Extended Abstracts of the 15th Conference on Solid State Devices and Materials, Tokyo, 1983, pp. 289-292

B-6-2

Growth of Selectively Doped Heterostructure by Organometallic Vapour Phase Epitaxy

Toshiyuki USAGAWA, Yuichi ONO, Susumu KAWASE,
Yoshifumi KATAYAMA, and Susumu TAKAHASHI
Central Research Laboratory, Hitachi, Ltd.
Kokubunji, Tokyo 185, JAPAN

The GaAs-AlGaAs heterostructure grown by organometallic vapor phase epitaxy is investigated by various characterization methods. The obtained carrier mobility of the grown heterostructure shows sufficient values(8,300 cm^2/Vs at room temperature and 45,000 cm^2/Vs at 77 K) for fabrication of FET's. The sharpness at the hetero-interface is found to be less than 2.5 nm by Auger electron spectroscopy.

1. Introduction

Recently, considerable interest has been paid to two-dimensional electron gas FET's[1-5] with GaAs-AlGaAs hetero-interface because of their high-speed performance. Until very recently, such heterostructures have been grown mainly by molecular beam epitaxy(MBE).

On the other hand, there have been few applications of organometallic vapor phase epitaxy(OM-VPE) to heterostructure devices, except semiconductor lasers[6], even though Dupius et al.[7] have succeeded in room-temperature CW operation of GaAs-AlGaAs double hetero-lasers by introducing high purification of source materials. For such improvement of the source materials, high-quality epilayers can be grown by OM-VPE.

If a reproducible control technique for multiple thin epitaxial layers is established by OM-VPE, strong impact is expected on the branch of large scale integrated circuits(LSI) using the above-mentioned selectively doped heterostructure FET's because of the potential advantages of OM-VPE: (1) uniformity of epitaxial layer thickness over a large area, (2) precise thickness controllability of thin films, and (3) mass-productivity and cost-performance.

In this paper we report on the selectively doped GaAs-AlGaAs heterostructures prepared for the fabrication of FET's, specifically, focusing on characterization of the heterostructure. Finally fabrication of the selectively doped heterostructure FET is reported.

2. Crystal Growth

The system used in our study was a vertical cold wall reactor with an rf-induction heated graphite susceptor. The reactor gas manifold and mixing system are constructed totally of stainless steel and leak-tight distribution tubes kept at a vacuum as high as 10^{-6} Pa.

Electronic-grade trimethyl gallium(TMG) and trimethyl alminium(TMA) (Sumitomo Co.,Ltd) were used for the Group III sources, while arsine (10% AsH_3 in H_2, Japan Oxygen Co., Ltd) provided the Group V source. H_2Se(10ppm in H_2, Japan Oxygen Co., Ltd) was used as n-type dopant. Palladium-purified H_2 was used as the carrier gas for the organometallics.

Single crystal layers were grown at atmospheric pressure on Cr-doped semi-insulating (100) GaAs substrate. The growth rate was held in the range between 50 nm/min and 70 nm/min.

Highly purified GaAs epilayers with controlled n-type doping and Al mole fraction in $Al_xGa_{1-x}As$ are indispensable for fabrication of selectively doped heterostructure FET's.

(A) Undoped GaAs epilayers

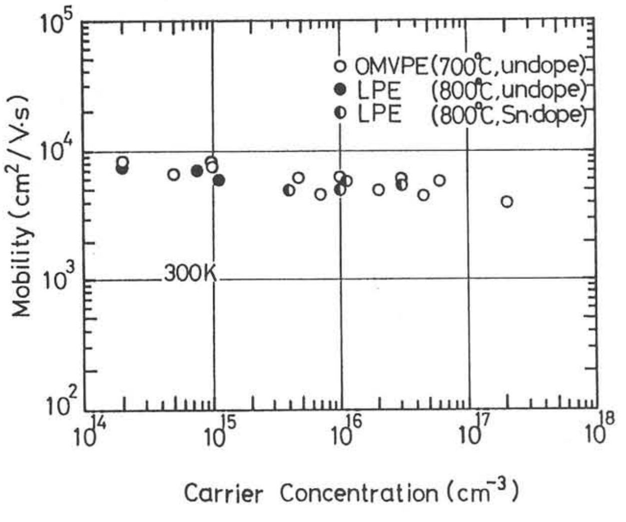


Fig.1 Room-temperature mobility versus n-type carrier concentration.

