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Super Low Noise AlGaAs/GaAs HEMT With One Tenth Micron Gate

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Abstract

Low noise AlGaAs/GaAs HEMT with 0.1 μm gate length have been successfully developed. A state-of-the-art low noise figure of 0.51 dB and 1.9 dB are obtained at 18 GHz and 40 GHz at room temperature, with an associated gain of 10.8dB and 5.3dB, respectively. The performance has been achieved by shortening the gate length to 0.1 μm and also by lowering the gate resistance drastically with a T shaped gate structure.

Introduction

Noise figure reduction of semiconductor devices has been successively pursued to meet ever increasing system needs in microwave and millimeter wave frequencies[1]. In order to realize very low noise field effect transistors(FETs), efforts have been made in many laboratories towards reducing gate length to less than a quarter micron and developing new material structures other than GaAs or AlGaAs/GaAs[2][3]. And, very high performance HEMTs using InGaAs materials have already been reported [4][5]. It is desirable, however, to utilize AlGaAs/GaAs HEMTs in systems when the similar performance to this of InGaAs HEMT was obtained, since a large number of AlGaAs/GaAs HEMTs have been applied to various kinds of systems with high reliability[6].

The purpose of this paper is to show that a very low noise figure of 0.51 dB has been obtained at 18 GHz at room temperature from a 0.1 μm gate AlGaAs/GaAs HEMT by incorporating a low resistance gate structure. The effects of gate length and gate resistance on microwave performance are also experimentally shown.

Device Fabrication

The cross section of developed HEMT is schematically drawn in Fig.1. Epitaxial wafers in this work consist of a 0.1 μm thick undoped GaAs buffer layer, a 100 Å thick n-$Al_{0.3}Ga_{0.7}As$ layer and a 300 Å thick n-GaAs cap layer, successively grown by MBE on undoped LEC semi-insulating substrates with 2 inch diameter. The $Al_{0.3}Ga_{0.7}As$ and GaAs cap layers were doped to 2.5×10^{18} cm^{-3} and 4.0×10^{18} cm^{-3} with Si, respectively. After mesa etching by 0.3 μm, the source and drain ohmic contacts, separated by 3 μm, were formed by alloying e-beam evaporated Ni/AuGe at 450 °C for two minutes. The gate patterns were delineated on PMMA closer to the source electrodes, using an electron beam lithography. Al/Ti and Au/Pt/Ti gate metals were deposited by an e-beam evaporator for 0.15–0.4 μm and 0.1 μm gate length HEMTs, respectively. All the metal patterns were formed by a lift-off technique.

The fabricated HEMTs have a 200 μm gate width with two bonding pads. Figure 2 shows a microphotgraph of the HEMT chip. The chip size is 300 μm x500 μm.

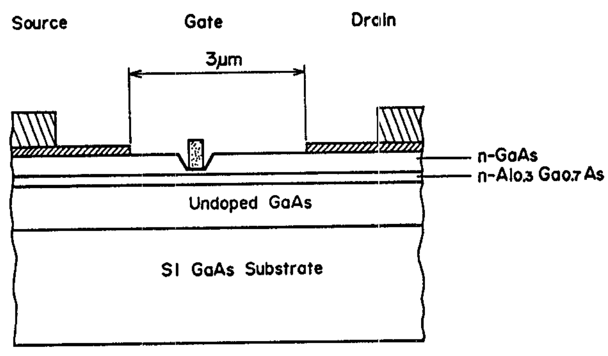

Fig.1 Cross section of HEMT

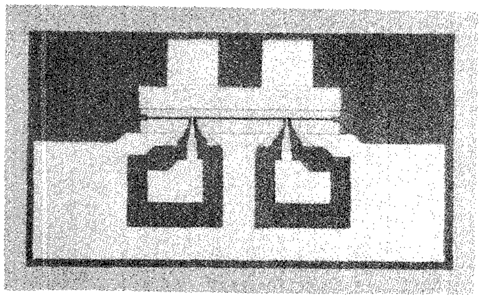

Fig.2 HEMT chip

Dependence of Microwave Performance on Gate Resistance and Gate Length.

a. Gate resistance dependence

For this experiment, we prepared three kinds of HEMTs with the same gate length but with different gate resistance. After gate pattern delineation on PMMA to a quarter micron length, the 2 inch wafer was cut to 3 pieces. The three pieces of wafer were metallized to different gate metal thicknesses of 4000 Å, 2500 Å and 1500 Å, respectively, by evaporating Al. The HEMTs were then fabricated on the three pieces of wafer.

