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High Current Gain GaInAs/InP Hot Electron Transistor

Shinji YAMAURA, Yasuyuki MIYAMOTO, and Kazuhito FURUYA

Department of Electric and Electronics Engineering,
Tokyo Institute of Technology
2-12-1 Meguro-ku, O-okayama, Tokyo 152, JAPAN

The highest current gain more than 100 at 77K was obtained in GaInAs/InP Hot Electron Transistor(HET) grown by organo-metallic vapour phase epitaxy. This result shows the promising of the GaInAs/InP material system for ballistic electron devices. An interesting phenomenon, that is a sudden increase of the collector current in the emitter-common characteristics was observed, which would be caused by the quantum interference effect.

1. Introduction

The hot electron transport in high-mobility compound semiconductors is very attractive for high-speed devices such as the Hot Electron Transistor(HET)$^{1)-6)}$, and is the basis of electron wave devices such as Electron-Wave diffraction Transistor$^{7)}$. The highest current gain of HETs, i.e., 41(at 4.2K)$^{5)}$ and 30(at 77K)$^{4)}$, were obtained in the GaInAs/AlGa(In)As material system. However, AlGa(In)As which is used for a collector barrier in these HETs has relatively narrow Γ−L valley separation. Thus, the ballistic transports of the hot electron are interrupted and the transit time for the collector barrier increases. On the other hand the GaInAs/InP system, where InP has wider Γ−L valley separation than AlGa(In)As, is more advantageous. Furthermore, the lattice constant of GaInAs is exactly matched to InP.

In this report, we present the current gain of over 100 for GaInAs/InP HET. An interesting phenomenon, that is a sudden increase of the collector current in the emitter-common characteristics was also reported.

2. Experiment and results

A schematic band diagram of the GaInAs/InP HET is shown in Figure 1 and the fabrication is shown in Figure 2.

At first, heterostructure wafers were grown by OMVPE. Growth temperature and pressure were 620°C and 76 Torr, respectively.

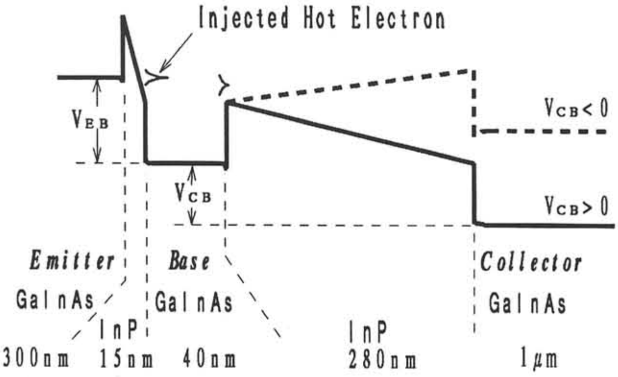

Fig.1 Schematic band diagram of GaInAs/InP HET structure.