It is well known that the conduction type and carrier concentration of undoped GaAs grown by OM-VPE depend on the V/III mole ratio. Undoped n-type GaAs epilayers 2 μm thick were grown at 700 °C(growth temperature).

In Fig.1, room-temperature carrier mobility is plotted against carrier concentration for GaAs crystals grown by two different methods: three circles denote, respectively, undoped GaAs(O) grown by OM-VPE in our studies, undoped GaAs(●) grown by liquid phase epitaxy(LPE), and Sn-doped LPE-GaAs(◐). These curves show that undoped OM-VPE GaAs crystals have the same quality as LPE grown GaAs crystals. As a typical example, the obtained high quality GaAs epilayers were characterized by an n-type carrier concentration of $2x10^{14}$ cm^{-3}, carrier mobility of 8,000 cm^2/Vs at room temperature and 54,000 cm^2/Vs at 77K. This mobility seems to be good enough for such thin(2 μm) epilayers.

(B) Doped GaAs and $Al_xGa_{1-x}As$

Undoped $Al_xGa_{1-x}As$ epilayers were grown at two different temperatures: 700 °C and 800 °C. Figure 2 shows the observed relation between Al mole fraction,x,in $Al_xGa_{1-x}As$ and (TMA)/(TMA+TMG) mole ratio. The Al mole fraction was evaluated by laser Raman spectroscopy[8), in which the energy shift of the peak due to Raman scattering by LO phonons depends on the Al mole fraction in

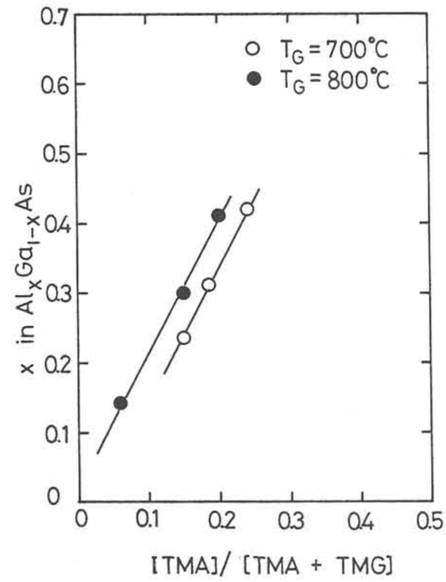


Fig.2 Al mole fraction in $Al_xGa_{1-x}As$ versus [TMA]/[TMA+TMG].

$Al_xGa_{1-x}As$. The analysed results completely coincide with those of X-ray diffraction.

Doping control into the GaAs and AlGaAs epilayers was studied by changing H_2Se/AsH_3 mole ratio for a fixed V/III ratio to give a low n-type carrier concentration.

3. Growth of GaAs-AlGaAs heterostrure

Figure 3 shows a cross-sectional view of the multiple thin epitaxial layers prepared for the fabrication of selectively doped heterostructure FET's.

The growth rate of OM-VPE epilayers is uniquely determined by the III/H_2 mole ratio. Using this fact, each epilayer thickness was controlled by the growth time with the aid of micro-computers.

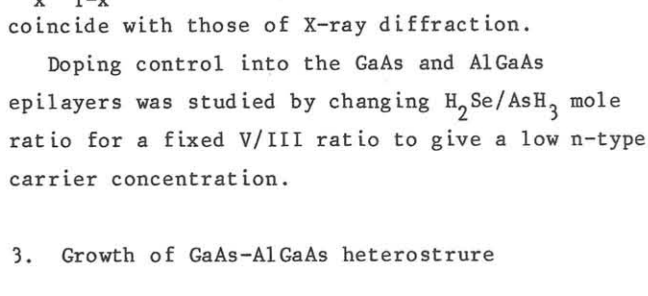


Fig.3 Cross-sectional view of multiple thin epilayers for fabrication of selectively doped heterostructure FET.

The growth rate was found to be 50 nm/min for a III/H_2 mole ratio of 10^{-4}, determined by Auger electron spectroscopy.

