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A High-Power-Density and High-Efficiency Atomic-Planar-Doped AlGaAs/InGaAs Quantum-Well HEMT for 2.4V Medium-Power Wireless Communication Applications

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A high-power-density and high-efficiency molecular-beam-epitaxy-grown atomic-planar-doped AlGaAs/InGaAs quantum-well power HEMT was developed for the 2.4 V medium-power wireless communication applications. High carrier concentration in the two-dimensional-electron-gas (2-DEG) InGaAs channel of the device contributes high current density and high transconductance, and enhances the power performance at the low operation voltage. An output power density of 177 mW/mm and a power-added efficiency of 61 % was achieved by the 2 mm HEMT at a 2.4 V drain bias.

1. INTRODUCTION

Advanced portable wireless communication systems require high performance low-voltage operation power transistors with high output power and high efficiency. Recently, the power MESFETs[1-3] and HFETs[4,5] for the wireless communication applications were demonstrated by using either high operation voltage or large gate width. High operation voltage implies the increase of the number of the batteries and causes large size, heavy weight, and high power dissipation in the wireless communication handsets. On the other hand, large gate width power devices suffer serious problems from low chip yield and high production cost.

In this work, a high-power-density and high-efficiency molecular-beam-epitaxy-grown atomic-planar-doped AlGaAs/InGaAs quantum-well power HEMT for the 2.4 V medium-power wireless communication applications was successfully developed. The atomic-planar-doped quantum-well structure provides high carrier concentration in the two-dimensional-electron-gas (2-DEG) InGaAs channel, contributes high output power density and high power-added efficiency at the low supply voltage. The device developed is suitable for the ISM (Industrial, Scientific, and Medical) band[6] wireless communication as well as the L-band mobile communication applications with the double 1.2 V battery cells..

2. DEVICE STRUCTURE AND FABRICATION

The material structure of the atomic-planar-doped AlGaAs/InGaAs power HEMT was grown by molecular-beam-epitaxy (MBE) on a 3-inch (100) orientated semi-insulating GaAs substrate, as shown in Fig.1. An undoped GaAs buffer layer, an undoped AlGaAs/GaAs superlattice buffer, then an undoped GaAs buffer again were sequentially grown. The active channel of the structure was an InGaAs layer sandwiched between an upper undoped AlGaAs layer and a lower undoped GaAs layer. The high-mobility two dimensional electron gas was formed in the InGaAs channel by electron transfer from atomic-planar-doping. The high-mobility carrier transport property in the InGaAs channel and large conduction-band discontinuity at the AlGaAs/InGaAs heterointerface provide good carrier confinement and high carrier

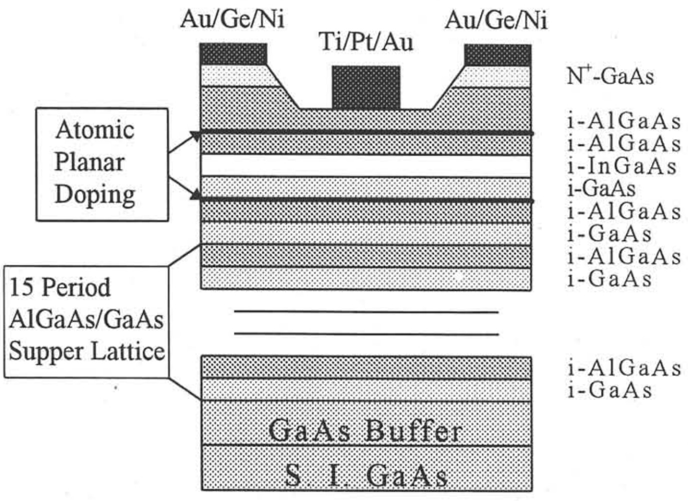

Fig. 1. Atomic-planar-doped AlGaAs/InGaAs quantum-well HEMT structure.

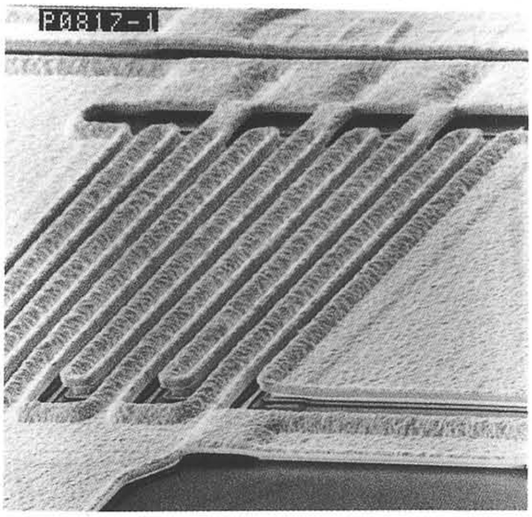

Fig. 2. Air bridges of source/drain fingers.

