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Novel High-Performance N-AlGaAs/InGaAs/N-AlGaAs Pseudomorphic DH MODFETs

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High-current driving pseudomorphic N-AlGaAs/InGaAs/N-AlGaAs double-heterojunction modulation-doped FETs (DH MODFETs) with high K-value have been successfully fabricated using an improved layer structure. The structure has been made by simply incorporating a thin N-AlGaAs layer at the heterointerface between InGaAs and GaAs buffer layer of a conventional GaAs/InGaAs/N-AlGaAs pseudomorphic MODFET structure. A very high transconductance of 835mS/mm and a K-value of 698mA/V^2mm were achieved at room temperature for a 0.35μm-gate FET. The maximum drain current of 600mA/mm was also obtained. Microwave results showed an f_T of 64GHz and f_{MAX} of 120GHz.

1. Introduction

InGaAs/N-AlGaAs pseudomorphic MODFETs have attracted much attention because of their excellent microwave gain and noise characteristics[1-3]. This structure is known to offer high electron concentration, smaller source resistance and possibly higher electron saturation velocity than the conventional GaAs/N-AlGaAs structure[4]. Taking advantage of the high current features for pseudomorphic MODFETs, pseudomorphic N-AlGaAs/InGaAs/N-AlGaAs double-heterojunction structures have been widely studied recently in order to improve the 2DEG concentration and current driving capability in microwave FETs[5].

One of the key points in designing the layer structure of such pseudomorphic DH MODFETs is how to suppress the parasitic conduction in the bottom electron supplying layer while maintaining the high 2DEG concentration in the channel layer. Too thick bottom N-AlGaAs or AlGaAs layer should be avoided because it will degrade the pinch-off characteristics of an FET and the average velocity of electrons. In order to satisfy such conditions, we have studied a new DH MODFET structure in which a thin N-AlGaAs was simply introduced at the interface between GaAs buffer and InGaAs channel layer in the conventional GaAs/InGaAs/N-AlGaAs pseudomorphic MODFET structure. This paper describes the fabrication and DC and microwave characteristics of pseudomorphic DH MODFETs based on this structure.

2. New pseudomorphic DH MODFET structure

The pseudomorphic DH MODFET structure employed in this work is shown in Fig. 1. This structure was grown by MBE on a semi-insulating GaAs substrate. Following 5000Å undoped GaAs buffer layer, 20Å undoped AlGaAs layer, 50Å bottom N-AlGaAs layer, 20Å undoped AlGaAs bottom spacer layer, 150Å InGaAs quantum well, 20Å undoped AlGaAs top spacer layer, 300Å top N-AlGaAs layer, and 100Å N-GaAs cap layer were successively grown. The AlAs mole fraction in AlGaAs layer was 0.15 and the doping level of Si in N-AlGaAs layer was $1.8 \times 10^{18} cm^{-3}$. The In mole fraction in

N-GaAs	100Å
N-$Al_{0.15}Ga_{0.85}As$	300Å
$Al_{0.15}Ga_{0.85}As$	20Å
$In_{0.2}Ga_{0.8}As$	150Å
$Al_{0.15}Ga_{0.85}As$	20Å
N-$Al_{0.15}Ga_{0.85}As$	50Å
$Al_{0.15}Ga_{0.85}As$	20Å
GaAs	5000Å
GaAs sub.	

Fig. 1 The layer structure of novel N-AlGaAs/InGaAs/N-AlGaAs pseudomorphic modulation-doped double-heterojunction structure.

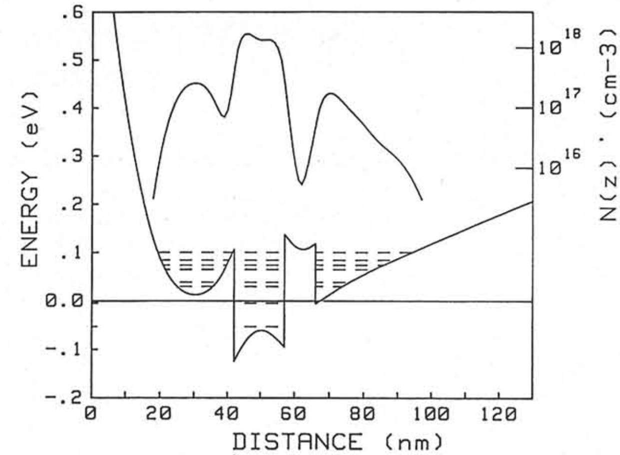

Fig. 2 The calculated electron density vs. position for the novel pseudomorphic DH MODFET structure and the calculated equilibrium conduction band energy relative to the Fermi level.

InGaAs layer was 0.2. The growth rate of GaAs was 1.0µm/h. The substrate temperature during MBE growth was 530°C.

