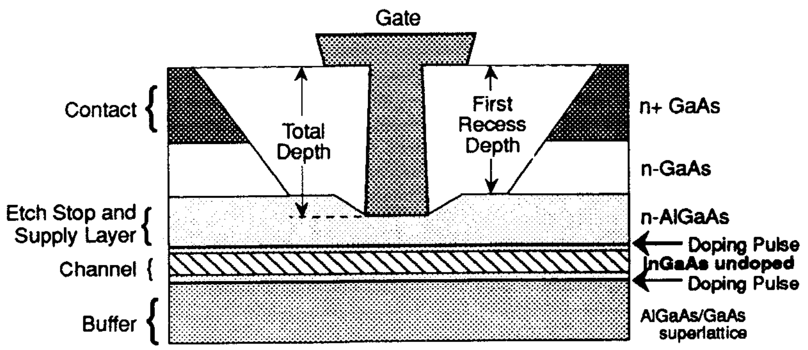

Figure 1. Cross section of a Power PHEMT.

PHEMT POWER PERFORMANCE

Once power PHEMT technology was developed, the devices were evaluated for numerous potential applications. The basic performance evaluation we make for power PHEMTs is in power amplifier configuration. Discrete transistors are tuned at input and output at the fundamental frequency of interest, as well as a harmonics. Typically several device sizes (peripheries) are evaluated at any frequency. Table 1 is a summary of power PHEMT performance at several key frequencies.

Table 1. PHEMT Power Performance Summary

Frequency (GHz)	**Periphery (mm)**	**Power (Watts)**	**Power Added Efficiency (%)**	**Associated Gain (dB)**
2.45	36.5	18.0	59.4	12.1
8.0	16.8	8.7	53.0	13.4
14.0	3.0	2.5	53.8	10.8
18.0	3.0	1.8	50.6	9.9
35.0	0.6	0.5	44.2	6.0
44.0	0.6	0.4	35.0	5.2

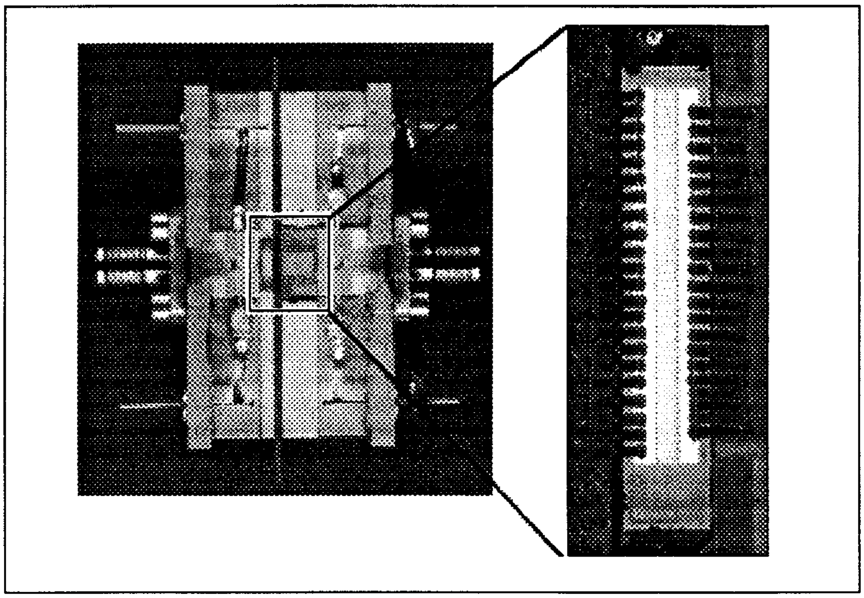

Figure 2. A large periphery PHEMT in a 8 Ghz tuned amplifier assembly

An example of a tuned transistor is shown in figure 2. This illustrates a large periphery PHEMT in a laboratory test fixture with 18 GHz tuning elements at the input and output. A complete power performance curve at 8 GHz, as well as performance of several PHEMT peripheries at 8 Ghz is shown in figure 3 [4]. It can be seen that power scales linearly with periphery, but gain drops as periphery is increased. Power Added Efficiency also drops off, because of the drop in gain.