The gate resistances of the HEMTs with 4000 Å, 2500 Å and 1500 Å gate metal thickness were measured to be 3.2 Ω, 4.5 Ω and 9.2 Ω, respectively. The noise figures of three kinds of HEMTs, each for 5 chips, were measured at 18GHz, mounted in a microwave test fixture biased at a drain voltage (Vds) of 3 V and a drain current (Ids) of 10 mA. Measured noise figures (NF), associated gains (Ga) and gate resistances are plotted in Fig.3 as a function of gate resistance. The dashed line in the figure is a curve calculated from Fukui's equation[7],

$$NF=10\log(1+2\pi KfCgs\sqrt{(Rg+Rs)/gm})$$

where, K(fitting factor)=0.95 was used.

From the dashed cuve in fig.3, an NF of 0.7 dB can be expected just by reducing a gate resistance to 0.5 Ω. To confirm it, we also fabricated T shaped quater micron gate HEMTs with a gate resistance of 0.6 Ω. Figure 4 shows the NF and Ga vs. Ids characteristics measured at 18 GHz and Vds=3V. The measured minimum NF is 0.69 dB. The datum is also plotted in Fig.3 with a triangular mark, showing the measured NF is very close to the prospected value from 0.6 Ω.

b. Gate length dependence

HEMTs with three different gate length were prepared on a 2 inch wafer, varying the conditions of electron beam lithography. The measured gate lengths of 0.15 μm, 0.25 μm and 0.4 μm were close to the objected ones.

Cgs and gm of each kind of HEMT chips were determined from S parameter measurements made over 2 to 18 GHz frequency range. Cgs, gm and f_T (calculated cut-off frequency) are shown in Fig.5 as a function of lg(gate length), where Vds=1.0 V and Ids=10 mA.