The electron distribution and energy band diagram for this pseudomorphic DH MODFET are shown in Fig. 2, which was calculated by numerically solving the Schrödinger and Poisson equations iteratively. Although there is a triangular potential well at the heterointerface between the GaAs buffer layer and bottom N-AlGaAs layer, the sheet electron concentration in this well is calculated to be only about 6% of the total electron concentration, which is due to the conduction bandgap discontinuity between the pseudomorphic InGaAs and GaAs. As a result, 80% of total electrons flow in a InGaAs well.

The sheet electron concentration and Hall mobility obtained for this structure were $3.2\times10^{12}cm^{-2}$ and $5500cm^2/Vs$ at room temperature and $2.9\times10^{12}cm^{-2}$ and $15600cm^2/Vs$ at 77K, respectively.

3. Fabrication and characteristics

The device fabrication process begins with the mesa-etching for the definition of the channel region. Source and drain ohmic contacts were formed by AuGe/Ni/Au. Ti/Pt/Au was used as a gate metal. DH MODFETs with the gate length of 0.8-5.3µm were fabricated at the same time. Both source-to-gate and gate-to-drain spacings are 1.1µm and the gate width is 70µm.

Figure 3 shows the gate length (Lg) dependence of maximum extrinsic transconductance (gm_{MAX}) and K-value (K) determined from the $I_{DS}=K(Vgs-V_T)^2$ relation. The solid squares (■) in the figure show the results obtained previously[6] for pseudomorphic DH MODFETs with a thicker bottom AlGaAs layer (150Å N-AlGaAs layer and 2000Å undoped AlGaAs layer). A high transconductance of 370mS/mm and a high K-value of $355mA/V^2mm$ were obtained for 0.8µm-gate MODFET. Although the value of gm_{MAX} and K-value decrease with the increase of gate length, they were found to be higher than 220mS/mm and $110mA/V^2mm$ even for the gate length of 5.3µm. Although the gm_{MAX} values for the new MODFETs are as high as those for the previous ones, the K-values for the new MODFETs are seen to be much

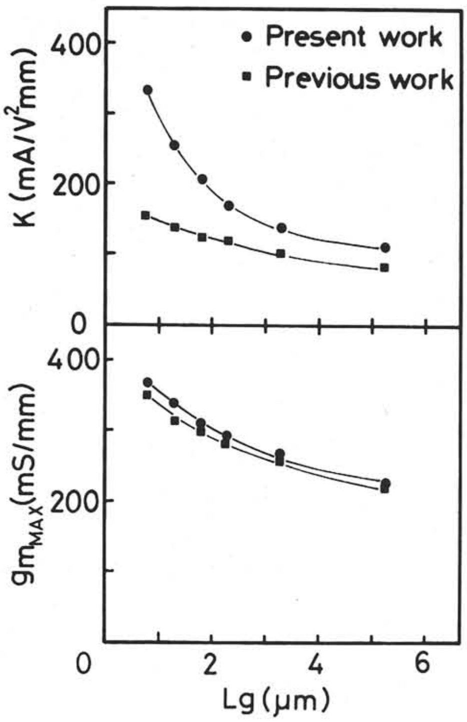

Fig. 3 Maximum extrinsic transconductance (gm_{MAX}) and K-value (K) as a function of gate length (Lg).

higher than that for the previous ones especially in the region of Lg less than 2μm. The difference in K-values between these DH MODFETs is considered to be caused by the electron overflow from InGaAs quantum well, especially near the drain region. In a new DH MODFET, the overflowed electrons are quickly transfered to the GaAs buffer layer side via a thin AlGaAs layer while in a previous DH MODFETs they will stay in a thick AlGaAs

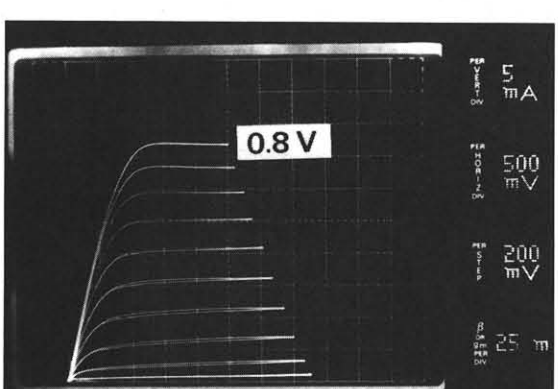

Fig. 4 DC characteristics of 0.8μm-gate novel pseudomorphic DH MODFET. The gate width is 70μm.