An illustration of a circuit in which PHEMTs are combined is shown in Figure 4. In this assembly four large periphery PHEMTs are mounted in the center, and each is individually

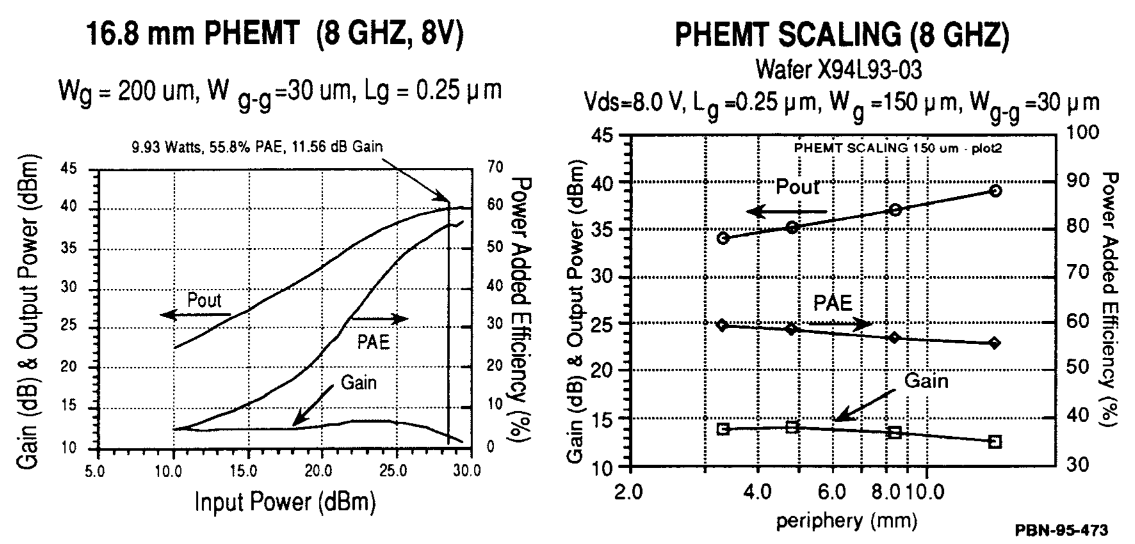

Figure 3. Power performance of a 16.8 mm PHEMT at 8 Ghz (left). Performance of several peripheries a 8 Ghz (right)

matched. Eighth wavelength power combiners are used. The resulting performance is excellent: 44 watts of power are achieved with 52% power added efficiency and 13 dB associated gain. This circuit operates at 2.45 Ghz.

Several PHEMTs can also be integrated on a single GaAs MMIC. Raytheon has produced many such circuits, with operating frequencies as low as 0.9 Ghz, and as high as 45 Ghz. Figure 5 is an illustration of such a MMIC. This is a three stage Q Band (45 Ghz) power amplifier with an output stage made up of four 0.48 mm periphery PHEMTs. Over 800 mW of output power was achieved with over 10 dB power gain [5].

APPLICATIONS

The excellent power performance of the power PHEMT makes it a candidate for many applications. There are numerous medium power level applications (1-10 watts) for radar and communications. A MMIC amplifier, like the one illustrated in figure 5, is typically developed for such applications. Often the amplifier is used in a phased array system with 100's to 10,000's of elements. One power amplifier is used at each array element. Total system transmit power or effective radiated power can then be very large.

For many satellite communications applications, power levels of 10-50 watts are needed. Some of these are phased arrays, others are not. The 8 Ghz amplifier illustrated in figure 2, for example, is intended for a satellite terminal. For multitone communications applications, the combination of linearity, power and efficiency is an important requirement. We have found the power PHEMT provides excellent performance for these applications as well [6].

Because of the high power and efficiency performance of PHEMTs, solid state generation of microwave power is another attractive application. For example, the 2.45 Ghz power amplifier illustrated in figure 4 has been mated with a driver amplifier and a small oscillator. The resulting dc to RF converter yielded 45 watts of output power with a conversion efficiency of 50%. Higher levels of performance, over 100 watts at 2.45 Ghz, can be anticipated. Similar performance may also be obtained at 5.8 Ghz.

