A 1.57 W/mm GaAs-BASED MISFET FOR HIGH-POWER AND MICROWAVE-SWITCHING APPLICATIONS*

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ABSTRACT

A GaAs-based MISFET delivered a record output power density of 1.57 W/mm at 1.1 GHz. An RF switch based upon this device has a figure of merit ($R_{on}C_{off}$) better than that of the best commercial MESFET we have tested.

We report the power and switching performance of a GaAs metal-insulator-semiconductor field-effect transistor (MISFET) made using low-temperature (LT) GaAs as the buffer layer[1] and the gate insulator. A LT GaAs MISFET with a gate length L_g of 1.5 µm delivered an output power density P_d of 1.57 W/mm with 4.4 dB gain and a power-added efficiency η_{PA} of 27.3% at 1.1 GHz.[2] This is the highest power density from a GaAs-based FET ever reported. The P_d and η_{PA} of this device at 1.1 GHz are shown in Fig. 1 as a function of input power. More recently, the LT GaAs MISFET has also demonstrated switch performance at 1.3 GHz that is comparable to that of the best commercially available FET switches that we have tested.

The epitaxial layer structure of the MISFET was grown by molecular beam epitaxy (MBE) and is shown in Fig. 2. The 1-µm-thick LT GaAs buffer layer and the 0.2-µm-thick LT GaAs gate insulator were deposited at a substrate temperature of 200°C, which is significantly lower than that typically used for the MBE growth of high-quality GaAs (~ 580°C). The low-temperature growth results in GaAs layers that have high resistivity,[1,3,4] high dielectric-breakdown strength,[1,4] and extremely short photo-excited carrier lifetime (~ 150 fs),[4] making possible the fabrication of MISFETs having high breakdown voltages, unprecedented power performance, and insensitivity to light.

Photomicrographs of the devices used in this study are shown in top view in Fig. 3. The device shown in Fig. 3(a) is a simple microwave FET with L_g = 1.5 µm, a gate width W_g of 600 µm, and a source-drain spacing of 6 µm. The device shown in Fig. 3(b) was designed for power applications in the 1-10 GHz range and has L_g = 1.5 µm, W_g = 1 mm, and a source-drain spacing of 4 µm. In both devices, the Ti/Au gate metal was deposited directly on the upper LT GaAs surface without a gate recess etch. The upper LT GaAs layer not only forms the gate insulator but also passivates the surface of the device. For the devices reported in this work the substrate was only thinned to a thickness of ~ 175 µm.

The gate forward turn-on and reverse breakdown voltages for the MISFET are ~ 9 and 42 V, respectively, as shown in Figs. 4(a) and 4(b). Values of these voltages for our GaAs MESFETs without the LT GaAs gate insulator are approximately 0.6 and 15 V, respectively. The substantial improvement is attributed to the LT GaAs gate insulator. The source-drain breakdown voltage at pinch-off for the LT GaAs MISFET is 43 V, as shown in Fig. 4(c). This contrasts with a value of ~ 15 V for our conventional GaAs MESFET. This improvement is attributed to the LT GaAs buffer and gate-insulator layers.

The transistor characteristics of the MISFET of Fig. 3(a) are shown in Fig. 5. The density for drain-source current I_{DS} reaches 750 mA/mm at V_{DS} = 4 V and gate-source bias V_{GS} = 2 V. This density is approximately a factor of two larger than that typically used in GaAs power MESFETs.[5] The high drain current coupled with the large breakdown voltages lead to the

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high output power density reported in Fig. 1.

The unity-current-gain frequency, f_T, and the maximum frequency of oscillation, f_{max}, of the MISFET at V_{GS} = -2 V and V_{DS} = 4 V are 8.5 and 14 GHz, respectively. These values are similar to those of our conventional GaAs MESFETs fabricated with the same mask set.

The MIS structure results in both a lower gate capacitance C_G and a more linear C_G with bias than for a MESFET of similar geometry and doping density.[2] The combination of low C_G, low channel resistance, and high breakdown voltages that can be achieved with the LT GaAs MISFET make it a strong candidate for microwave switching applications. As a result of the LT GaAs gate insulator, the MISFET can have a high channel doping (> 4×10^{17} cm^{-3}) and yet still pinch off before gate breakdown. In addition, since the conducting channel can be fully open without drawing significant forward-bias gate current, a very low on resistance can be achieved. Furthermore, the MIS structure and the LT GaAs buffer result in a lower drain-source capacitance in the off state than for a comparable MESFET.