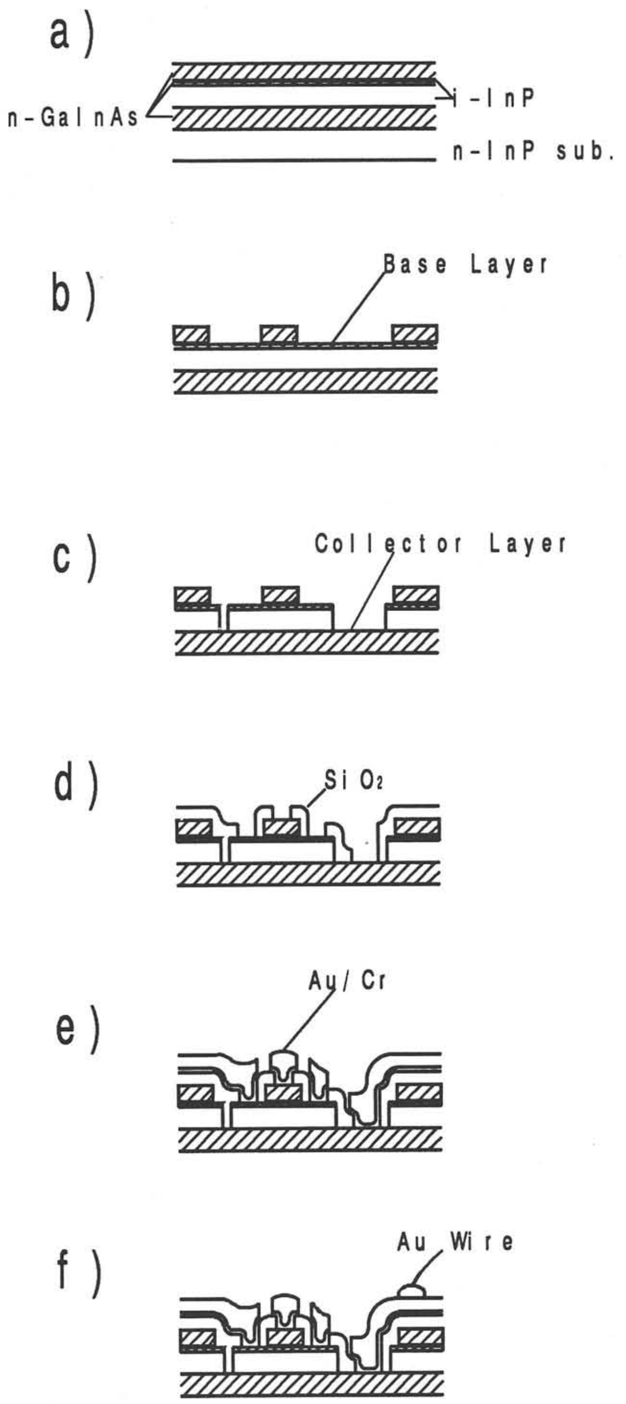

Fig.2 Fabrication process of HET.
(a)Epitaxial Growth.
(b)Exposure of Base layer.
(c)Exposure of Collector layer.
(d)SiO_2 deposition and Window opening.
(e)Electrodes with Au/Cr non-alloy contact by lift-off process.
(f)Dising and wirebonding.

Trimethylindium, triethylgallium, arsine and phosphine were used for sources. The n-type dopant source was disilane(Si_2H_6). This time the crystal quality grown by organo-metallic vapour phase epitaxy (OMVPE) was further improved, using a new OMVPE apparatus. n-GaInAs collector layer of 1μm, undoped-InP collector barrier layer of 280nm, n-GaInAs base layer of 40nm, undoped-InP emitter barrier layer of 15nm, and n-GaInAs emitter layer of 300nm were grown successively on a n^+InP substrate. The carrier density of each n-GaInAs layer was $1.2\times10^{17}cm^{-3}$. To prevent the diffusion of n-dopant to the undoped-InP barrier layers, the undoped-GaInAs spacer layers of 1.7nm were inserted on both sides of each InP barrier layer.

After the growth, surfaces of the base and collector GaInAs layers were exposed by using material selectivity of the wet chemical etching and conventional photolithography (Fig.2(b) and Fig.2(c)). the emitter-base junction was $20\times50\mu m^2$. Then, after deposition and patterning of isolation layer(SiO_2) (Fig.2(d)), electrodes with Au/Cr non-alloy contact were formed by lift-off process (Fig.2(e)). Finally, dicing and wire-bonding were done (Fig.2(f)). Transistor characteristics were measured at 77K using a transistor parameter analyzer system YHP-4142B.

