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A Buried-Channel WN_x/W Self-Aligned GaAs MESFET with High Power-Efficiency and Low Noise-Figure for Single-Chip Front-End MMIC in Personal Handy Phone System

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Microwave performance is presented for the buried-channel WN_x/W-gate self-aligned GaAs MESFET (BC-MESFET) with the combined process of ion-implantation and epitaxial growth. The 0.6 μmx 1 mm FET has a power added efficiency of 57 % at 1.9 GHz and the 0.6 μm x 100 μm FET has a minimum noise figure of below 0.4 dB at 2 GHz. These results demonstrate that the BC-MESFET is suitable for single-chip front-end MMIC in personal handy phone system.

1. INTRODUCTION

Recently, the mobile communication has advanced to the L-band personal handy phone system (PHS). The PHS includes several blocks; RF transmission, RF reception, RF switch, and so on. The integration of these blocks in a single-chip MMIC is one of the preferred approaches for realizing smaller-size PHS. Some authors[1,2] reported GaAs FETs with low noise and high power characteristics, intending to integrate the front-end blocks into an RF single-chip MMIC. However, the fabrication process of these FETs seems to be slightly complicated and not cost-effective to realize the single-chip MMIC because the FETs consist of many epitaxial layers. This paper describes superior noise and power performance of the buried channel MESFET (BC-MESFET)[3] applicable for these applications. The BC-MESFET, which consists of one epitaxial layer on an ion-implanted channel, is more suitable for large-scale single-chip MMICs because its fabrication process could easily realize FETs with different threshold voltage.

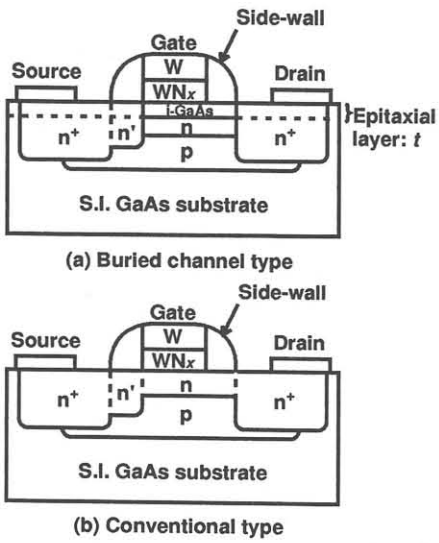

Fig. 1. Schematic cross-sectional views of the BC-MESFET and conventional MESFET.

2. DEVICE STRUCTURE AND FABRICATION

Figure 1 shows schematic cross-sectional views of the BC-MESFET and conventional MESFET.[4] They have 0.6-μm WN_x/W-gate self-aligned asymmetric structure so that both low on-state resistance and high gate-drain breakdown voltage can be achieved. The BC-MESFET has an undoped i-GaAs epitaxial surface layer on an ion-implanted channel. The surface layer is grown by MOVPE technique after capless-annealing to activate implanted dopants and remove implantation-induced surface defects of the ion-implanted channel. Details of the process have been described in Ref. 3.

3. DC CHARACTERISTICS

The undoped surface layer contributes to enhancing breakdown voltage which is important for highly-efficient power operation. Figure 2 shows gate-drain breakdown voltage of the BC-MESFETs as a function of threshold voltage. The breakdown voltage increases with increasing surface layer thickness. The breakdown voltage for the BC-MESFET with

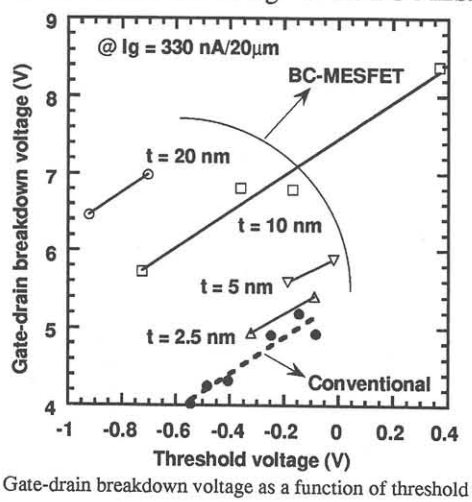

Fig. 2. Gate-drain breakdown voltage as a function of threshold voltage.