A switch using the LT GaAs MISFET of Fig. 3(b) operating at 1.3 GHz had an on resistance of 3.4 Ω at V_{GS} = 1 V and a drain-source capacitance of 0.4 pF at pinch-off. A comparison of the relevant transistor switching characteristics of a commercially available MESFET, the LT GaAs MISFET, and a permeable base transistor (PBT) is shown in Table 1. A figure of merit for a switch, defined as the product of the on resistance, R_{on}, and the off capacitance, C_{off}, is already better for the MISFET than that obtained with the best commercial MESFETs that we have tested. Furthermore, because of the low gate-leakage current and the high breakdown voltages, the LT GaAs MISFET can handle higher power than typical GaAs MESFET-based switches.

We expect that by increasing the doping in the channel, the on resistance can be reduced without sacrificing the low off capacitance or high breakdown voltages. Also the dimensions of the source and drain contact pads can be made smaller on a future MISFET mask set to reduce the off capacitance. By reducing the on resistance and the off capacitance we should be able to achieve further improvements in switch performance.

The LT GaAs MISFET holds substantial promise for microwave and millimeter-wave circuits such as power amplifiers, switches, phase shifters, and attenuators.

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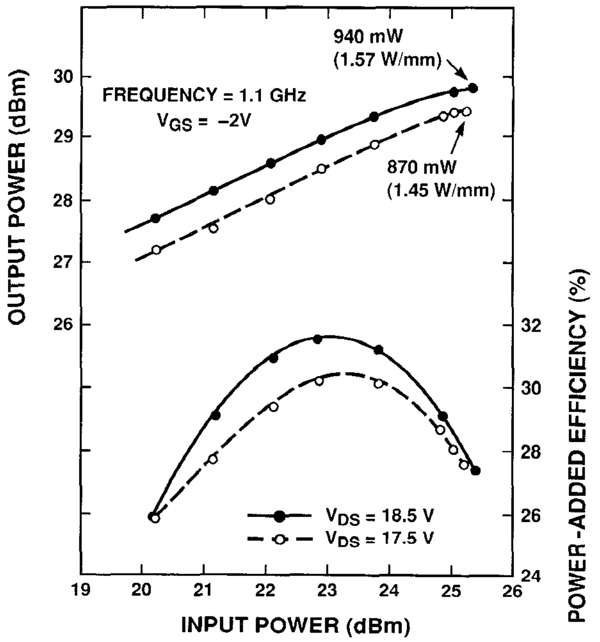

Fig. 1 Measured P_d and η_{PA} as a function of input power for the LT GaAs MISFET.

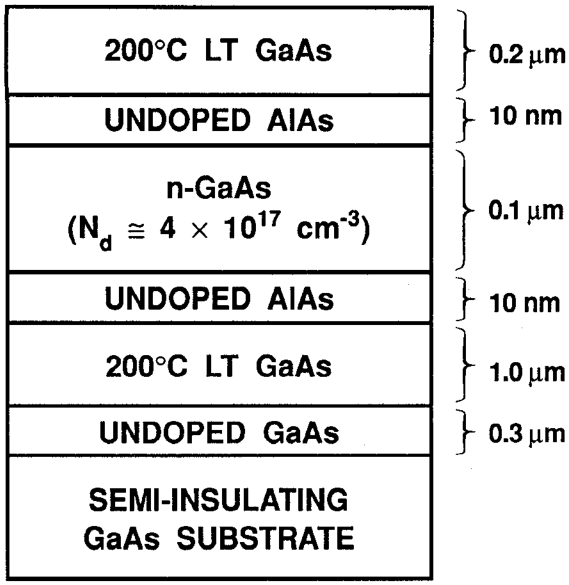

Fig. 2 Schematic cross section of the epitaxial layer structure of the LT GaAs MISFET.

