InAlAs/InGaAs Metamorphic Low-Noise HEMT

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***Abstract*—An $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ metamorphic low-noise high electron mobility transistor (HEMT) has been developed. A growth temperature by molecular beam epitaxy (MBE) and a thickness of a linearly graded InAlAs buffer layer have been optimized in order to reduce the density of lattice-misfit dislocation. Relatively high sheet electron density and mobility of 2.6×10^{12} cm^{-2} and 9500 cm^2/V sec at room temperature, respectively, are obtained. A 0.1-μm-gate low-noise HEMT is fabricated using the developed epitaxial wafer. A minimum noise figure of 0.48 dB with an associated gain of 14.2 dB has been obtained at 18 GHz.**

I. Introduction

InP-BASED InAlAs/InGaAs high electron mobility transistors (HEMT's) have been demonstrating extremely low noise-figure (NF) and high gain at millimeter-wave frequencies [1]–[3]. InP-based HEMT's, however, have several device processing difficulties, such as formation of via-holes and stable surface passivation layer. A GaAs substrate is preferable to InP to overcome these difficulties and to lower the wafer cost and make the wafer size larger. A highly mismatched HEMT, with InAlAs/InGaAs layers grown on a GaAs substrate, has been proposed [4]. The structure is called an "metamorphic HEMT" [5]. The growth of InAlAs/InGaAs on GaAs has several problems due to the large difference in the lattice constant between the InAlAs layer and GaAs substrate. This lattice-constant difference leads to the formation of high-density misfit dislocations and, hence, lower mobility.

In order to reduce the dislocation density, the growth of a step-graded [6] or linearly graded [7] InAlAs buffer layer with a thickness of around 1 μm has been reported. By using these techniques, an electron mobility over 10 000 cm^2/V sec, which is comparable to InP-based HEMT, has been achieved [7], [8]. As for rf performances, however, little is reported except for [9], where noise performance at 12 GHz is shown.

In this letter, the growth, fabrication, and performance of the developed InAlAs/InGaAs metamorphic low-noise HEMT's are described. In order to reduce dislocation density, a thin, linearly graded InAlAs buffer layer has been newly developed by optimizing the growth temperature. The fabricated HEMT showed a minimum NF of 0.48 dB with an associated gain (Ga) of 14.2 dB at 18 GHz. This is the first report of the noise performance at Ku-band. The obtained result, although worse than that of InP-based HEMT [10], is better than that of GaAs-based pseudomorphic HEMT [11].

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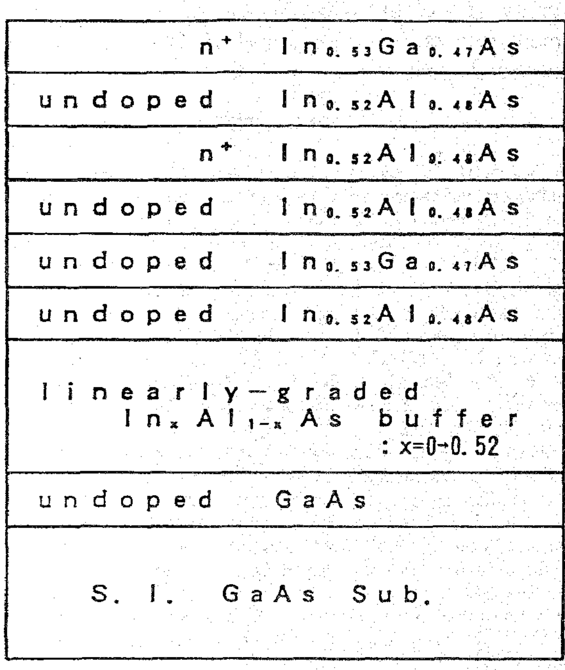

Fig. 1. Schematic cross section of the developed epitaxial wafer.

II. Epitaxial Growth

A schematic cross section of the developed epitaxial wafer is shown in Fig. 1. All the layers were successively grown on (001) GaAs substrate by molecular beam expitaxy (MBE). The key for obtaining high mobility is the growth of a thin, linearly graded InAlAs buffer layer. The growth was initiated with a 80-nm-thick undoped GaAs layer at the temperature of 520°C. After the growth was interrupted for several minutes, the substrate temperature was lowered to 360°C. Then, an $In_xAl_{1-x}As$ buffer layer was grown by varying the In composition x linearly from 0.01 to 0.52. The thickness of InAlAs buffer layer was thinned to 300 nm. The growth temperature was again raised up to 380°C and upper $In_{0.52}Al_{0.48}As$ and $In_{0.53}Ga_{0.47}As$ layers were grown. By using this growth procedure, lattice mismatch between an InAlAs buffer layer and GaAs substrate was fully relaxed, even with an InAlAs thickness of 300 nm, and high quality upper InAlAs and InGaAs layers were grown. Relatively high sheet electron density and mobility of 2.6×10^{12} cm^{-2} and 9500 cm^2/V sec at room temperature, respectively, have been obtained.

