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Gas-Source MBE Growth of High Quality AlGaAs Using Trimethylamine Alane as the Aluminum Source

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We report the effect of growth conditions on the incorporation of background impurities and optical properties of undoped $Al_{0.3}Ga_{0.7}As$ grown by gas source molecular beam epitaxy using trimethylamine alane. The minimum background carbon concentration was $7x10^{16}$ cm^{-3}. The 77 K photoluminescence spectrum was dominated by excitonic band-edge emission, which was not observable in AlGaAs grown using triethylaluminum. The n-type doping of $Al_xGa_{1-x}As$ (x=0-0.27) using disilane was studied. The net carrier concentration of n-AlGaAs was reproducibly controlled between $5x10^{17}$- $3x10^{18}$ cm^{-3} by varying the disilane flow rate from 1 to 8 sccm.

§1. Introduction

Gas source molecular beam epitaxy (GSMBE) using metalorganic group III sources and hydride group V sources has been increasingly attracted much interest for the growth of various III-V compound semiconductors.[1] Using GSMBE, it is possible to realize highly carbon-doped GaAs epilayers having hole concentrations greater than 10^{20} cm^{-3}.[2] We have reported on the application of this feature of GSMBE by the growth of the carbon-doped base heterojunction bipolar transistor (HBT).[3] An AlGaAs emitter-layer of the carbon-doped base HBT was grown using triethylaluminum ($(C_2H_5)_3Al$, TEAl) as the aluminum source. However, AlGaAs grown using TEAl has a high background carbon concentration of more than 10^{18} cm^{-3}.[4] This is mainly attributed to the high chemical reactivity of Al and the strong Al-C bond of this metalorganic source. In order to further improve the characteristics of such electron devices, it is necessary to reduce the background carbon concentration of AlGaAs.

Recently, the reduction of the background carbon concentration in AlGaAs by using trimethylamine alane ($(CH_3)_3N{:}AlH_3$, TMAAl) which aluminum does not directly bond to carbon, instead of TEAl was reported.[5] In this paper, we report the effect of growth conditions on the incorporation of background impurities (carbon, oxygen), and optical properties of undoped AlGaAs grown by GSMBE using TMAAl, triethylgallium ($(C_2H_5)_3Ga$, TEGa), and arsine (100% AsH_3) as source gases. Furthermore, we present the results of a study in the n-type doping of AlGaAs using disilane (10% Si_2H_6, diluted in H_2) as an n-type gaseous dopant source.

§2. Growth and characterization

The growth system used consists of a conventional MBE growth chamber (VG80H) and a gas handling system which was designed by ourselves. Metalorganic sources were introduced into the growth chamber without the use of a carrier gas.[6] AsH_3 was cracked at a temperature of 1100°C. Undoped $Al_xGa_{1-x}As$ (x~0.3) epilayers having thicknesses in the range 2-3 μm were grown at substrate temperatures (T_{sub}) of 520-640°C and AsH_3 flow rates of 2-4 sccm. The growth rate of undoped AlGaAs was 1.17 μm/h. The atomic concentration of background impurities (carbon, oxygen) in the epilayers was evaluated by secondary ion mass spectroscopy (SIMS). The optical properties of the epilayers were characterized by photoluminescence (PL) measurement at 77 K.

The n-type $Al_xGa_{1-x}As$ (x=0-0.27) epilayers were grown at a T_{sub} of 580°C, an AsH_3 flow rate of 4 sccm, and Si_2H_6 flow rates of 0.2-8 sccm. The aluminum composition (x) of n-AlGaAs was controlled by changing the flow rate of TMAAl with a

constant flow rate of TEGa. The growth rate of n-$Al_xGa_{1-x}As$ (x=0-0.27) was in the range 0.74-1.06 μm/h. The carrier concentrations of n-AlGaAs were determined by capacitance-voltage (C-V) measurement.

