Novel InGaP/AlGaAs/InGaAs Heterojunction FET for X-Ku Band Power Applications

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Abstract

We have successfully fabricated a novel heterojunction FET (HJFET) with an InGaP surface layer for high yield X-Ku band power applications. Standard deviation in the threshold voltage of 60mV was achieved by using a highly-selective wet recess etching technique. The fabricated HJFET(Wg=16.8mm) delivered an output power of 9.5W and a power-added efficiency of 35 % with a low carrier-to-third-order intermodulation distortion ratio of -29.5dBc at 12GHz. Moreover, the 25.2mm HJFET delivered an output power of 12.2W.

Introduction

GaAs-based AlGaAs/InGaAs pseudomorphic heterojunction FETs(HJFETs) have been developed as high-efficiency power devices at microwave frequencies. To obtain high power with high power-added efficiency, we have developed the AlGaAs/InGaAs HJFET with the buried gate structure[1][2]. It is well known that the buried gate structure is effective in suppressing the surface effect which causes the premature power saturation in power FETs[1]. Although the surface effect can be decreased by increasing the narrow recess depth, the breakdown voltage is also reduced in the AlGaAs/InGaAs HJFET[2].

In the present study, we propose a novel InGaP/AlGaAs/InGaAs HJFET structure where the gate electrode was buried in the InGaP layer. Because the impact ionization coefficient in InGaP[3] is smaller than that in AlGaAs[4] by a factor of ten, avalanche multiplication can be suppressed in this novel HJFET. Furthermore, a double recess structure of this new device can be fabricated by highly material-selective etching of GaAs against InGaP and of InGaP against AlGaAs[5], which provides a technological advantage in yield and homogeneity.

Device Fabrication

The InGaP/AlGaAs/InGaAs HJFET structure is composed of an $Al_{0.22}Ga_{0.78}As$/GaAs buffer layer, an n-type $Al_{0.22}Ga_{0.78}As$ donor layer, an undoped $In_{0.2}Ga_{0.8}As$ channel layer, an n-type $Al_{0.22}Ga_{0.78}As$ donor layer, an undoped $Al_{0.22}Ga_{0.78}As$ Schottky layer, a 40nm-thick undoped $In_{0.49}Ga_{0.51}P$ surface layer, and a heavily-doped n-type GaAs cap layer, as illustrated in Figure 1. These

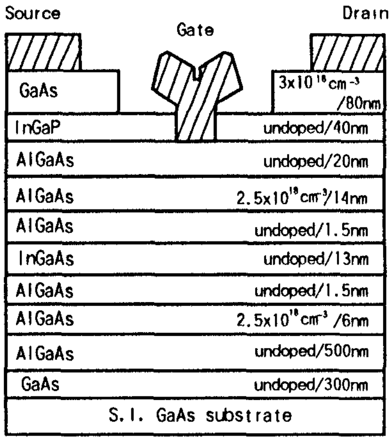

Figure 1 Cross section of InGaP/AlGaAs/InGaAs HJFET.

layers were grown by metal-organic chemical vapor deposition method on a 3-inch GaAs semi-insulating substrate.

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Figure 2 shows the process sequence for the InGaP/AlGaAs/InGaAs HJFET. Wide recess etching was performed in H_2SO_4 solution at 20℃ as shown in Figure 2a and Figure 2b. The etching rate of GaAs was over 100 times as fast as that of InGaP. Following the removal of GaAs cap layer, gate recess etching was carried out using HCl at 20℃ as shown in Figure 2c. The HCl etching yielded almost complete selectivity for removing InGaP over AlGaAs. The 0.4μm buried gate was fabricated by sputter deposition of WSi. Ohmic contacts were formed using AuGe/Ni alloys by thermal evaporation and subsequent annealing at 440℃(Figure 2d). The device surface was passivated by a 100nm-thick SiO_2 film.