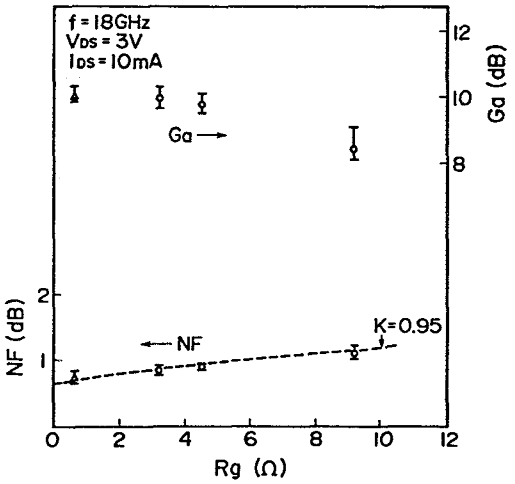

Fig.3 NF,Ga versus gate resistance

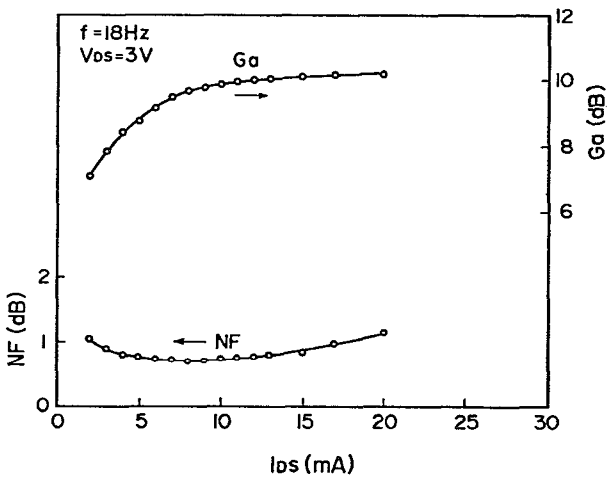

Fig.4 Performance of T shaped quarter micron gate HEMT

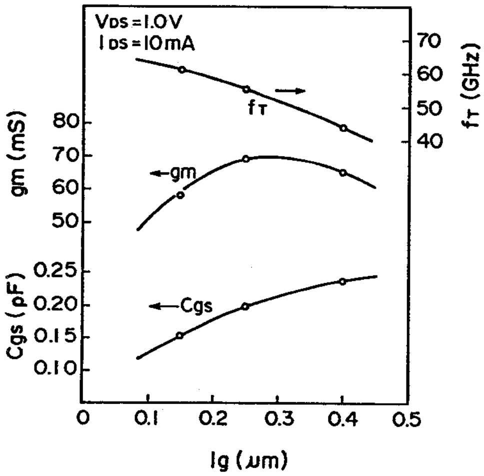

Fig.5 Cgs,gm and f_T dependence on gate length

It is clear from this figure that shortening the gate length to less than 0.1 µm is still effective to improve microwave performance, if other parameters, such as a gate resistance, are kept nearly constant. Substituting the values of Cgs and gm, extrapolated to lg=0.1 µm in Fig.5, into fukui's equation, we can expect the noise figure of 0.46 dB for 0.1 µm gate HEMTs,if the same gate resistance as that of the fabricated T shaped quarter micron gate is realized.

One Tenth Micron Gate HEMT

A cross-sectional view of the fabricated 0.1 µm gate HEMT is shown in Fig.6. The footprint of the gate is 0.1 µm long and the upper part is around 0.5 µm long. It is obvious from the SEM picture that the gate resistance is dominated by the upper area of the gate cross section. The gate resistance was measured to be 0.6 Ω.

Figure 7 shows the I-V characteristics of 0.1 µm gate HEMTs. The gm at saturated drain current is around 300 mS/mm. The compression of gm is severe near pinch off at higher drain voltages, caused by carrier injection into the buffer layer.

NF and Ga were measured in chip form at 18 GHz at room temperature. In Fig.8, the measured optimized NF and Ga are plotted as a function of Ids at Vds=1.2 V. An NF of 0.51 dB with Ga of 10.8 dB is observed at Ids= 15 mA, being very close to the one expected from Fukui's equation. To the authors' knowledge, this is the lowest NF at 18 GHz reported so far by AlGaAs/GaAs HEMT.