§3. Results and discussion

Figure 1 shows the variation of the backbround carbon concentration of undoped $Al_xGa_{1-x}As$ (x~0.3) grown using TMAAl and TEAl, with T_{sub} and AsH_3 flow rate. By using TMAAl, a minimum carbon concentration of $7x10^{16}$ cm^{-3} was obtained at T_{sub} between 520-580°C and an AsH_3 flow rate of 4 sccm. The carbon concentration is more than one order of magnitude less than that using TEAl. Carbon concentrations are almost independent on the substrate temperatures. This allows greater choice for the growth temperature of device structures. The carbon concentration of undoped AlGaAs grown at a T_{sub} of 580°C and an AsH_3 flow rate of 2 sccm was $2x10^{17}$ cm^{-3}. This result suggests that a carbon concentration could be more effectively reduced by increasing the AsH_3 flow rate. These results are almost similar to published data[7].

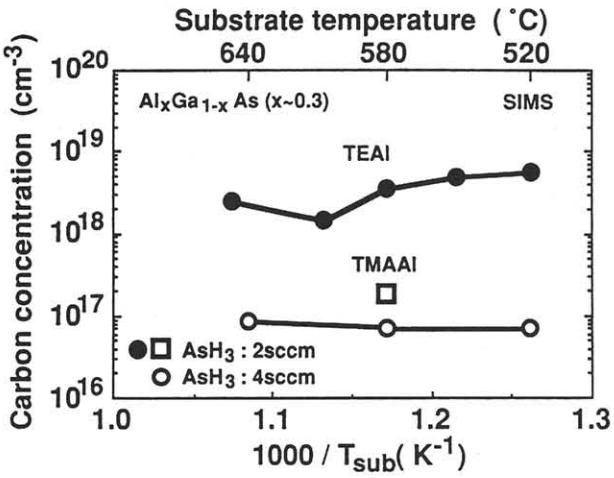

Figure 1. Variation of the background carbon concentration of undoped $Al_xGa_{1-x}As$ (x~0.3) grown using TMAAl and TEAl, with substrate temperature and AsH_3 flow rate

When undoped $Al_xGa_{1-x}As$ (x~0.3) epilayers were grown at T_{sub} between 520-640°C and an AsH_3 flow rate of 4 sccm using TMAAl, the oxygen concentration in the epilayers showed a constant value of $4x10^{17}$ cm^{-3} which was one order of magnitude less than published data[7]. However, the oxygen concentration was almost comparable to that using TEAl. This result differs from published data[7] and suggests that oxygen contamination of the epilayers is not attributable to the difference in aluminum source gases. Oxygen incorporation is thought to be due to the contamination of source gases or metalorganic gas supply lines.

Figure 2 shows the 77 K photoluminescence spectrum of undoped $Al_{0.34}Ga_{0.66}As$ grown at a T_{sub} of 520°C and an AsH_3 flow rate of 4 sccm using TMAAl. The spectrum is dominated by excitonic band-edge emission, which was not observable in AlGaAs grown using TEAl. The full-width-at-half-maximum of the luminescence peak is 14 meV. Emission related to the carbon acceptor (free electron to bound acceptor recombination) appears at the shoulder of the main peak. This result demonstrates the superior optical quality of undoped AlGaAs grown using TMAAl over that using TEAl.

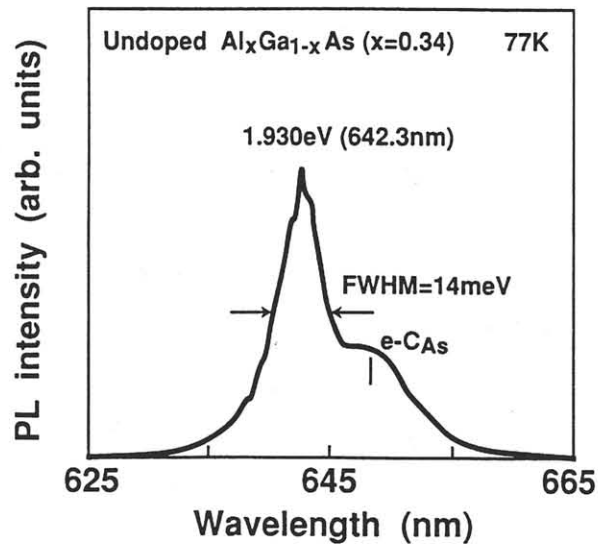

Figure 2. 77 K photoluminescence spectrum of undoped $Al_{0.34}Ga_{0.66}As$ grown at a T_{sub} of 520°C and an AsH_3 flow rate of 4 sccm using TMAAl