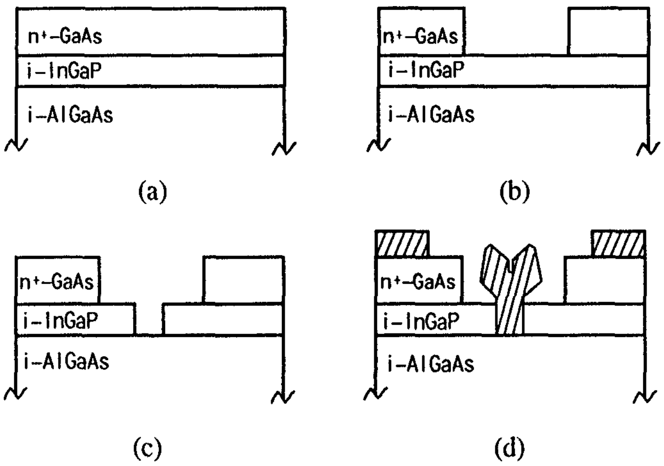

Figure 2 Process sequence for InGaP/AlGaAs/InGaAs HJFET.

Device Characteristics

Drain I-V characteristics of the fabricated InGaP/AlGaAs/InGaAs HJFET are shown in Figure 3. A maximum drain current(I_{max}) of 500mA/mm was obtained at a gate voltage (V_g) of 1.0V. A peak transconductance measured at source-drain voltage(V_{ds}) of 2V was 300mS/mm and a gate-to-drain breakdown voltage(BV_{gd}) was 16V. As shown in Figure 4, the standard deviation in the threshold voltage(σ_{VT}) of 60mV was achieved due to high selectivity in the recess etching. Employing wet-etching technique, σ_{VT} of the InGaP/AlGaAs/InGaAs HJFET is less than one fifth of that of the AlGaAs/InGaAs HJFETs. Figure 5 shows the correlation between BV_{gd} and the narrow recess depth in the InGaP/AlGaAs/InGaAs HJFET and the conventional AlGaAs/InGaAs HJFET. Provided that the narrow recess depth of the InGaP/AlGaAs/InGaAs HJFET was identical to that of the conventional AlGaAs/InGaAs HJFET, higher BV_{gd} was attained in the InGaP/AlGaAs/InGaAs HJFET as compared to the conventional AlGaAs/InGaAs HJFET. This result indicates that avalanche multiplication is suppressed in the InGaP/AlGaAs/InGaAs HJFET.

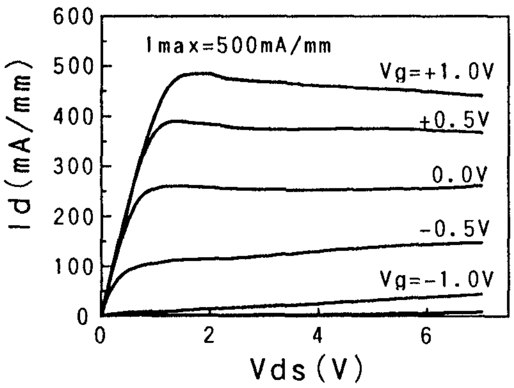

Figure 3 Drain I-V characteristics.

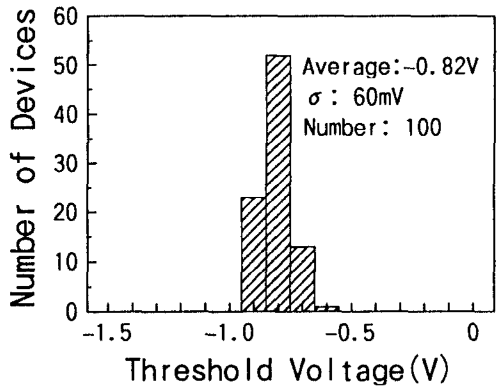

Figure 4 Histogram of threshold voltage across 3-in wafer.