III. HEMT Fabrication

A 0.1-μm-gate low-noise HEMT was fabricated on the developed epitaxial wafer. The fabrication process is as fol-

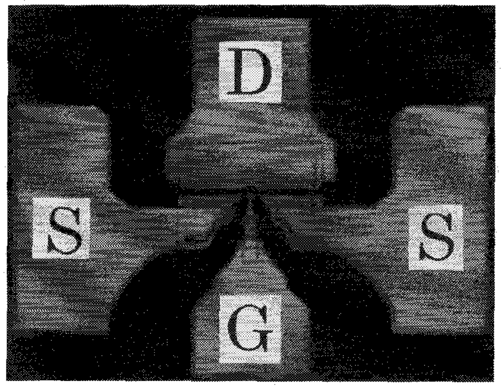

Fig. 2. Top view of the fabricated HEMT chip. The chip size is 170 × 150 μm^2.

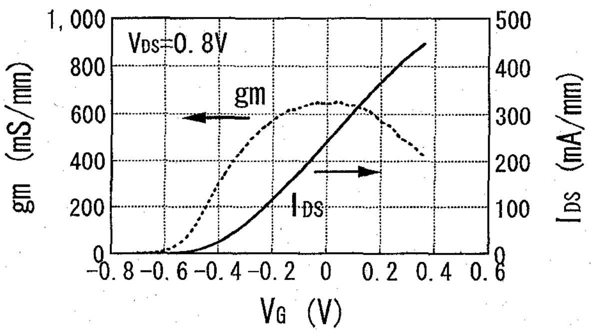

Fig. 3. Dependence of drain current and transconductance on gate voltage for a fabricated HEMT chip.

lows. After the mesa-isolation by wet chemical etching, source and drain ohmic contacts were formed by depositing and alloying of AuGe/Ni. The gate was patterned by electron-beam lithography and the recess was carried out by wet chemical etching. The gate has a T-shaped cross section with Ti/Pt/Au. Finally, the device was passivated with SiN of 80 nm to ensure the reliability. Fig. 2 shows the top view of the fabricated HEMT chip. The total gate width is 100 μm with chip size of 170 × 150 μm^2.

IV. DC and RF Performances

DC characteristics were measured by on-wafer probing system. Fig. 3 shows the result, where drain current (I_{DS}) and transconductance (gm) are plotted against gate voltage (V_G) at a drain voltage (V_{DS}) of 0.8 V. A maximum gm of 650 mS/mm has been obtained. Breakdown voltages between source and gate, and source and drain were 2.5 and 3 V, respectively. No noticeable hysteresis was observed in the dc characteristics up to the drain voltage of 3 V. This implies that the dislocations introduced in the buffer layer does not affect the dc characteristics.

RF performances was measured at 18 GHz with mounting HEMT chips on a test fixture. Fig. 4 shows I_{DS} dependence of NF and Ga. A minimum NF of 0.48 dB is obtained at I_{DS} = 14 mA with Ga of 14.2 dB. This is, to the authors' knowledge, the first report of the noise performance of metamorphic HEMT at Ku-band. Although these values are worse than those of the best values of InP-based HEMT

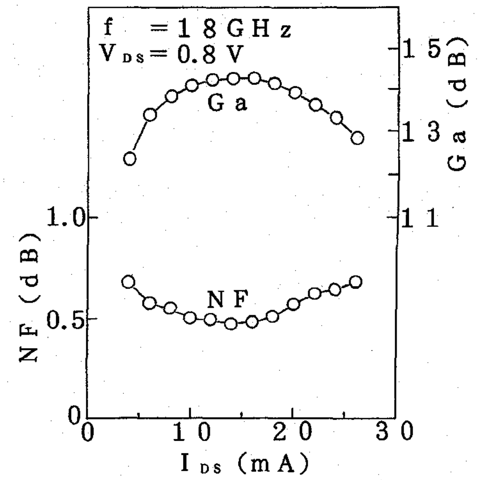

Fig. 4. NF, Ga versus I_{DS} of a fabricated HEMT at 18 GHz.

[10], they are better than those of GaAs-based pseudomorphic HEMT [11].

V. Conclusion

InAlAs/InGaAs HEMT on GaAs substrate (metamorphic HEMT) has been developed. A growth condition of a thin, linearly graded InAlAs buffer layer has been optimized in order to obtain higher mobility. A 0.1-μm-gate HEMT is fabricated. It showed a minimum NF of 0.48 dB with Ga of 14.2 dB at 18 GHz.

These values are, although worse than those of InP-based HEMT, are better than those of GaAs-based pseudomorphic HEMT. When taking account of the difficulties of InP substrate processing, a metamorphic HEMT will open the door for realizing low-noise monolithic microwave integrated circuits (MMIC's) comparable to InP-based HEMT's at millimeter-wave frequencies.

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