3V OPERATION L-BAND POWER DOUBLE-DOPED HETEROJUNCTION FETs

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ABSTRACT

This paper describes the microwave power performance of double-doped AlGaAs/InGaAs/GaAs pseudomorphic heterojunction field-effect transistors (HJFETs) operated at a DC drain bias of 3V. The fabricated 1.1 μm gate-length HJFET with an undoped AlGaAs Schottky layer exhibited a maximum drain current of 220mA/mm, a peak transconductance of 200mS/mm, and a gate-to-drain breakdown voltage of 21V. Power performance evaluated at a 3V drain bias for a 12mm gate-periphery device demonstrated a maximum output power of 1.4W with a 61% power-added efficiency at 950MHz. The results indicate that the double-doped pseudomorphic heterojunction FETs have a high potential for battery-operated portable power applications.

INTRODUCTION

There is an increasing demand for small-size power modules for cellular portable radio communication systems which can be operated with a low DC supply voltage. To date an output power of 32.5dBm with a power-added efficiency of 70% has been reported at 950MHz with a DC drain bias of 4.7V using a GaAs MESFET[1]. However, there have been only a few reports of power performance obtained with a lower supply voltage while maintaining a reasonable output power level[2,3].

Under the 3V DC bias voltage condition, which is expected to be used in the next generation cellular portable radio systems, increasing the total gate width is the most straightforward way to compensate the reduced output power density resulting from the limited drain voltage swing. This scheme, however, causes a lower output impedance that makes output matching fairly difficult. The wider gate width also accompanies an increase in the total gate leakage current, resulting in unstable setting in the quiescent gate bias point. Furthermore, it leads to an increase in the chip size and a drop in the chip yield, both of which are undesirable aspects from the production point of view.

An alternative approach to the wider gate-periphery scheme is to increase the available drain current density. Since the battery voltage is limited to 3V, the pinch-off voltage of the device should be designed to have a smaller value ($<$ 3V). This requires reasonably high transconductance in addition to high drain current density upon the device. These requirements strongly suggest that a selectively-doped heterojunction FET (HJFET) is a good candidate for 3V-operated power applications. The purpose of this paper is to present fabrication and power performance of 1.1 μm gate-length double-doped AlGaAs/InGaAs/GaAs HJFETs. The advantage of using undoped AlGaAs Schottky layer is also discussed.

DEVICE STRUCTURE AND FABRICATION

The material structure used for the developed HJFET, as illustrated in Fig.1, is based upon a pseudomorphic double-doped heterostructure similar to that previously reported[4]. The structure consists of an $Al_{0.22}Ga_{0.78}As$ buffer layer, a 40Å n-$Al_{0.22}Ga_{0.78}As$ layer, a 10Å undoped $Al_{0.22}Ga_{0.78}As$ spacer layer, a 130Å undoped $In_{0.2}Ga_{0.8}As$ channel layer, an 80Å n-$Al_{0.22}Ga_{0.78}As$ layer, a 260Å undoped $Al_{0.22}Ga_{0.78}As$ Schottky layer, and a 600Å n^+-$GaAs$ cap layer. The doping densities for the upper(80Å) and

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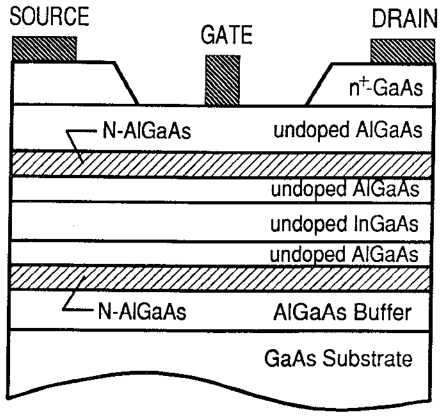

Figure 1. Structure of double-doped heterojunction FET.

the lower(40$\AA$) AlGaAs donor layers are 4.5x10^{18} and 4x10^{18}cm^{-3}, respectively. For comparison purpose, a similar double-doped structure with no undoped AlGaAs Schottky layer but with a 340$\AA$ uniformly-doped (2x10^{18}cm^{-3}) $Al_{0.22}Ga_{0.78}As$ donor layer is also prepared.

Devices with 1.1μm long Ti/Al/Ti gates were fabricated using the standard photolithography technique. Prior to gate deposition, a gate recess, 1.9μm wide, was etched by a wet-chemical process. There are 56 gate fingers for a total gate width of 12mm. After thinning the wafer to 30μm, a backside metal plane was evaporated and gold-plated to obtain low thermal resistances. All the devices were finally passivated with a 100nm-thick SiN film to attain reliable and stable performances.

