A 12-GHz, 12-W HJFET Amplifier with 48% Peak Power-Added Efficiency

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***Abstract*—This letter describes a Ku-band power amplifier fabricated with a one-chip 0.45 μm × 16.8 mm GaAs-based heterojunction FET (HJFET), in which a 40.9 dBm (12.3 W) output power with 48% power-added efficiency (PAE) and 10.1 dB linear gain was achieved at 12 GHz. To our knowledge, this is the highest PAE, gain and output power combination achieved by a single FET power amplifier at this frequency.**

I. Introduction

There is a growing demand for solid state power amplifiers (SSPA's) that are capable of delivering increased output power with reasonable efficiency. Power GaAs MESFET's with over 10 W output power have already been reported at Ku-band [1], [2]. However, because of the increased chip size and the limited gain performance of the GaAs MESFET's, further improvements in the output power from a single MESFET chip are becoming rather difficult.

Recently, a GaAs-based heterojunction FET (HJFET) has emerged as a viable candidate for microwave power applications. This device has demonstrated excellent performance of high output power, gain and PAE, making it attractive for various SSPA applications [3]–[11]. This is due to its inherent high drain current and high gain characteristics along with its high gate breakdown voltages [5], [7], [10]–[12]. To minimize power combining loss in the multiwatt power amplifiers, large-periphery devices capable of providing higher output power density with higher efficiency are of great interest.

To date, GaAs-based heterojunction FET's with small gate periphery have already demonstrated impressive power performance. These include an output power of 0.6 W, 75.8% PAE with 1.2-mm gate-width at 10 GHz [7] and 0.97 W, 70% PAE with 1.2-mm gate-width at 10 GHz [9]. More recently, impressive results have been reported on larger-periphery devices, in which an output power level of 6 W with PAE of greater than 50% has been achieved at 12 GHz [11], [13]. In order to further improve the output power level under high PAE, we have developed a larger gate-width HJFET with state-of-the-art output power and efficiency at Ku-band.

In this letter, a record power performance of an amplifier composed of a single HJFET chip with internal matching circuits is described.

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II. HJFET Amplifier

Step-recessed 0.45-μm gate-length HJFET's were fabricated on a 3-in. GaAs substrate. The layer structure is the same as that described in our previous report [13]. The active part of the MBE-grown HJFET structure consists of a 130Å undoped $In_{0.2}Ga_{0.8}As$ channel layer sandwiched between two Si-doped $Al_{0.22}Ga_{0.78}As$ layers. The doping densities for the upper (80Å) and the lower (40Å) AlGaAs donor layers are 4.5×10^{18} and $4 \times 10^{18}cm^{-3}$, respectively. To achieve high gate-to-drain breakdown voltage BV_{gd} while maintaining high maximum drain current (I_{max}), an n^+/n dual cap layer and an undoped AlGaAs Schottky layer were employed [12]. After thinning the device thickness to 30 μm, slot via-holes were etched underneath each source pad. The flip-side of the wafer was then plated with 20 μm of gold to reduce source inductance as well as to ensure low thermal resistance.

The device exhibited a drain saturation current of 270 mA/mm with I_{max} of 550 mA/mm. I_{max} was defined as a drain current measured at a gate bias of +1 V. The device exhibited a maximum transconductance of 370 mS/mm and a BV_{gd} of more than 12 V. Microwave S-parameter measurements, performed from 0.5 to 40 GHz for a 100-μm device, exhibited a peak power-gain cutoff frequency of 158 GHz. The power performance of a 1.05-mm gate-width HJFET evaluated at 12 GHz was 810-mW output power, 10-dB associated gain, and 60% PAE. The device was biased for Class AB operation at $V_d = 7$ V.

A one-chip device with a total gate-width of 16.8 mm was used as a power amplifier building block. The output matching circuit was designed using a large-signal load impedance determined from load-pull measurements performed on a 1.05-mm HJFET. The input and output matching circuits consist of L-C-L section transformers, quarter wave transformers and low-impedance transmission lines. The input matching circuit was designed to achieve higher gain by using the small-signal equivalent circuit of a 16.8-mm HJFET. The low-impedance transmission lines were used to reduce the insertion loss in the matching circuits.

Fig. 1 shows the photograph of the internally matched HJFET power amplifier fabricated. The L-C-L section transformer is composed of a metal-insulator-metal capacitor with 150-μm-thick barium titanate and bonding wire inductors. The quarter wave transformer and low-impedance transmission lines were formed on a 250-μm-thick alumina substrate. The package size of the power amplifier, excluding the bias lines, was 16.5×9.7 mm^2 with an actual circuit size of 5.0×7.5 mm^2.

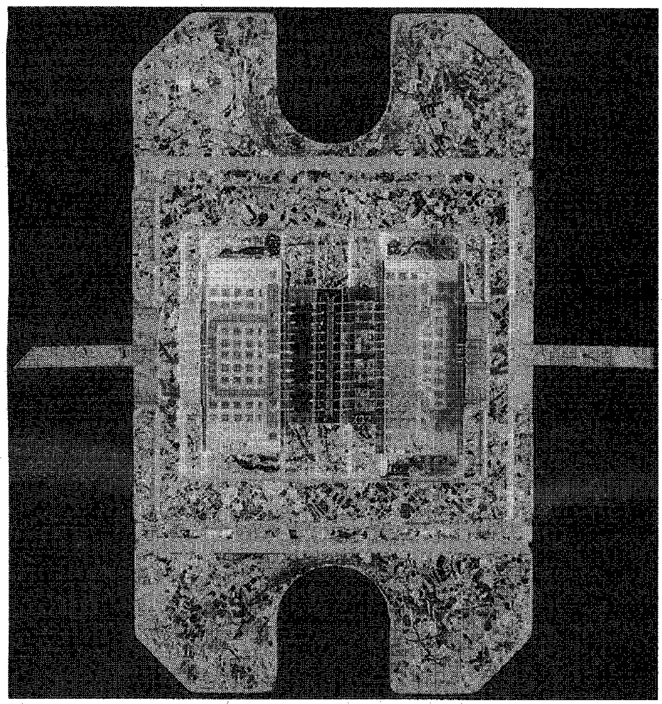

Fig. 1. Photograph of internally matched HJFET amplifier.