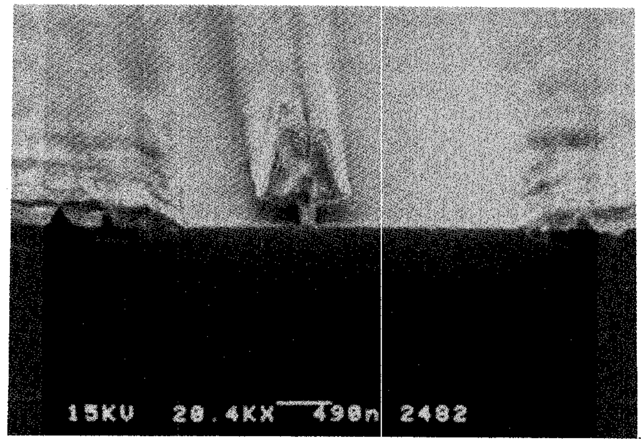

Fig.6 Cross section of 0.1µm gate HEMT

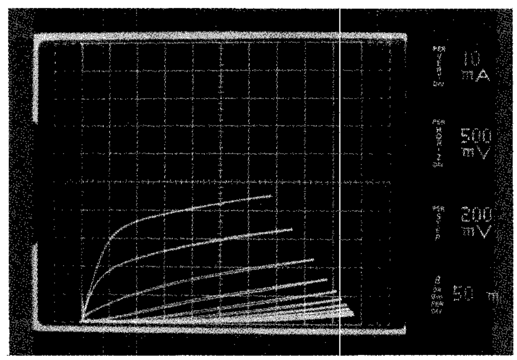

Fig.7 I-V characteristics of 0.1µm gate HEMT

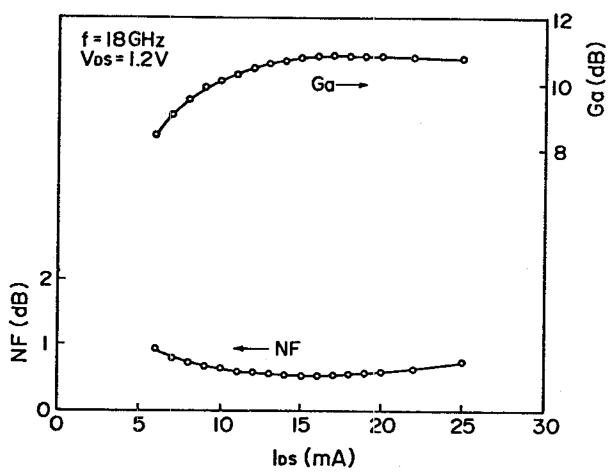

Fig.8 NF,Ga versus Ids of 0.1µm gate HEMT

Figure 9 shows the dependence of NF and Ga on drain voltage(Vds).
When Vds is increased, the minimum NF value is observed at the relatively high drain current due to the severe gm compression. Figure 10 shows a frequency dependence of NF and Ga measured at room temperature. The HEMT has shown minimum NF and Ga of NF=0.9 dB and Ga=8.8 dB, NF=1.9 dB and Ga=5.3dB at 26.5 GHz and 40 GHz, respectively. A lower NF could be expected by preparation of higher quality material and structual improvement to suppress carrier injection.

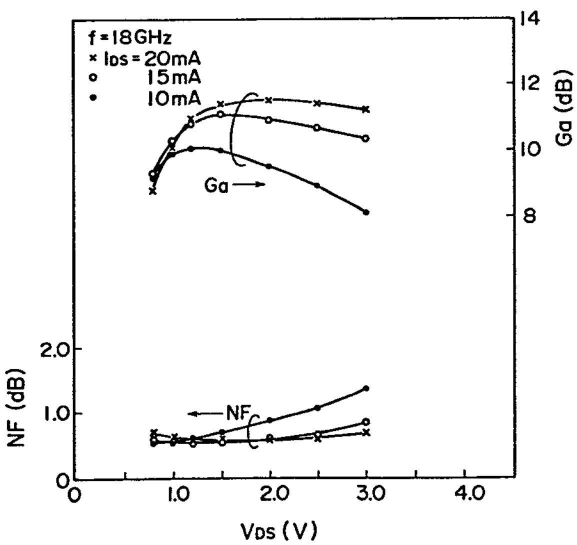

Fig.9 NF,Ga versus Vds of 0.1μm gate HEMT

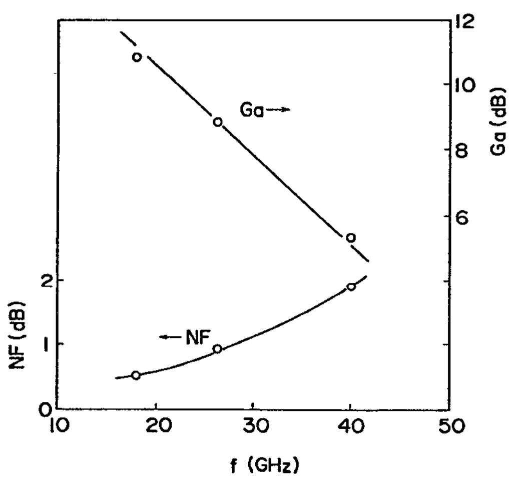

Fig.10 NF,Ga versus Frequency of 0.1μm gate HEMT

Conclusion

State-of-the-art low noise AlGaAs/GaAs HEMTs have been developed, realizing 0.1 μm gate length and T shaped gate structure. The best noise figure was 0.51 dB at 18 GHz with an associated gain of 10.8 dB. At 40 GHz, the HEMT exhibited 1.9 dB minimum noise figure with 5.3 dB associated gain. Further improvement could be expected from higher quality material preparation and carrier confinement in the channel by laying high potential barrier material like AlGaAs under the channel layer.

Acknowledgment

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