DEVICE PERFORMANCE

Figure 2 shows the typical DC $I_d - V_d$ characteristics for the developed HJFET with a 200μm gate width. A maximum extrinsic transconductance g_m of 200mS/mm was measured at V_{gs}=-0.3V. The maximum drain current density I_{max}, defined as the drain saturation current density measured at V_{gs}=0.5V, was 220mA/mm. The gate-to-drain breakdown voltage BV_{gd}, measured at a gate current of 1mA/mm, was 21V. In contrast, the device without the undoped AlGaAs Schottky layer exhibited 3-4V smaller breakdown voltage (see Fig.3) although the measured g_m and I_{max} were comparable. The higher BV_{gd}, obtained from the device with an undoped AlGaAs Schottky layer, is due to the reduction in both thermionic emission and tunneling injected currents from the gate electrode. Since there is a trade-off relation between BV_{gd} and I_{max} [5,6], the undoped AlGaAs Schottky structure enables us to design a device that permits a larger drain current swing to generate more RF power under limited battery voltage conditions.

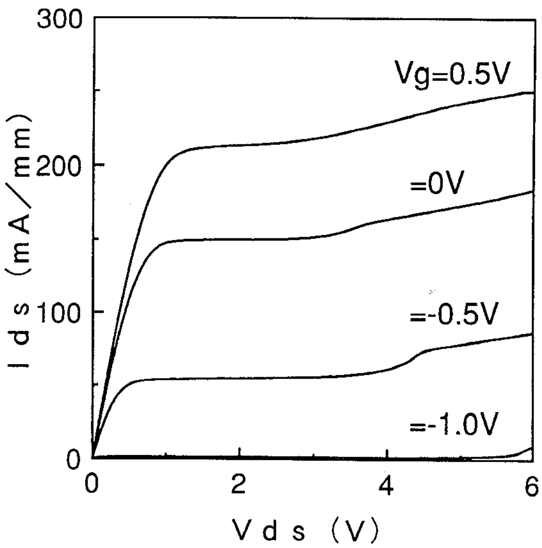

Figure 2. Typical DC Id-Vd characteristics of double-doped HJFET.

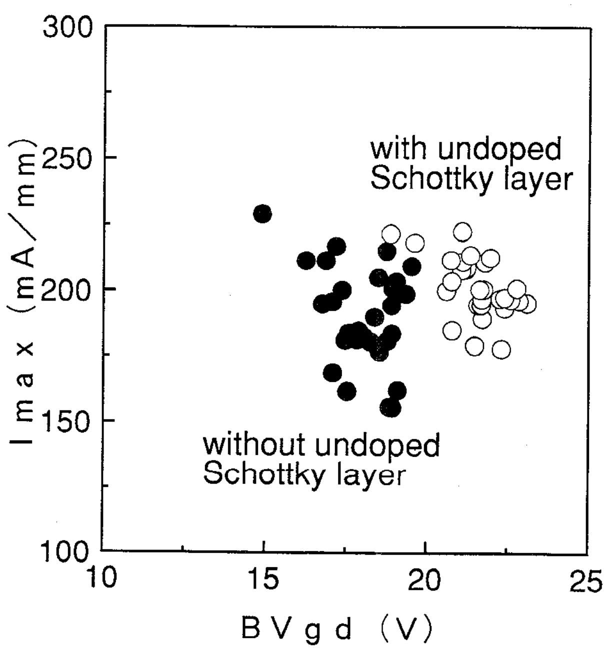

Figure 3. Maximum drain current as a function of gate-to-drain breakdown voltage.

Another advantage of using the undoped AlGaAs Schottky layer structure is the improvement in the knee (saturation) voltage V_k. Since V_k is difficult to define near the full channel region, we have introduced an effective V_k which is defined as the V_{ds} value when I_d becomes 100mA/mm with V_{gs}=0.5V. The effective V_k is determined in the linear region and thus is measured more precisely. Figure 4 plots the relationship between V_k and I_{max}. The effective V_k was 0.35-0.45V for the device with an undoped Schottky layer while that for the standard HJFET with no undoped Schottky layer was 0.45-0.6V. The lower V_k values obtained by using an undoped Schottky layer are ascribed to the reduction in parasitic parallel conduction through the AlGaAs layer. Self-consistent calculations at V_{gs}=0.5V show that 11% of the total electrons are permitted to flow in the AlGaAs layer for the conventional uniformly-doped device while the present HJFET with an undoped Schottky layer allows only 5% of the total electrons to populate within the AlGaAs layer.