Figure 3 shows the variation of the net carrier concentration of n-type $Al_xGa_{1-x}As$ (x=0-0.27) grown using TMAAl and TEAl, with Si_2H_6 flow rate. The carrier concentration is normalized to a growth rate of

1 μm/h. The carrier concentration of n-AlGaAs grown using TEAl was less than that of n-GaAs at the same Si_2H_6 flow rate. This difference is due to the higher background carbon concentration in AlGaAs grown using TEAl than GaAs. In contrast, the carrier concentration of n-$Al_xGa_{1-x}As$ (x=0.09-0.27) grown using TMAAl was reproducibly controlled between $5x10^{17}$-$3x10^{18}$ cm^{-3} by varying the Si_2H_6 flow rate from 1 to 8 sccm. The variation of the carrier concentration with Si_2H_6 flow rate is almost independent on the aluminum composition (x=0-0.27). This is due to the reduction of the background carbon concentration in AlGaAs by using TMAAl. The doping controllability of n-type AlGaAs could be also drastically improved by the use of TMAAl which enables growth of high quality AlGaAs.

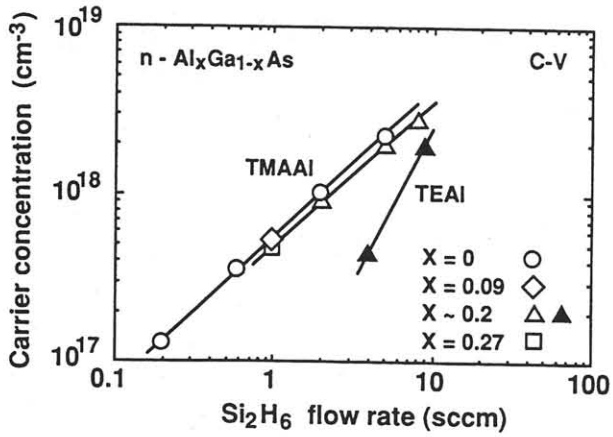

Figure 3. Variation of the net carrier concentration of n-type $Al_xGa_{1-x}As$ (x=0-0.27) grown using TMAAl and TEAl, with Si_2H_6 flow rate

§4. Conclusion

We reported the effect of growth conditions on the incorporation of background impurities and optical properties of undoped $Al_xGa_{1-x}As$ (x~0.3) grown by GSMBE using TMAAl. The minimum carbon concentration of AlGaAs grown using TMAAl was $7x10^{16}$ cm^{-3}. By using TMAAl as the aluminum source, the background carbon concentration could be reduced more than one order of magnitude less than that using TEAl. However, the minimum oxygen concentration of AlGaAs grown using TMAAl was almost comparable to that using TEAl. The 77 K photoluminescence spectrum of undoped AlGaAs grown using TMAAl was dominated by excitonic band-edge emission, which was not observable in that using TEAl. This result demonstrated the superior optical quality of undoped AlGaAs grown using TMAAl over that using TEAl. Furthermore, we presented the results of a study in the n-type doping of AlGaAs using Si_2H_6 as an n-type gaseous dopant source. The net carrier concentration of n-AlGaAs grown using TMAAl was reproducibly controlled between $5x10^{17}$-$3x10^{18}$ cm^{-3} by varying the Si_2H_6 flow rate from 1 to 8 sccm. The variation of the carrier concentration with Si_2H_6 flow rate was almost independent on the aluminum composition (x=0-0.27). The doping controllability of n-type AlGaAs could be also drastically improved by using TMAAl. Our results show that there is great potential for the use of GSMBE for the growth of devices such as HBT's.

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