20-nm-thick surface layer is more than 3 V higher than that for the conventional MESFET. There has to be a trade-off between the breakdown voltage and controllability of threshold voltage (V_{th}) in the BC-MESFET, because thicker surface layer (t) leads to larger threshold-voltage dependence on an ion-implantation dosage (Q) into the channel as shown in the following equation

$$V_{th} = \phi_b - \frac{q}{\varepsilon}\eta Q(t + t_0)$$

where ϕ_b is the Schottky barrier height, q the elementary charge, ε the dielectric constant of GaAs, η the activation efficiency of the implanted silicon atoms, and t_0 the constant related to acceleration energy of the ion-implantation. Thus, we have chosen the surface layer thickness of 20 nm so that the stable threshold voltage can be achieved.

Figure 3 shows the transconductance (g_m) as a function of gate voltage (V_g) for the BC-MESFET with 20-nm thick surface layer, together with the conventional MESFET which have almost the same threshold voltage. Although the peak value of the transconductance is smaller for the BC-MESFET, the transconductance is almost equal or larger below the gate voltage of - 0.2 V ($V_g - V_{th} < 0.5$ V), where low noise FETs will be operated. Therefore, the superior microwave performance should be obtained in this gate-bias range since the gate capacitance (C_{gs}) is inherently smaller for the BC-MESFET because of its buried channel structure.

4. POWER PERFORMANCE

Figure 4 shows the output power and power added efficiency for a power BC-MESFET (W_g = 1 mm) with 20-nm-thick surface layer as a function of the input power at 1.9 GHz. We have measured these data using automated tuner system at a drain bias voltage of 2.7 V and a gate voltage of - 0.5 V so as to obtain the maximum output power at around 1-dB gain compression. An output power of 19.2 dBm and power added efficiency of 57 % are obtained at a gain compression of 1 dB and a drain current of 53 mA. These values are sufficient for the application of a highly-efficient linear power amplifier block in the PHS with long battery lifetime. Figure 5 shows the output power and power added efficiency at 1-dB gain compression as a function of incremental gate bias voltage from threshold voltage ($V_g - V_{th}$) for the BC-MESFET with 20-nm-thick surface layer and the conventional MESFET. Larger power added efficiency is obtained for the BC-MESFET than that for the conventional MESFET. The efficiency shows the peak near the $V_g - V_{th}$ = 0.2 V, where these power FETs are driven under class AB condition. The improvement of efficiency for the BC-MESFET could be attributed to higher gate-drain breakdown voltage of the BC-MESFET.

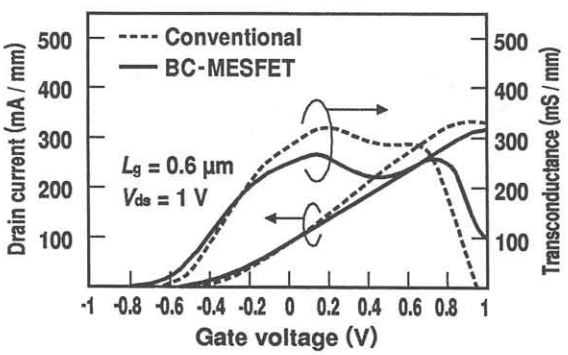

Fig. 3. Transconductance and drain current of the BC-MESFET and conventional MESFET as a function of gate voltage.

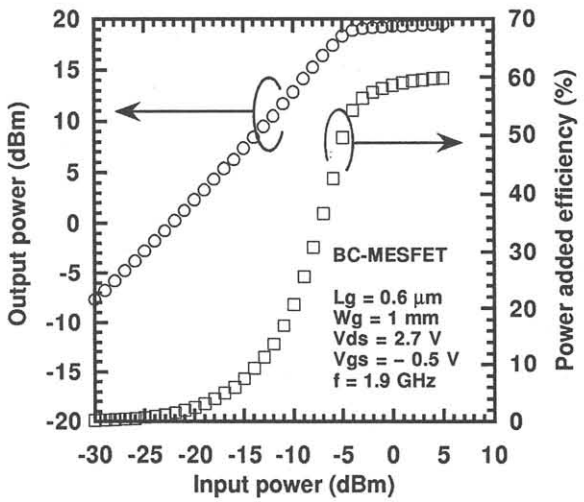

Fig. 4. Input-output characteristics of the power BC-MESFET.