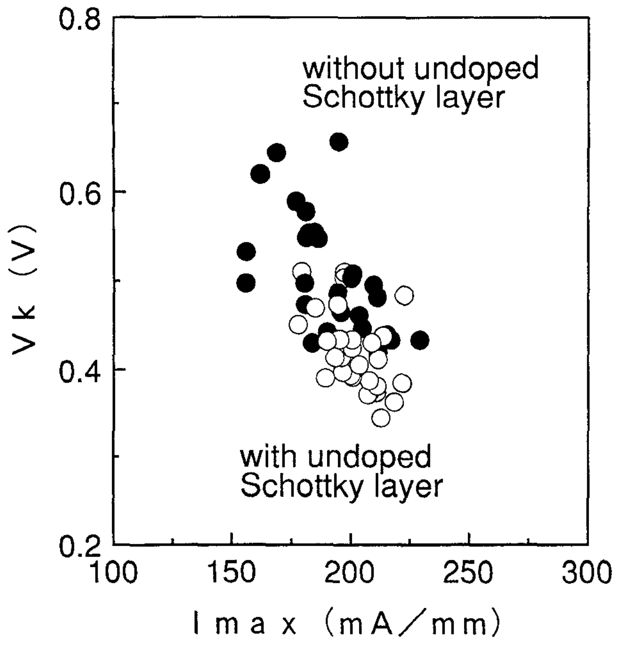

Figure 4. Effective knee voltage as a function of maximum drain current.

S-parameter measurements were performed from 0.5 to 40GHz for the 200μm-wide devices using an on-wafer prober and automated network analyzer. Typical f_T and f_{max} values estimated at V_{gs}=0.0 and V_{ds}=3V were 15 and 85GHz, respectively. Very slight decreases in f_T and f_{max} were observed with increasing V_{ds} up to 7V, where they were 13 and 80GHz, respectively. No significant differences in small-signal characteristics have been observed between devices with and without the undoped Schottky layer.

Power performance of the HJFETs (with undoped Schottky layers) was tested at 950MHz with a drain bias of 3V. Figure 5 shows output power, power-added efficiency, and I_d as a function of input power for a 12mm-wide HJFET. The device was operated under class AB condition with a quiescent bias current of 0.4A (15% of I_{max}). Linear gain was 12.7dB. Maximum output power was 31.4dBm(1.4W) with an assosiated power-added efficiency of 60% and 7.7dB gain. Peak power-added efficiency was 61% with an associated output power of 30.9dBm(1.2W) and 9.2dB gain. The devices were also tested at higher V_{ds}. Maximum output power of 32.4dBm(1.7W) and 34.1dBm(2.6W) with peak power-added eficiency of 60% and 61% were recorded at V_{ds}=4 and 5V, respectively.

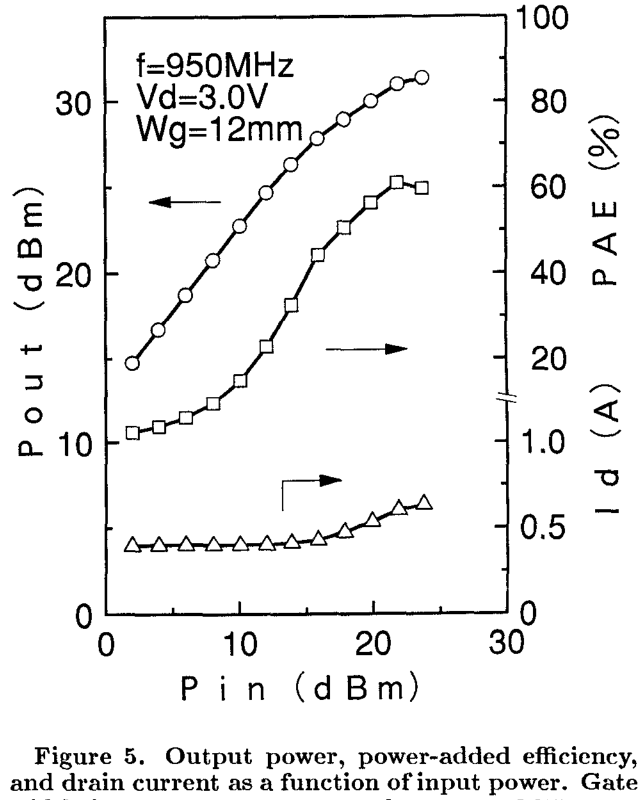

Figure 5. Output power, power-added efficiency, and drain current as a function of input power. Gate width is 12mm. Data were taken at 950MHz at a drain bias of 3V.

CONCLUSIONS

A double-doped AlGaAs/InGaAs/GaAs pseudomorphic HJFET with an undoped AlGaAs Schottky layer has been developed. The fabricated 1.1μm device exhibited I_{max}, g_m, and BV_{gd} of 220mA/mm, 200mS/mm, and 21V, respectively. It has been demonstrated that the knee voltage is noticeably improved by the use of an undoped Schottky layer. At 950MHz, an output power of 1.4W with power-added efficiency of 61% has been obtained under 3V drain bias conditions. These initial results demonstrate that the double-doped HJFET has great promise for battery-operated portable power applications.

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