U-6

NOISE PERFORMANCE OF MICROWAVE HEMT

K.Joshin,T.Mimura,M.Niori,Y.Yamashita,K.Kosemura and J.Saito

Fujitsu Laboratories Ltd.
1677,Ono,Atsugi,243-01,Japan

Abstract

Low noise HEMTs (High Electron Mobility Transistors) with 0.5μm gate have been made using direct electron beam lithography. At 12 GHz a noise figure of 1.4 dB with an associated gain of 11 dB has been obtained at room temperature. Noise figure has been reduced to 0.35 dB by decreasing ambient temperature to 100K.

Introduction

HEMTs based on a modulation-doped GaAs/n-AlGaAs single heterojunction structure offer new possibilities for high speed logic and microwave devices.[1,2] Due to its high electron mobility,it is expected that HEMTs will provide good high frequency operation,specifically higher cutoff frequency f_T for current gain than those of conventional GaAs MESFETs. For GaAs MESFETs the minimum noise figure is described by[3]

$$F_{min}=1+K \frac{f}{f_T}\sqrt{G_m(R_g+R_s)} \quad , \qquad (1)$$

where K is a fitting factor and f is the operating frequency.

According to (1),higher cutoff frequency leads to a lower minimum noise figure. Thus a superior noise performance is also expected of HEMTs. This paper describes the fabrication process and the noise performance of 0.5μm gate length microwave HEMTs.

Material Preparation

A cross-sectional structure of an MBE wafer is shown in Fig.1. The epitaxial layers consisting of undoped GaAs,Si-doped n-type AlGaAs and n-type GaAs were grown on a semi-insulating GaAs substrate at a temperature of 680°C by MBE. For fabrication of the prototype HEMT,the doping concentration was 2 x $10^{18}cm^{-3}$,and the n-AlGaAs and the n-GaAs were 0.05μm in thickness. The surface n-GaAs layer was prepared to obtain improved ohmic contacts.

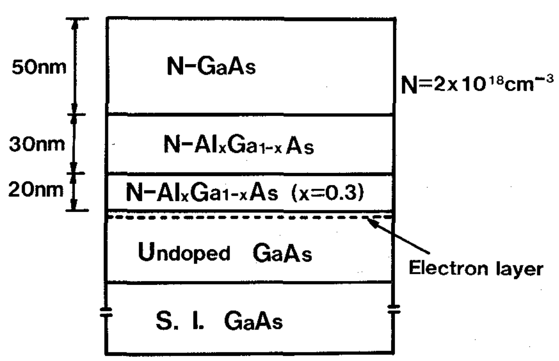


Fig.1 Schematic representation of an MBE wafer.

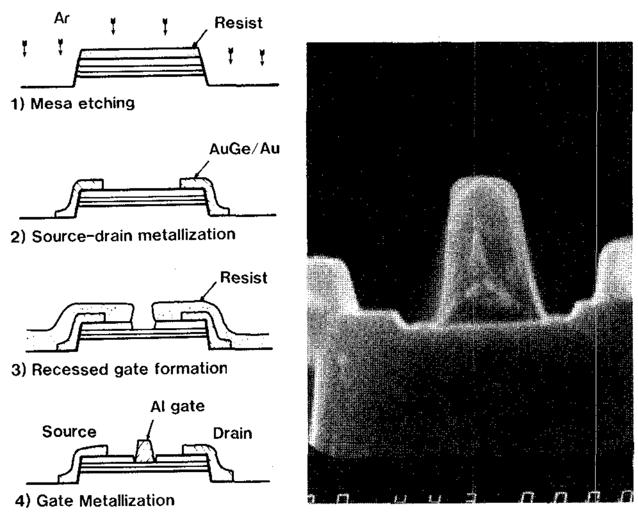
The hall mobilities,μ, the sheet electron concentrations,n,and the sheet resistances,ρ,were measured with and without the n-GaAs cap layer. These measurements are listed in Table 1. The n-GaAs layer was removed by selective dry etching.[4]

Due to the low mobility electrons in n-GaAs and n-AlGaAs layers,the electron mobility of the as-grown wafer was lower than that of wafer with the n-GaAs layer stripped off. The hall mobilities of 2-dimentional electron gas (2DEG) were about 6000 $cm^2/V \cdot s$ at room temperature and 26000 $cm^2/V \cdot s$ at 77K. The mobility at 77K is lower than ordinarily reported because there was no undoped AlGaAs layer in the heterojunction.[5]

Device Fabrication

Fabrication steps for the 0.5μm gate HEMT is shown in Fig.2(a). (1)To isolate the mesas,the Si-doped layers were etched by Argon ion beam. (2)Ohmic source-drain contacts were made of alloyed AuGe/Au at 450°C. (3)The gate region was wet-chemically recessed to adjust the drain current. (4)The process was completed by a 0.8μm thick aluminum gate formation.

All patterns were delineated by direct electron beam lithography. The gate length was about 0.5μm with a total gate width of 200μm,and the channel length was 2μm. Fig.2(b) is a gate cross-sectional view by SEM.