Pulsed I-V measurements (DC to 1MHz), performed at V_g values between -1.5V and +1.0V, are shown in Figure 6. No appreciable frequency dispersion in the drain current was measured by the use of InGaP surface layer with the buried gate structure, ensuring high output power performance capability with good linearity.

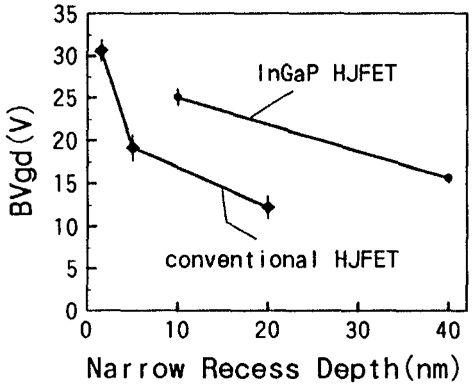

Figure 5 Correlation between narrow recess depth and gate-to-drain breakdown voltage.

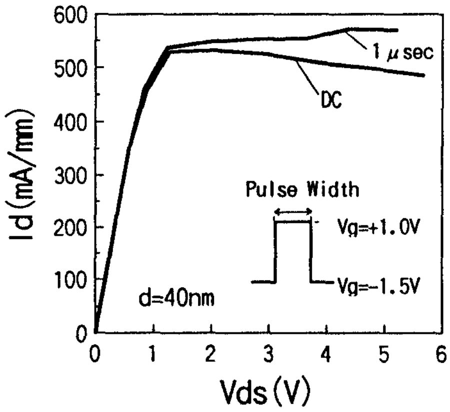

Figure 6 Pulsed I-V characteristics.

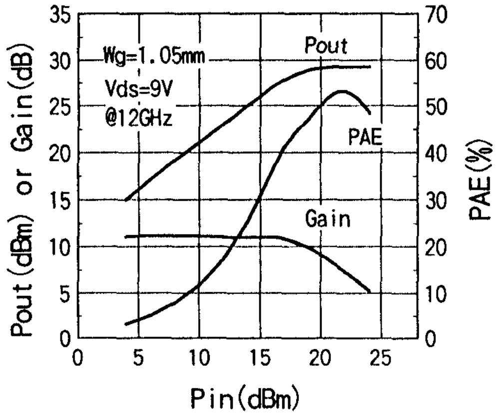

Figure 7 Measured output power, gain and power-added efficiency as a function of input power at 12GHz for 1.05mm HJFET.

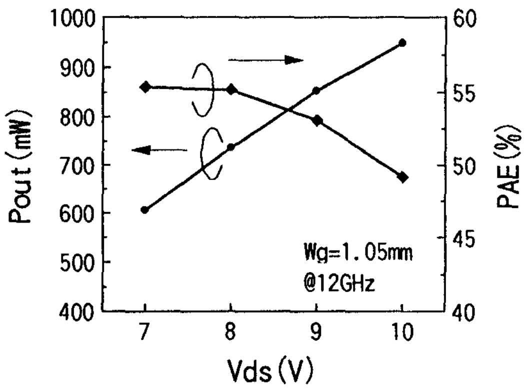

Figure 8 Operation drain bias dependence of output power and power-added efficiency.

The unit cell HJFET(Wg=1.05mm) was power tested under C.W. operating conditions at 12GHz with a drain current of 30%I_{max}. Measured output power, gain and power-added efficiency(η_{add}) as a function of input power with V_{ds}=9V are shown in Figure 7. The output power of 850mW, linear gain of 11dB and η_{add} of 53% were obtained. Good linearity was exhibited due to the suppression of the frequency dispersion realized by the introduction of the InGaP surface layer. Figure 8 shows the drain bias dependence of output power and η_{add} with a drain current of 30%I_{max}. Output power increases linearly from 600mW to 950mW with increasing the drain bias, and η_{add} is higher than 48% in the drain bias range investigated from 7V to 10V.