In the fabricated heterostructure, the $Al_xGa_{1-x}As$ epilayer was too thin (50 nm) to determine exactly the Al mole fraction by X-ray diffraction. However, laser Raman spectroscopy is a convenient,exact measurement method of Al mole fraction. Figure 4 shows an example of the spectrum due to Raman scattering from a fabricated heterostructure.

Abrupt GaAs-AlGaAs heterojunctions are of great interest for selectively doped heterostructure FET's because the sharpness at the hetero-interface is considered to affect FET performance. We analysed the heterostructure of n-type AlGaAs(15 nm)-GaAs(1000 nm) grown on a semi-insulating GaAs substrate under the same conditions as for a fabricated FET. Auger electron spectroscopy with Ar ions accelerated by 500 V was used for analysis. Figure 5 shows the analysed results in terms of the signal intensity of the Auger electron and the etching time. The Ar ion etching rate was found to be 0.21 nm/min for $Al_{0.3}Ga_{0.7}As$ from comparison with the etching time of standard sample whose layer thickness was measured by ellipsometry. The signal intensity-change of Al atoms varied from 90% to

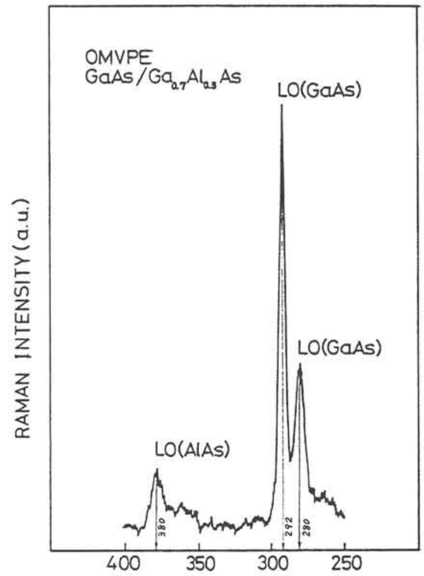


Fig.4 Raman spectrum from a selectively doped heterostructure grown by OM-VPE.

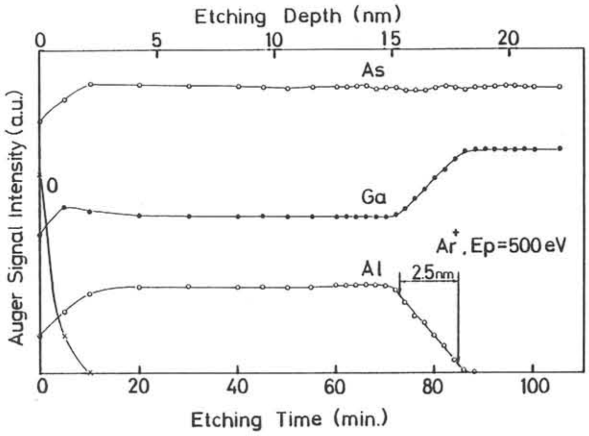


Fig.5 Auger studies of AlGaAs-GaAs heterostructure.

10% gives a definition of sharpness at the hetero-interface. Figure 5 shows the sharpness is less than 2.5 nm. To our knowledge, this sharpness of the hetero-interface is the best value observed for heterostructures grown by OM-VPE.

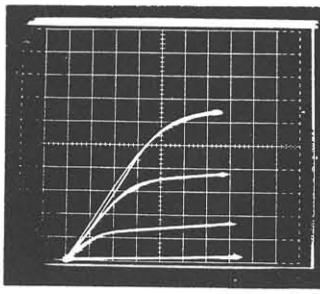
The indicated thickness of the epilayers in Fig.3 were determined from the Ar ion etching time,in which ions were accelerated by 5 keV.

Carrier sheet concentration and mobility in the fabricated FET's were evaluated by Hall measurements. We observed Shubnikov-de Haas oscillation of the conductance at 4.2 K ,which provides direct evidence for the existence of two dimensional electron gas at the hetero-interface.