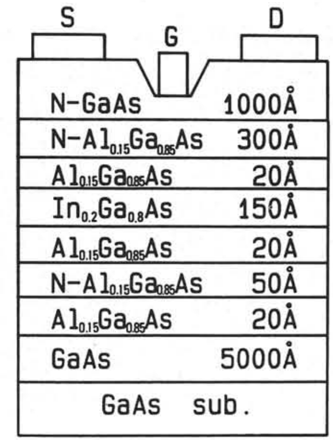

Fig. 5 The cross section of a high frequency FET using the novel pseudomorphic DH MODFET.

layer. Thus the average electron velocity may well become higher in a new DH MODFET.

Figure 4 shows the drain I-V characteristics for the 0.8μm-gate novel DH MODFET in which the maximum drain current of about 600mA/mm (Vgs=1.0V) was obtained.

4. Application to high frequency device

Figure 5 shows the cross section of high frequency FET using the new pseudomorphic DH MODFET structure. In order to reduce the source resistance we have adopted 1000Å N-GaAs cap layer and a deep recess gate structure. The 0.35μm-T-shape gate was

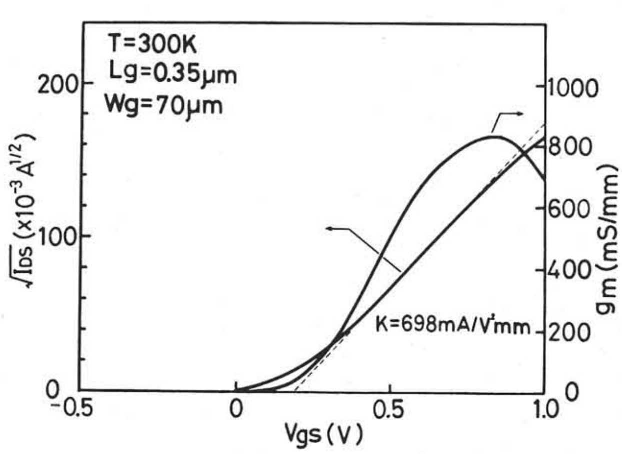

Fig. 6 Square root of drain current ($\sqrt{I_{DS}}$) and extrinsic transconductance (gm) as a function of gate voltage.

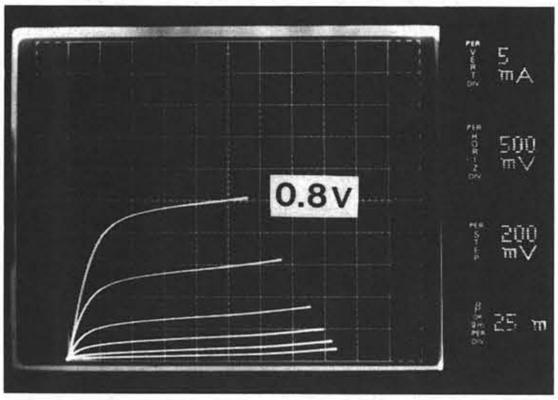

Fig. 7 DC characteristics of 0.35μm-gate novel pseudomorphic DH MODFET using deep recess structure. The gate width is 70μm.

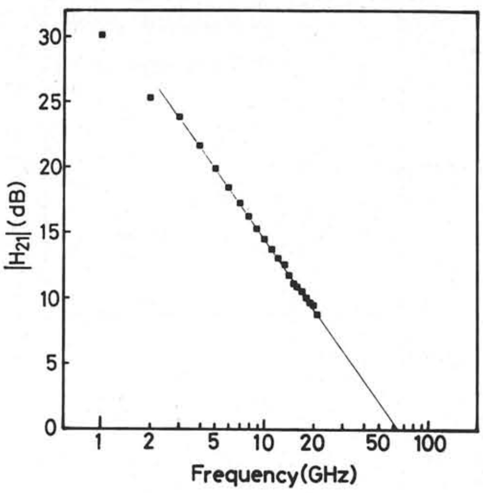

Fig. 8 Current gain ($|H_{21}|$) as a function of frequency.

fabricated by using conventional photolithography and double insulator technique.

Figure 6 shows the dependence of square root of drain current ($\sqrt{I_{DS}}$) and extrinsic transconductance (gm) on gate voltage for this pseudomorphic DH MODFET. Maximum transconductance of 835mS/mm and K-value of 698mA/V^{2}mm were obtained. The excellent I-V characteristics is shown in Fig. 7. Figure 8 shows the dependence of current gain ($|H_{21}|$) on frequency. Cut-off frequency (f_T) of 64GHz is estimated. Maximum frequency of oscillation (f_{MAX}) of 120 GHz was obtained.

5. Summary

In summary, we have demonstrated the high concentration and high-performance features of a new N-AlGaAs/InGaAs/N-AlGaAs pseudomorphic DH MODFET in which the parasitic conduction in the bottom AlGaAs layer was effectively suppressed. This FET with shorter gate length is expected to extend its f_T value well over 100GHz.

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