Measured output power, linear gain and η_{add} as a function of input power for the internally-matched 12cell HJFET (Wg=16.8mm) are shown in Figure 9. The 16.8mm HJFET delivered a 7.2W output power with 41% power-added efficiency and 9.4dB linear gain at 12GHz with V_{ds}=7V. At V_{ds}=9V, 9.5W output power, 35% power-added efficiency and 8.9dB linear gain was obtained. As shown in Figure 10, the carrier-to-third-order intermodulation distortion ratio of -29.5dBc was obtained for the 16.8mm HJFET at 3dB input backoff with a drain bias of 9V. The frequency separation of the two tone was 50MHz.

Figure 11 shows an output power, linear gain and η_{add} as a function of input power for the internally-matched 25.2mm HJFET. The 25.2mm HJFET delivered a 10.0W output power with 32% η_{add} with V_{ds}=7V, and a 12.2W output power with 25% η_{add} with V_{ds}=8V.

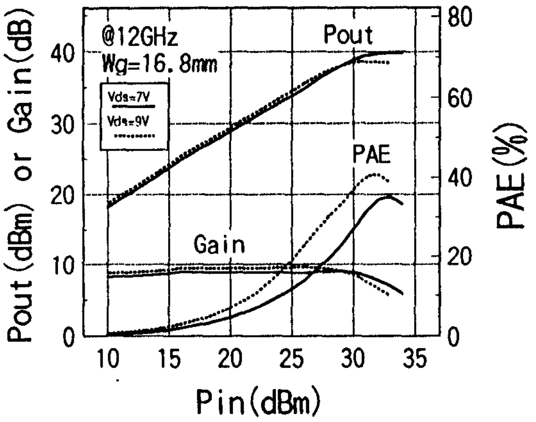

Figure 9 12GHz power performance for 16.8mm internally-matched HJFET.

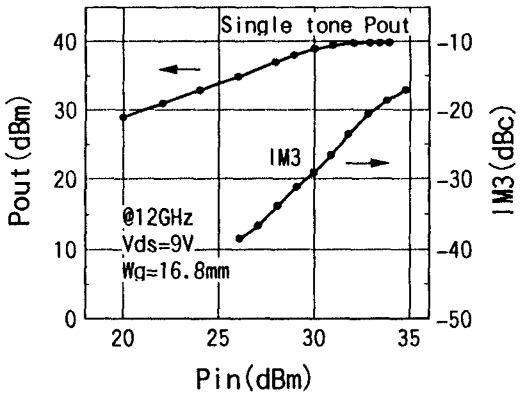

Figure 10 Third-order intermodulation characteristics as a function of input power.

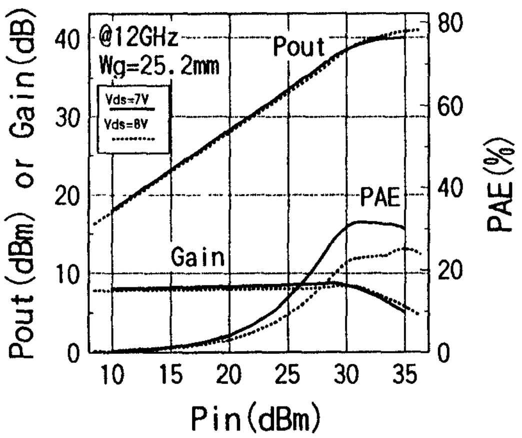

Figure 11 12GHz power performance for 25.2mm internally-matched HJFET.

Conclusion

We have successfully fabricated a novel InGaP/AlGaAs/InGaAs HJFET with a low σ_{VT} of 60mV by using a highly-selective wet recess etching technique. The 16.8mm HJFET delivered an output power of 9.5W and a power-added efficiency of 35 %. Moreover, the 25.2mm HJFET delivered an output power of 12.2W. The InGaP/AlGaAs/InGaAs HJFET is promising for microwave power applications, especially for high power MMIC applications which require excellent uniformity and high breakdown voltage.

Acknowledgments

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