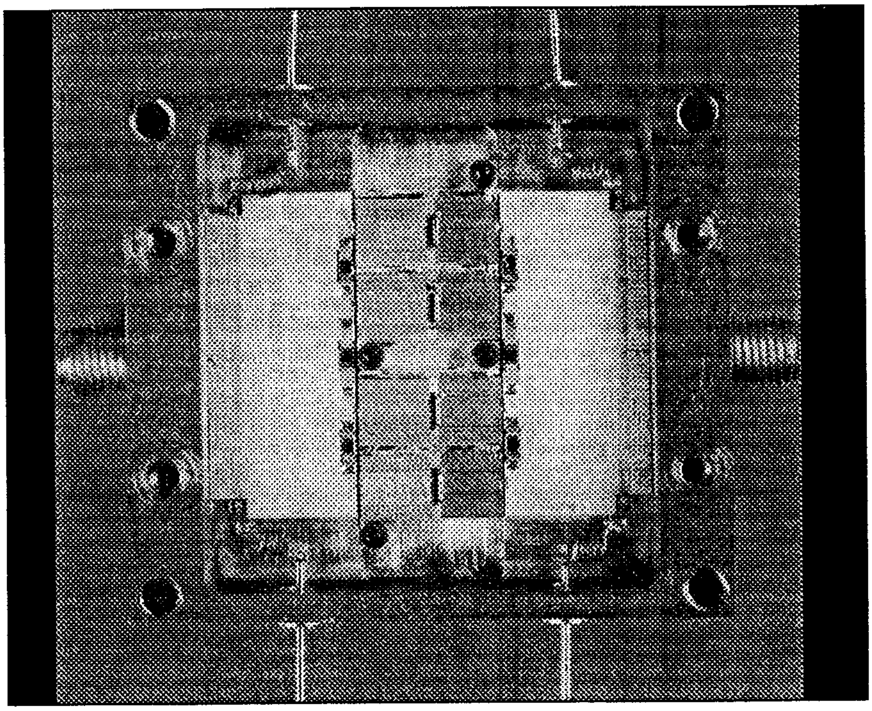

Figure 4. A 4-way large periphery PHEMT power combined assembly.

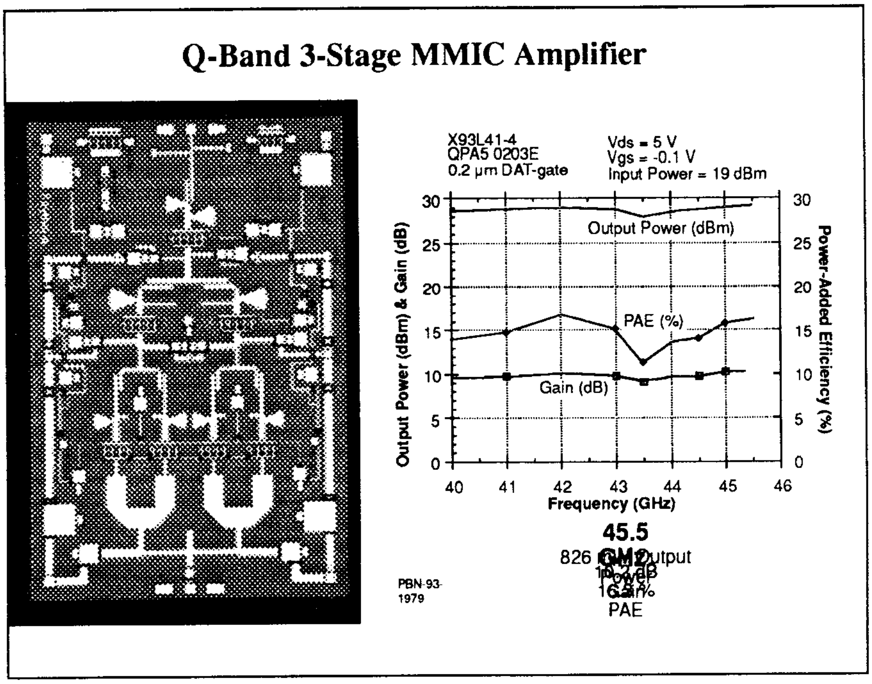

Figure 5. A Q Band PHEMT MMIC power amplifier and its performance.

CONCLUSION

The GaAs power PHEMT is a recently developed device that has shown excellent power performance from 1 to 50 Ghz. Power levels of up to 50 Watts have been demonstrated, and levels over 100 Watt are envisioned. Efficiencies of 50 to 60% are routinely achieved. A wide range of applications can benefit from PHEMT technology, including RF power generation, radar and communications.

ACKNOWLEDGMENTS

The work reported in this paper is the result of the efforts of a great number of colleagues. Chief among them are A. Platzker, S. Shanfield, S. Bouthillette, L. Aucoin, D. Teeter, F. Rose, W. Boulais, J. Huang, and R. Wohlert.

REFERENCES

[1] J. Huang et. al., "An AlGaAs/InGaAs Pseudomorphic High Electron Mobility Transistor for X and Ku Band Applications," 1991 MTT-S IMS Digest, pp. 713-716.

[2] S. Shanfield et. al., "One Watt, Very High Efficiency 10 and 18 Ghz Pseudomorphic HEMTs Fabricated by Dry First Recess Etching," 1992 MTT-S IMS Digest, pp. 639-642.

[3] D. Danzilio et. al., "High Efficiency 0.25 µm PHEMT Power Process," 1992 GaAs IC Symposium, pp. 255-257.

[4] D. Teeter et. al., "High Power, High Efficiency PHEMTs for use at 8 GHz," 1995 MTT-S IMS, pp. 323-326.

[5] W. Boulais et. al., "A High Power Q Band GaAs PHEMT Monolithic Amplifier," 1994 MTT-S IMS, pp. 649-652.

[6] A. Platzker et. al., "Variable Output Power, High Efficiency-Low Distortion S-Band Power Amplifiers and their Performances under Single Tone and Noise Power Excitations," 1995 MTT IMS, pp. 441-444.