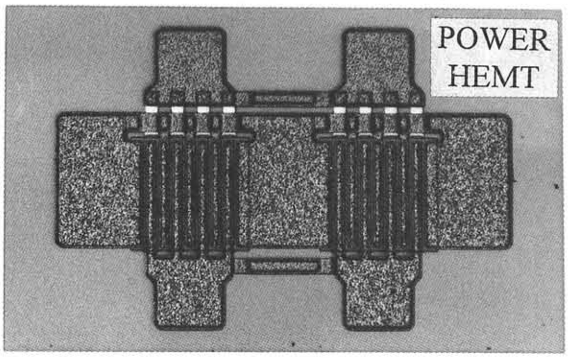

Fig. 3. Atomic-planar-doped AlGaAs/InGaAs quantum-well HEMT with 2mm gate width.

concentration in the InGaAs layer which lead to high current density and high transconductance (g_m). An undoped AlGaAs Schottky barrier layer was grown on the upper planar doping layer to obtain high gate-to-drain breakdown voltage (BV_{gd}). A heavily doped GaAs layer was grown on the top to provide the good ohmic contact, reduce the source resistance, and improve the knee voltage. The excellent characteristics of the current density, transconductance, breakdown voltage, and knee voltage benefit the power performance of the devices. The device fabricated had a total gate width of 2mm which was formed by air bridging the multi-source/drain-finger, as shown in Fig.2. The completed 1um-gate-length atomic-planar-doped AlGaAs/InGaAs quantum-well HEMT is shown in Fig.3.

3. DEVICE PERFORMANCE

Fig.4 shows the typical current-voltage (I-V) characteristics of the power HEMTs developed. The maximum drain current (I_{max}), measured at a gate-to-

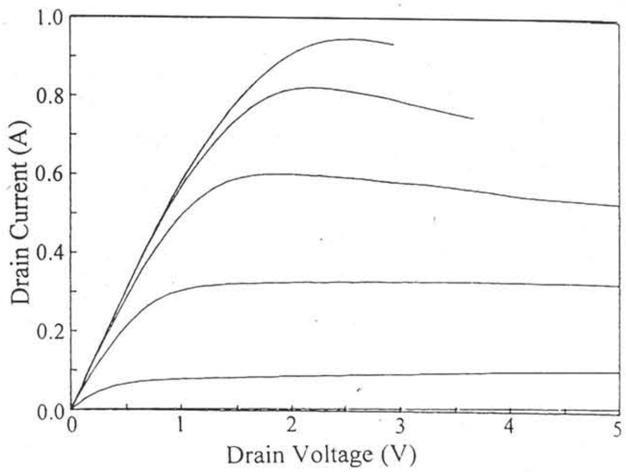

Fig. 4. Current-voltage (I-V) characteristics of atomic-planar-doped AlGaAs/InGaAs quantum-well HEMT. Top curve is Vgs= +1.0V, Vgs step = -0.5V.

source voltage (V_{gs}) of +0.5 V, is 840 mA. The associated current density is 420 mA/mm. The maximum transconductance was 275 mS/mm. These values are higher than those of MESFETs and HFETs[1-5]. Both the higher drain current density and transconductance are attributed to the atomic-planar-doped AlGaAs/InGaAs quantum-well HEMT structure. The pinch-off voltage (V_p) of the HEMTs was about -1.7 V. The gate-to-drain breakdown voltage, defined at a gate current of 1 mA/mm, was more than 17 V. The effective knee voltage , defined as the drain bias (V_{ds}) value when the drain current (I_{ds}) becomes 100 mA/mm with V_{gs} = 0 V, was about 0.3 V which was comparable and even better than those of the MESFETs and HFETs[1-5].

The power performance of the HEMTs was measured by a computer-controlled power tuning system. The input and output tuners with variable capacitors and inductors provided the conjugate matched input and load impedance to obtain the optimum power performance of the device under test. The output power and the power-added efficiency as a function of the input power at a drain bias of 2.4 V and the class AB condition are depicted in Fig.5 and Fig.6. The 2 mm HEMT when measured at 900 MHz exhibited an output power of 25.5 dBm, corresponding to a power density of 177 mW/mm. The power-added efficiency was 61 %. When the device was measured at 2.4 GHz, it achieved an output power of 25.3 dBm and a power-added efficiency of 57.4 %. Fig.7 illustrates the dependence of the output power and the power-added efficiency on the drain bias at 2.4 GHz. The output power of 24.4 dBm at 2.1 V drain voltage was accomplished when the power-added efficiency of the HEMT was kept at 57.4 %.

The atomic-planar-doped AlGaAs/InGaAs quantum-well power HEMT developed achieved the superior power characteristics at 2.4 V operation voltage. The enhancement of the power performance under the low supply voltage was due to the high carrier density and high electron mobility of the HEMT structure used.

