44-GHz Monolithic GaAs FET Amplifier

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Abstract—**Millimeter-wave monolithic GaAs FET amplifiers have been developed. These amplifiers were fabricated using FET's with MBE-grown active layers and electron-beam defined sub-half-micrometer gates. Source groundings are provided through very low inductance via holes. The single-stage amplifier has achieved over a 10-dB gain at 44 GHz. A 300-μm gate-width amplifier has achieved an output power of 60 mW with a power density of 0.2 W per millimeter of gate width.**

I. Introduction

RECENT advances in material preparation, device fabrication, and circuit implementation techniques have pushed the performance of GaAs FET's well into the millimeter-wave regions. Hybrid GaAs FET amplifiers operating up to 60 GHz [1]–[4] and hybrid oscillators with an oscillation frequency as high as 110 GHz [5]–[7] have been reported. The performance of these amplifiers and oscillators can be further improved by incorporating the monolithic impedance matching technique currently being used extensively at microwave frequencies. The monolithic impedance matching approach allows for precise placements of matching elements close to the active device. In this way the detrimental effects of bonding and mounting parasitics associated with the hybrid technique can either be minimized or eliminated. In this paper, the design, fabrication, and performance of the first 44-GHz monolithic GaAs FET amplifier are described.

II. Amplifier Design

For the device design, a parallel finger FET having a gate finger width of 25 μm and gate length of 0.3 μm was used. The spacing between the source and drain ohmic contacts was 3.5 μm. An n^+ ledge channel structure with a doubly recessed channel region [8] was used to reduce the parasitics and to maximize the device gain. The gate was placed very close to the source with a gap of under 0.5 μm. To further improve the gain performance of the FET, very low inductance via holes were used for source groundings. Fig. 1 shows the SEM photographs of both the channel structure prior to the air-bridge formation and the completed FET.

Circuit topology of an amplifier with total gate width of 300 μm is shown in Fig. 2. As shown, two 150-μm FET's were reactively combined on chip. To see the two cell's power combining effect, an amplifier with a 150-μm FET (one cell) was also designed. These amplifiers were designed for operation at 44 GHz. The optimized circuit element values

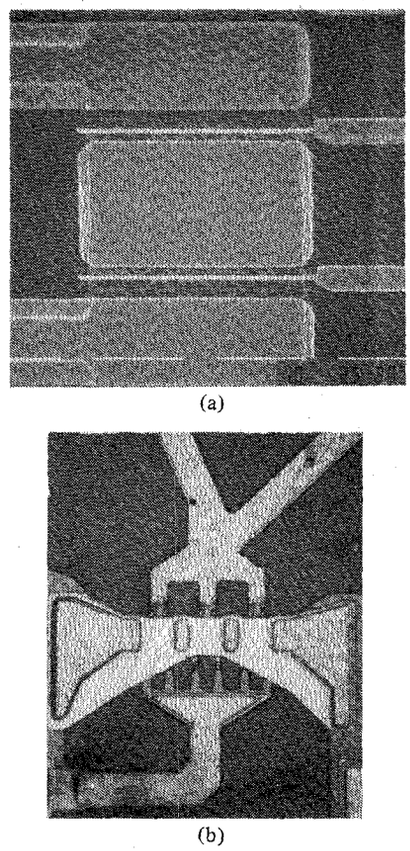

Fig. 1. SEM photos of millimeter-wave GaAs FET. (a) Channel area. (b) Completed FET.

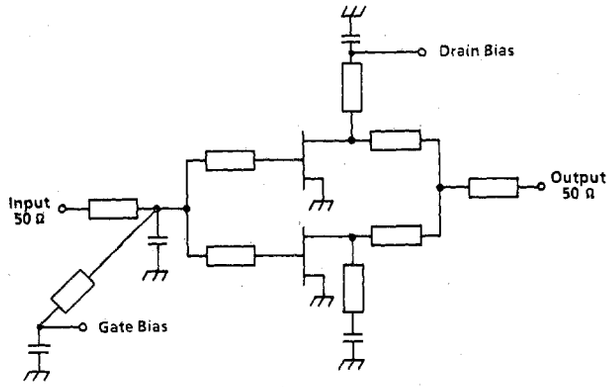

Fig. 2. Circuit topology of 44-GHz monolithic amplifier with two 150-μm gate-width FET's.

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were obtained by a conventional computer optimization technique using FET models generated from *S*-parameter measurements at lower frequencies. A characteristic impedance of 85 Ω was used for the transmission lines.

III. Circuit Fabrication

Fig. 3 shows the two completed amplifiers. The chip sizes are 24 × 54 × 4 mil and 28 × 60 × 4 mil, respectively. The substrates used in this work were 2-in-diameter Cr-doped LEC slices. The epitaxial layers were grown by the Perkin–Elmer 425B molecular beam epitaxy (MBE) system. The material structure is comprised of three epitaxial layers: a 1-μm undoped buffer layer; a 0.3-μm n-GaAs active layer doped to $4.2 \times 10^{17}/cm^3$; and a 0.1-μm n^- GaAs contact layer doped to about $5 \times 10^{18}/cm^3$. The doping transition at the interface between the n-layer and the buffer layer has a maximum slope of about 0.030 μm/decade.