(a) (b)

Fig.2 (a)Fabrication process and (b)SEM view of the cross-section of the microwave HEMT.

Performance

DC Characteristics

The drain I-V characteristics of the HEMT are shown in Fig.3. Low drain voltage at current saturation and high transconductance of about 60 mS are obtained.

	n (cm^{-2})	μ ($cm^2/V \cdot s$)	ρ ($\Omega/\square$)
300K with n-GaAs	1.1 x 10^{13}	2800	197
without n-GaAs	1.2 x 10^{12}	6000	894
77K with n-GaAs	3.9 x 10^{12}	13000	122
without n-GaAs	0.98 x 10^{12}	26000	248

Table 1 Hall mobilities,μ,sheet electron concentrations,n,and sheet resistances,ρ,of the wafer.

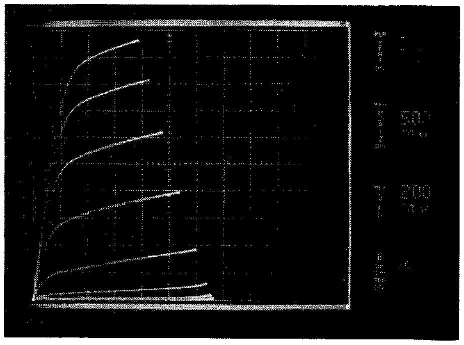


Fig.3 Drain I-V characteristics.

Because of the conduction of the low mobility electrons in the AlGaAs layer, the transconductance was low at small gate voltages. The n-AlGaAs layer in the present device may be thick enough to prevent complete depletion of the AlGaAs layer.

High Frequency Performance

For microwave evaluation, HEMT chips were mounted on carriers with 0.38 mm aluminum microstrip input and output transmission lines, which were slid into a test fixture. Noise figure measurements were made at 12 GHz. Tuning was done by gold chips along the 50 Ω input and output lines of the carrier. The results are shown in Fig.4. A minimum noise figure of 1.4 dB with 11 dB associated gain was obtained, which is comparable to the best result yet reported for GaAs MESFETs with comparable gate length. Also, the noise figure depends weakly on the drain current. It is important to note that the reported noise figure was obtained by measuring only two or three devices. Hence, the minimum noise figure of 1.4 dB may be the mean value of this wafer lot.

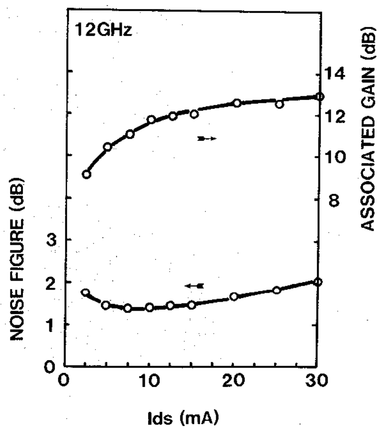


Fig.4 Noise figure and associated gain as a function of drain current.

Device Model

The S-parameters of HEMTs were measured over a 2-18GHz frequency range, using an automatic network analyzer. These S-parameters were then used to determine the maximum available gain, the current gain, and the equivalent circuit element values. The circuit model was the same as for GaAs MESFETs, as shown in Fig.5. At Ids=10mA, the gate capacitance was 0.26 pF and the source resistance was 4 Ω, both larger than those of low noise GaAs MESFETs. They seem to be the critical factors for noise performance.

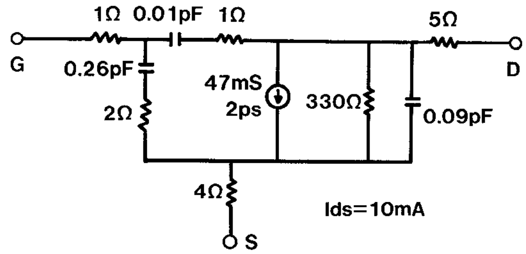


Fig.5 Equivalent circuit of the HEMT.

Current gains are plotted in Fig.6. The cutoff frequencies were 35 GHz at Ids=20mA and 30 GHz at 10mA. The relatively low noise figure of 1.4 dB is obtained with higher cutoff frequency (30GHz) than those of conventional GaAs MESFETs, in spite of the relatively high source resistance. Thus, with reduction of the source resistance to less than 2 Ω, the minimum noise figure would be reduced to 1 dB at 12 GHz.

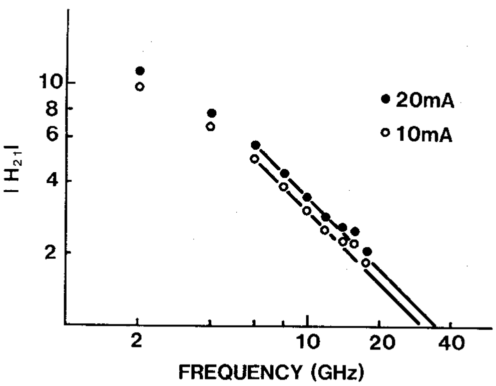


Fig.6 |h21| as a function of frequency.