Figure 3 shows the typical common-emitter characteristics. The base current was in the range of 0 to 200μA at 20μA step. At the emitter-collector voltage V_{CE} of 2V, quite high value of over 100 was obtained for small signal current gain $\delta\beta$ (=dI_C/dI_B). To investigate this precisely, common-emitter I_B-I_C and I_B-$\delta\beta$ characteristics were measured as shown in Figure 4. The parameter V_{CE} was in the range of 1.8 to 2.4V at 0.2V step. The current gain $\delta\beta$

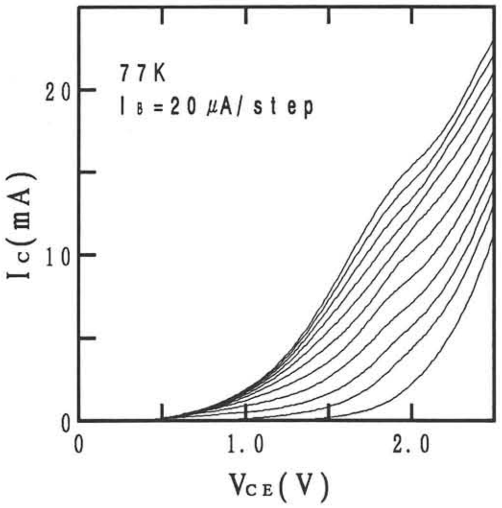

Fig.3 Common-emitter characteristics at 77K.

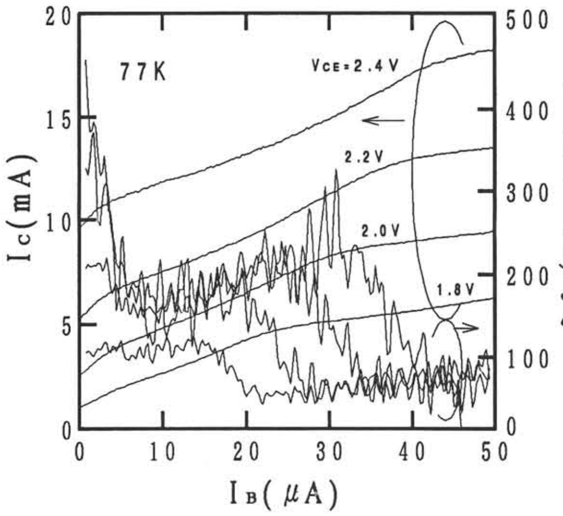

Fig.4 Common-emitter I_B-I_C and I_B-$\delta\beta$ characteristics at 77K.

was more than 100 over almost entire region of I_B and more than 400 in small I_B region. The highest $\delta\beta$ was 440 when I_B and V_{CE} were 0.75μA and 2.4V, respectively. This value is the highest value for the HET ever reported to our knowledge.

Furthermore, some interesting phenomenon was observed in this device. Figure 5 shows the common-emitter characteristics at

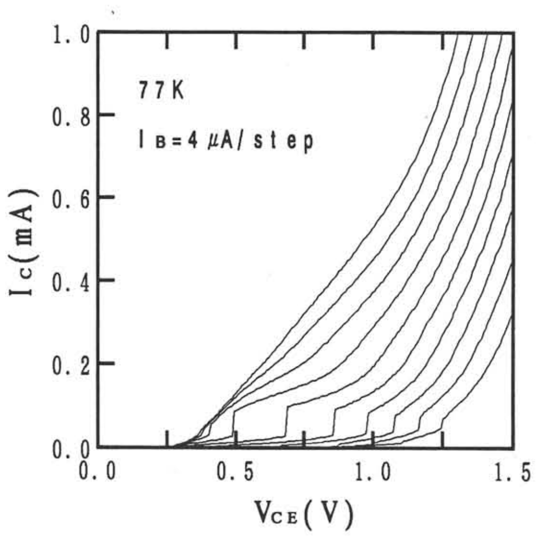

Fig.5 Common-emitter characteristics at small I_B and small V_{CE} region at 77K.

small I_B and small V_{CE} region. The step-like increase of collector current was observed. We think that this phenomenon would be caused by quantum interference of electrons in the base region.

3.Conclusion

We have achieved the highest small signal gain $\delta\beta$ of 440 in OMVPE grown GaInAs/InP HET. From this experiment, the GaInAs/InP material system is found to be very promising for the ballistic electron devices.

4.Acknowledgment

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5.References

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