Following the epitaxial layer growth, mesas were etched to isolate FET's and AuGe/Ni/Au ohmic contacts were formed. The wide recess pattern (~ 1.5 μm wide) of the n^+ ledge structure was then defined in PMMA by electron beam lithography and the channel was etched through the n^+ layer into the n layer. The 0.3-μm gate pattern is then similarly defined in a 0.5-μm-thick layer of PMMA and the GaAs is etched again down to the final desired saturation current value. The 0.5-μm-thick Ti/Pt/Au gates were then fabricated. The same set of alignment marks was used for both the wide recess and the gate definition. A 1.6-μm-thick Au layer was then evaporated and lifted off to produce the capacitor bottom plates, the inductors and the source grounding pads. MIM capacitors were fabricated, with 0.4-μm-thick silicon nitride as a dielectric. Then plated gold air bridges for contacting FET sources and capacitor top plates were formed. Transmission lines and all pads were plated with ~ 3 μm of gold at the same time. The slice was then lapped to a thickness of 100 μm. Grounding vias (2 mil × 3 mil) were etched by the reactive ion etching technique. A 10-μm-thick plated gold heat sink interconnects all the vias.

IV. Microwave Performance

The measured gain-frequency responses of the amplifiers are shown in Fig. 4. Without any external tuning, the 150-μm device has a 9.5-dB gain centered at 43 GHz. When the output was tuned, the gain was increased to 11 dB. A 300-μm amplifier achieved more than a 10-dB gain across the 44–46 GHz band, without any tuning. The power saturation characteristics of these amplifiers were also tested at 44 GHZ. Fig. 5 shows the measured results. The 150-μm amplifier delivered 30 mW of output power with a 6-dB gain and 7-percent efficiency. A drain bias of 5 V and a gate bias of −0.1 V were used for the results shown in Fig. 5. The 300-μm amplifier generated 60 mW of power with a 5-dB gain. The corresponding power density is 0.2 W/mm. It is seen that there is no performance degradation caused by the two cell combining. With further device optimization, an output power density of at least 0.5 W/mm can be expected.

V. Conclusions

Monolithic millimeter-wave GaAs FET amplifiers with sub-half-micrometer gates have been designed, fabricated, and RF

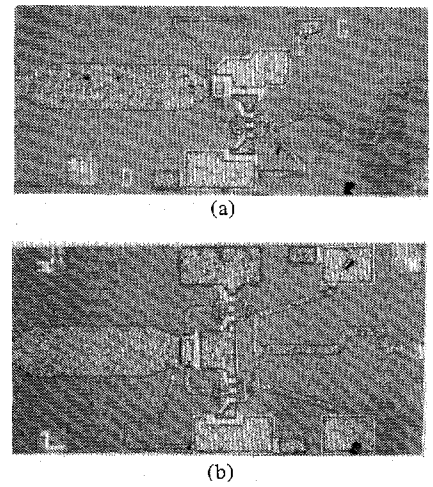

Fig. 3. Photographs of completed 44-GHz monolithic amplifiers. (a) Amplifier with 150-μm gate-width FET. (b) Amplifier with 300-μm gate-width FET.

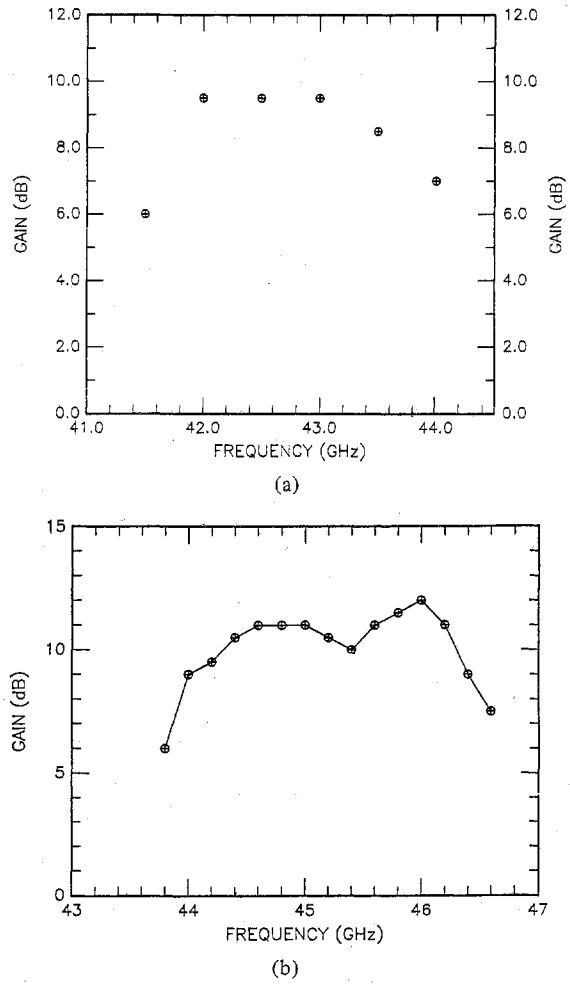

Fig. 4. Gain frequency response of 44-GHz monolithic amplifiers. (a) 150-μm gate-width FET. (b) 300-μm gate-width FET.

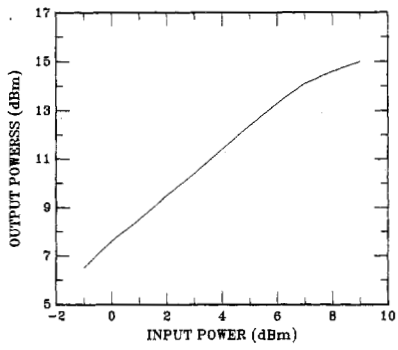

Fig. 5. Gain compression characteristics of the 150-μm FET amplifier.

tested. Amplifiers with gate widths of 150 and 300 μm have achieved over a 10 dB gain at 44 GHz. This is the first report of the monolithic implementation of GaAs FET amplifiers above 40 GHz. These excellent gain results were achieved by the use of submicrometer gate FET and optimized circuit topology. Even though the power density is a modest 0.2 W/mm, these results show that monolithic GaAs FET amplifier is a viable millimeter-wave active component useful for system applications. With further device optimization, it is believed that the power density can be further improved to at least 0.5 W/mm of gate width.

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