Temperature Dependence of Noise Figure

Even though the mobility of 2DEG was high at room temperature, at lower temperatures a notable increase in mobility can be seen. We measured the temperature dependence of S-parameters, the noise figure, and associated gain. In Fig.7, the measurement setup is shown. The carrier of the HEMT chip, which led to the stainless steel jacketed coaxial cables with hermetically sealed connectors, was fixed on the cooling head of a cryo pump.

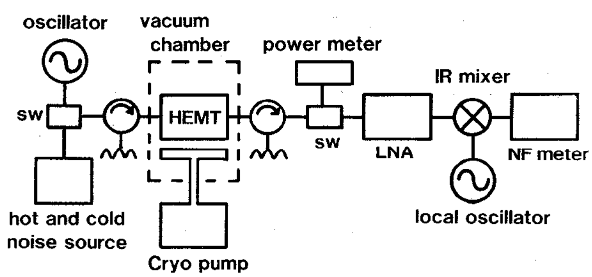


Fig.7 Setup for measuring temperature dependence of noise figure and associated gain.

Results of low-temperature measurements indicate significant improvement in the microwave performance of the HEMTs.

Fig.8 shows S-parameters between 2 and 14 GHz at temperatures of 300K,200K and 100K. Notable increase in S21 was observed with decrease of temperature.

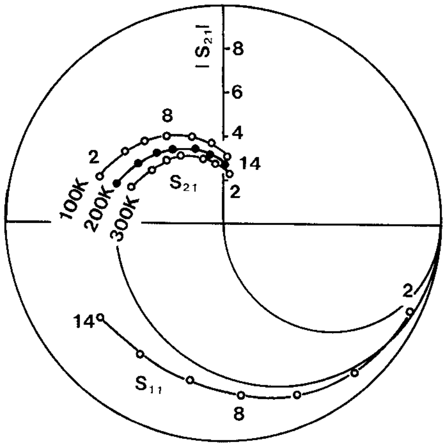


Fig.8 S11 and S21 parameters of the HEMT.

The temperature dependence of the noise figure and associated gain are shown in Fig.9. As temperature is decreased these quantities are greatly improved. At 100K the noise temperature of the HEMT was 24K (0.35 dB) with 12dB associated gain. This improvement in the noise figure and associated gain is thought to be due to the reduction of thermal noise and the increase of the electron mobility from 6000 $cm^2/V \cdot s$ to 26000 $cm^2/V \cdot s$.

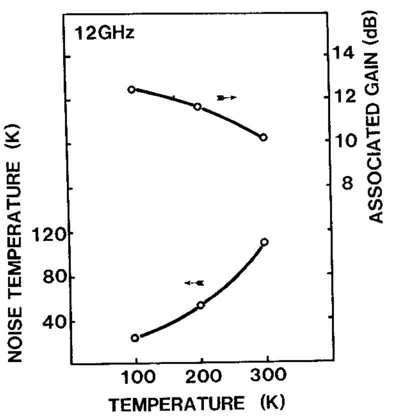


Fig.9 Noise temperature and associated gain as a function of temperature.

Summary

High performance 0.5μm gate low noise HEMTs have been developed. The preliminary results (noise figure of 1.4 dB with 11 dB associated gain at 12 GHz) show the promise of HEMTs for low noise applications.

Acknowledgements

The authors would like to thank M.Abe,S.Yamamoto, H.Ishikawa, S.Hiyamizu,H.Komizo,Y.Tokumitsu,N.Nakayama, and T.Saito for their supports on this work and warm encouragement. They are also grateful to M.Nunokawa for his assistance in fabricating the devices.

References

1. Abe,M.,Mimura,T.,Yokoyama,N.and Ishikawa,H.,"New technology towards GaAs LSI/VLSI for computer applications," IEEE.Trans.Microwave Theory & Tech.,vol.Mtt-30,p992-998,July,1982.
2. Niori,M.,Saito,T.,Joshin,K.and Mimura,T.,"A 20 GHz high electron mobility transistor amplifier for satellite communications," ISSCC DIGEST OF TECHNICAL PAPERS,p198-199,Feb.,1983.
3. Fukui,H.,"Optimal Noise Figure of Microwave GaAs MESFET's," IEEE.Trans.Electron Devices,vol.ED-26,p.1032-1037,July,1979..
4. Hikosaka,K.,Mimura,T.and Joshin,K.,"Selective Dry Etching of AlGaAs-GaAs Heterojunction," Jpn.J.Appl. Phys.,20,p.L847-L850,1981.
5. Hiyamizu,S.and Mimura,T.,"High Mobility Electrons in Selectively Doped GaAs/n-AlGaAs Heterostructures Grown by MBE and their Application to High-Speed Devices," J.Cryst.Growth,vol.56,p.455-463,Jan.,1982.