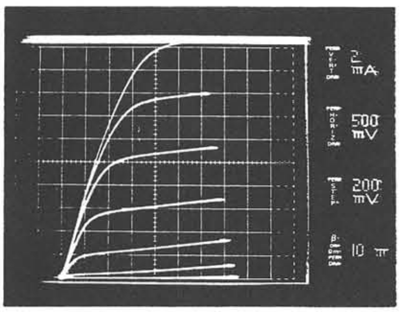
Table I shows typical examples of the mobility of the heterostructures shown in Fig.3 grown at two different temperatures for the undoped GaAs layer. The growth temperature of the $Al_{0.3}Ga_{0.7}As$ epilayers was 700 °C in both cases. The obtained value of mobility is sufficient for fabrication of the selectively doped heterostructure FET's.

Table I Typical carrier mobilities of heterostructures for two different growth temperatures.

	μ(T_G= 700 °C)	μ(T_G= 650 °C)
300 K	7,700 Cm^2/Vs	8,300 Cm^2/Vs
77 K	33,000 Cm^2/Vs	45,000 Cm^2/Vs



(a)



(b)

Fig.6 $I_{ds}-V_{ds}$ characteristics of selectively-doped heterostructure FET at room temperature (a), and at 77 K (b).

4. Fabrication of selectively doped heterostructure FET

Fabrication of an FET starts with the mesa isolation among devices. After depositing SiO_2 with a thickness of 300 nm on the sample, the source and drain electrodes, AuGe/Ni/Au, were evaporated and lifted off with help of photolithography. Following the alloying of the samples in an H_2 atmosphere at 400°C, the Schottky gate metal, Ti/Pt/Au, was evaporated and lifted off.

Figure 6 shows an examle of the $I_{ds}-V_{ds}$ static characteristics of a fabricated FET with gate length and width of 6 μm and 200 μm, respectively. They show a transconductance, g_m, of 42 mS/mm and 120 mS at room temperature and 77 K, respectively. The triple transconductance enhancement from room temperature to 77 K is a reflection of the mobility enhancement. As shown in Fig.6 , the FET on-resistance is still large.

The contact resistance at the source and drain electrodes were analysed by transmission line model. The large contact resistance was found to limit FET performance. By subtracting the contact resistance from the observed $I_{ds}-V_{ds}$ characteristics, the estimated intrinsic transconductance, g_m, was found to be 56 mS/mm and 420 mS/mm at room temperature and 77 K, respectively. The estimated intrinsic transconductance, g_m, at 77 K is as high as those for selectively doped heterostructure FET's by MBE, in which very low contact resistance has already been obtained[4].

5. Conclusion

The OM-VPE growth of GaAs-AlGaAs heterostructure for fabrication of FET's has been investigated using various characterization methods. Thick(2 μm) undoped GaAs epitaxial layers exhibit high quality. The obtained GaAs-AlGaAs heterostructures show the sufficient carrier mobility(=8,300 cm^2/Vs at room temperature and = 45,000 cm^2/Vs at 77 K) for fabrication of selectively doped heterostructure FET's.

Auger studies indicate that the sharpness at the GaAs-AlGaAs hetero-interface is less than 2.5nm, whch is the sharpest for heterostructures by OM-VPE.

References

[1] S.Hiyamizu and T.Mimura : J.Cryst.Growth 56 (1982) 455.

[2] M.Laviron, D.Delagebaudeuf, J.Chaplart, and N.T.Linh: Electron. Lett. 17 (1981) 536.

[3] S.L.Su, R.Fischer, T.J.Drummond, W.G.Lyons, R.E.Throne, W.Kopp, and H.Morkoc: Electron. Lett. 18 (1982) 794.

[4] C.P.Lee and W.T.Wang: Electron. Lett. 19 (1983) 155.

[5] J.Maluenda and P.M. Frijlink: Jpn. J. Appl. Phys. 22 (1983) L127.

[6] N.Holonyak, Jr, R.M.Kolbas, W.D.Laidig, B.A. Vojak, R.D.Dupuis, P.D.Dapkus 33 (1978) 737.

[7] R.D.Dupius and P.D.Dapkus Appl.Phys.Lett. 31 (1977) 466.

[8] R.Tsu, H.Kawamura, and L.Esaki: in the Proceeding of the International Conference on the Physics of Semiconductors, Warsaw, 1972 P_{1135}.