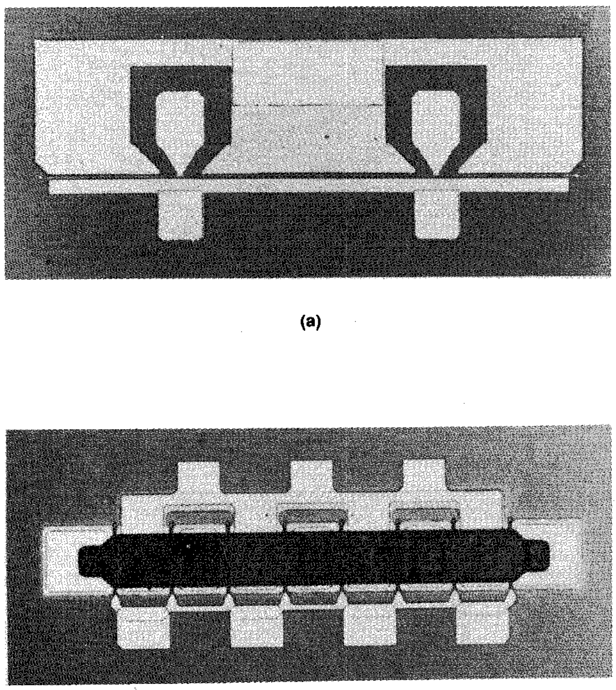

Fig. 3 Photomicrographs of the LT GaAs MISFETs used in this study. (a) Conventional MISFET with L_g = 1.5 μm, W_g = 600 μm, and source-drain spacing of 6 μm. (b) Power MISFET with L_g = 1.5 μm, W_g = 1 mm, and source-drain spacing of 4 μm.

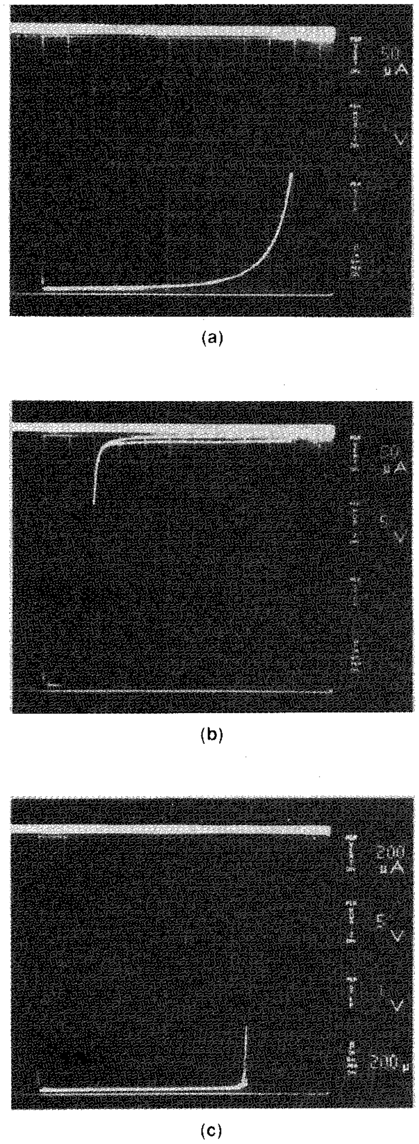

Fig. 4 The (a) forward and (b) reverse gate characteristics of the LT GaAs MISFET. (c) The I_{DS}-V_{DS} characteristics of the LT GaAs MISFET for V_{GS} = -8 V (pinch-off).

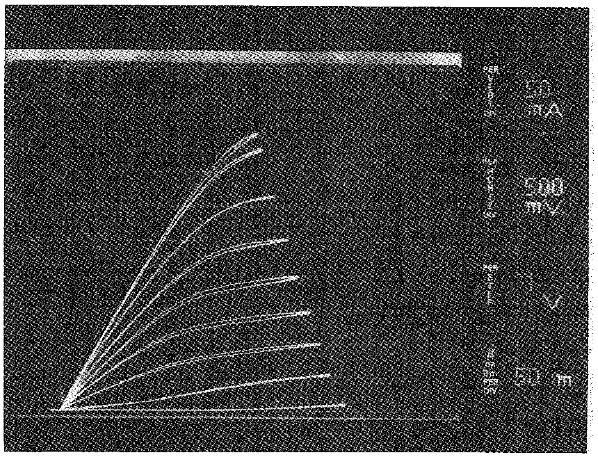

Fig. 5 The I_{DS}-V_{DS} characteristics of the 600-μm-wide LT GaAs MISFET. The upper trace is for V_{DS} = 2 V.

Device Characteristic	Commercial MESFET	GaAs PBT	LT GaAs MISFET
On-Resistance R_{ON} (Ω)	5.0	4.5	3.4
Off-Capacitance C_{OFF} (pF)	0.3	0.1	0.4
Figure of Merit $R_{ON}C_{OFF}$ (Ω pF)	1.50	0.45	1.36
Voltage Range (V)	-15 to 0.6	-20 to 0.6	-42 to 9
f_T (GHz)	8	45	8.5
f_{max} (GHz)	15	265	14
Structure	Horizontal	Vertical	Horizontal

Table 1 Comparison of transistor switching characteristics for devices having a 1-mm effective gate width.