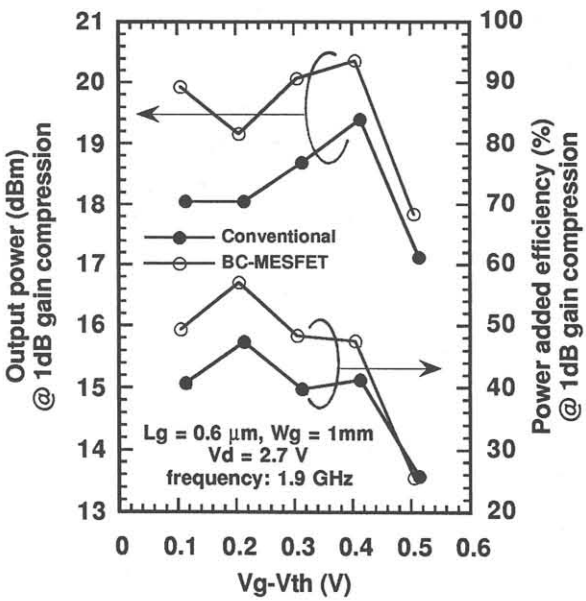

Fig. 5. Output power and power added efficiency at 1-dB gain compression as a function of incremental gate bias voltage from threshold voltage.

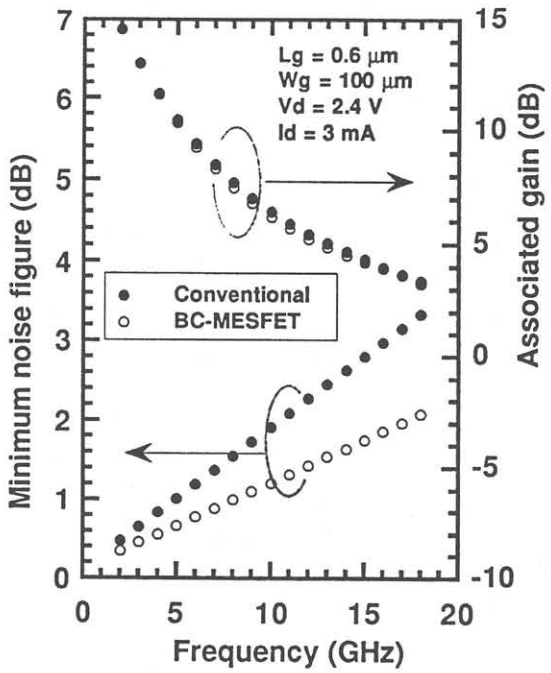

Fig. 6. Minimum noise figure and associated gain of the BC-MESFET and conventional MESFET as a function of frequency.

5. NOISE PERFORMANCE

Low noise performance should also be required to integrate the reception block into the single-chip front-end MMIC. Figure 6 shows minimum noise figure and associated gain for the BC-MESFETs with 20-nm-thick surface layer as a function of frequency. The values of conventional MESFET are also shown for comparison. In the measurement, the dissipated drain current is 3 mA (V_g = – 0.48 V) for a gate width of 100 μm. We have obtained a minimum noise figure of below 0.4 dB and an associated gain of 14.6 dB at 2 GHz for the BC-MESFET. These values are sufficient for the reception-block application in the PHS. It can be noted that a minimum noise figure of 1.43 dB at 12 GHz is obtained for the BC-MESFETs in spite of long gate length of 0.6 μm. This value is 0.8-dB smaller than that for the conventional MESFET and close to the value for other epitaxial-channel FETs[5] with comparable gate length.

The improvement of noise figure should be attributed to the buried channel structure *i.e.* intrinsic part of the FET, because the parasitic part is almost the same between the BC-MESFET and conventional MESFET. The minimum noise figure is expressed by well-known Fukui's equation or, in case of small source and gate resistance, the equation as follows:

$$F_{\min} \cong 1 + \frac{4\pi f C_{gs}}{g_m}\sqrt{PR\left(1-C^2\right)}$$

where P and R are dimensionless parameters related to noise current sources and C is the correlation coefficient between the gate and drain noise sources.[6] As mentioned before, the BC-MESFET has comparable value of g_m at the gate bias range of $V_g - V_{th} < 0.5$ V, where the noise measurement was carried out. Furthermore, the BC-MESFET has smaller value of C_{gs} than the conventional MESFET because the depletion layer is thicker. The calculated value of C_{gs} for the BC-MESFET was 56 fF / 100 μm, while that for the conventional MESFET was 94 fF / 100 μm. Thus, the lower noise figure should be obtained in the above equation. We have also calculated the correlation parameter of C and obtained C = 0.72 for the conventional MESFET and C = 0.83 for the BC-MESFET as typical values. Therefore, the noise reduction in the BC-MESFET could be partly originated in the cancellation effect between drain noise current and induced gate noise current.

6. CONCLUSION

The power and noise performance of the BC-MESFET has been successfully demonstrated. In spite of its simple structure, the BC-MESFET shows both high power efficiency and low minimum noise figure, which are superior to the conventional MESFET. The BC-MESFET will be one of the most promising candidates for realizing single-chip MMICs that integrate transmission and reception blocks in the PHS.

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