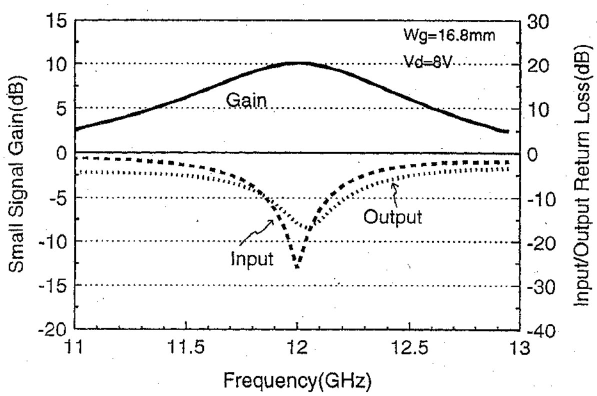

Fig. 2. Measured small signal response of power amplifier. V_d = 8 V.

III. Amplifier Performance

The power amplifier was mounted on a specially designed waveguide test fixture for evaluating gain, return loss and large-signal power characteristics. The fixture loss of 0.25 dB at 12 GHz was de-embedded from all measurement results.

Fig. 2 shows the measured small signal gain, input and output return losses of the power amplifier as a function of frequency. The small signal gain was 10.1 dB at 12 GHz with V_d = 8 V. The input and output return losses were less than −26 dB and −16 dB, respectively. The measured power characteristics are shown in Fig. 3. The fabricated power amplifier demonstrated an output power of 40.3 dBm (10.7 W) with 10.3 dB linear gain and 55% PAE with V_d = 7 V under C.W. operating conditions at 12 GHz. At V_d = 8 V, it delivered 40.9 dBm (12.3 W) output power with 10.1-dB linear gain and 48% PAE. To the authors' knowledge, this is the highest output power ever achieved from a single FET power amplifier at this frequency. At 1-dB gain-compression point, an

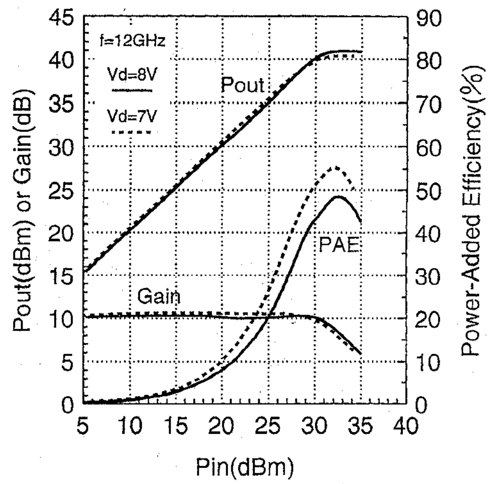

Fig. 3. Measured output power, gain, and power-added efficiency versus input power at 12 GHz for power amplifier. V_d = 7 and 8 V.

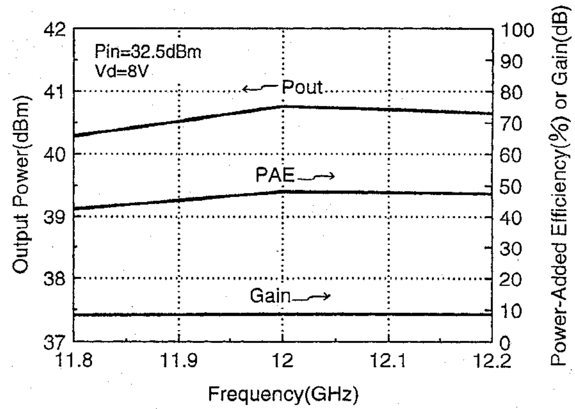

Fig. 4. Measured frequency response of power amplifier.

output power of 40.7 dBm (11.7 W) with an associated PAE of 47% was obtained with V_d = 8 V. These power performances can be attributed to higher drain current which was obtained by the optimized step-recessed structure, as well as to the use of low-impedance transmission line which significantly reduce the loss in the matching circuits at a designed frequency. The frequency dependence of the power characteristics were shown in Fig. 4. Over the 11.8–12.2 GHz frequency range, the amplifier exhibited 10.6–11.9 W output power with PAE of 42–48% and associated gain of 7.8–8.3 dB at V_d = 8 V with an input power of 32.5 dBm.

IV. Conclusion

High output power amplifier fabricated with a one-chip 0.45-μm gate HJFET was demonstrated at Ku-band. The developed HJFET amplifier with 16.8-mm gate periphery delivered a 40.9-dBm (12.3 W) output power with 48% power-added efficiency and10.1-dB linear gain at 12 GHz. To the authors' knowledge, this is the highest output power ever achieved from a single FET power amplifier at this frequency. Moreover, the developed HJFET exhibited more than 0.7-W/mm output power density, suggesting great potential of the HJFET approach for the future multi-10 W power amplifier applications at Ku-band. The present power HJFET technology is promising for various satellite communication and radar system applications.

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