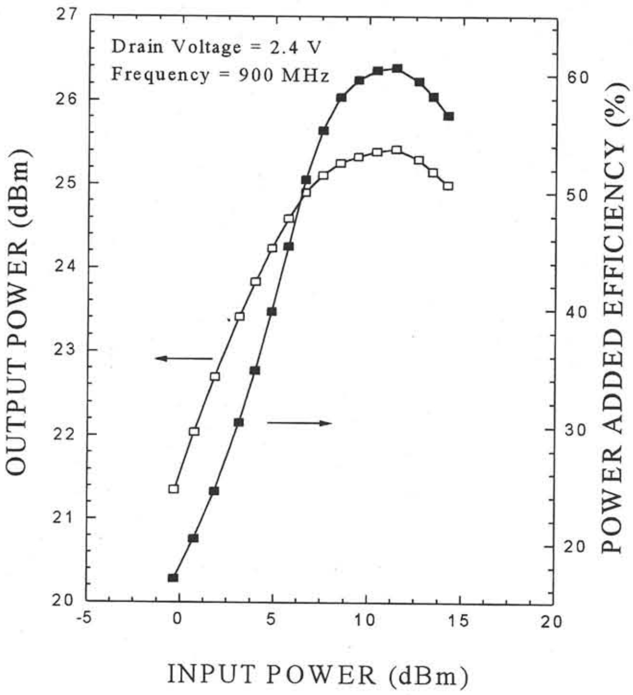

Fig.5 Output power and power-added-efficiency as a function of input power at a drain bias of 2.4V. The measurement frequency is 900 MHz.

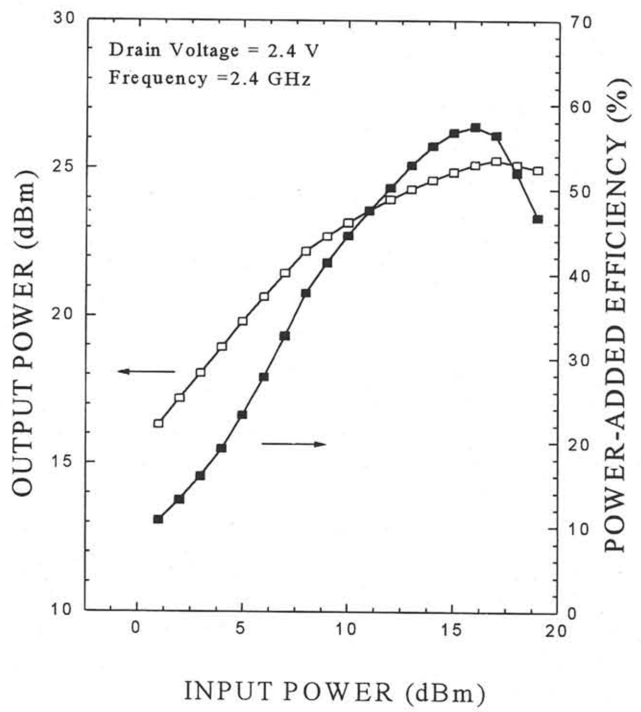

Fig.6 Output power and power-added-efficiency as a function of input power at a drain bias of 2.4V. The measurement frequency is 2.4 GHz.

4. CONCLUSIONS

A high performance atomic-planar-doped AlGaAs/InGaAs quantum-well power HEMT has been

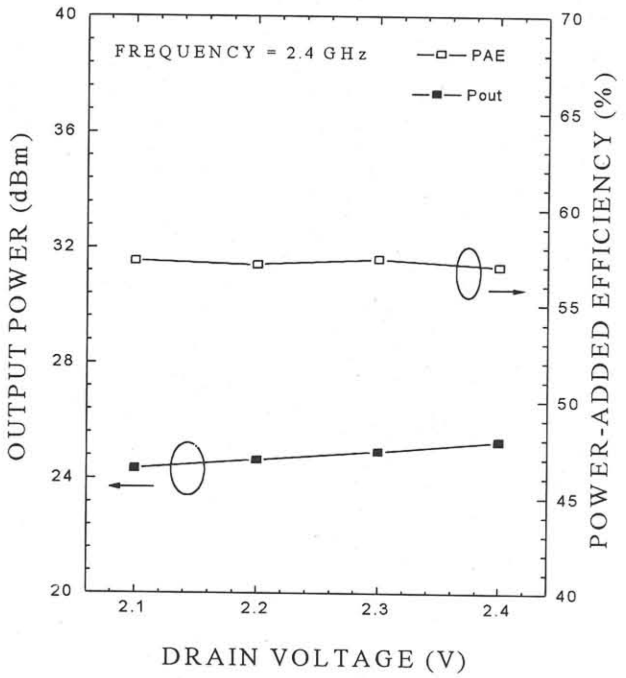

Fig. 7. Output power (P_{out}) and power-added-efficiency (PAE) as a function of drain voltage. The measurement frequency is 2.4 GHz.

developed. The HEMT exhibited a maximum drain current of 420 mA/mm. The maximum transconductance of the device was 300 mS/mm. At a measurement frequency of 900 MHz, the 2 mm HEMT with a drain bias of 2.4 V demonstrated an output power of 25.5 dBm and a power-added efficiency of 61 %. An output power of 24.4 dBm and a power-added efficiency of 57.4 % were achieved at 2.4 GHz. The developed HEMTs demonstrated great potential for the future generation portable wireless communication applications at ISM and L bands.

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