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Highly Uniform Growth of AlGaAs/GaAs Hetero- Epitaxial Wafer for Solar Cell Application by Large-Capacity MOCVD Reactor

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The uniformity of AlGaAs/GaAs hetero-epitaxial layers (solar cell structure) grown by a barrel-type metalorganic chemical vapor deposition reactor has been investigated on their thickness, carrier concentration and cell efficiency. The variation in thicknesses among twenty 50x45 mm^2 wafers was 7.7 %, and the variations in carrier concentrations of Se- and Zn-doped GaAs layers among twenty wafers were 24.0 % and 34.1 %, respectively. The variation in efficiencies at AM0 of forty three 20x20 mm^2 solar cells was 8.3 %. The distribution in cell efficiency is correlated with that in carrier concentrations of Zn-doped GaAs layers.

1. Introduction

In recent years, metalorganic chemical vapor deposition (MOCVD) technology has been used in many high performance electronic and optical devices such as a high electron mobility transistor (HEMT)[1], a double hetero-structure laser diode[2], and a solar cell[3]. However, most of these achievements have been limited to the growth on laboratory-scale, and the MOCVD technology is not widely used in production yet. There is room for improvement in the structure of a MOCVD reactor and the uniformity of the layer properties grown by the MOCVD method.

The purpose of this paper is to demonstrate the usefulness of the MOCVD technology for large-scale production of III-V semiconductor devices. The AlGaAs/GaAs hetero-epitaxial layers (solar cell structures) were grown by a barrel-type MOCVD reactor, and the uniformity in thickness, carrier concentration and solar cell efficiency was investigated.

2. Experimental procedure

AlGaAs/GaAs hetero-epitaxial layers were grown by the large-capacity MOCVD reactor MR-200 built by Cambridge Instruments. Figure 1 shows the structure of a susceptor used in this study. The susceptor is made of a SiC-coated graphite and consists of ten facets as shown in Fig. 1. Each facet has two recessed 8 cm diameter pockets, A and B, (A: upper site, B: lower site). Thus, in this reactor, twenty 3 inch diameter wafers can be grown at a time. The susceptor is heated by infra-red lamps with a patterned reflection panel through a quartz bell jar.

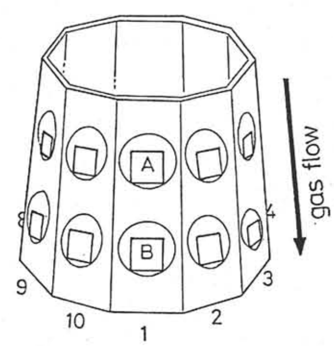

Fig. 1. The susceptor used in this experiment. A and B indicate upper and lower pockets, respectively. Each number indicates a facet.

The hetero-epitaxial layers were grown on 50x45 mm^2 Si-doped GaAs (100) substrates. The uniformity was examined for the layers grown on these twenty substrates. Figure 2 shows the layer structure, which is the same as solar cell mentioned later. Each thickness and carrier concentration in Fig. 2 denotes average values.

The substrate temperature and the reactor pressure were 720 °C and 130 Torr, respectively. The flow rate of carrier H_2 gas was 70 SLM. Trimethylgallium (TMG) and trimethylaluminum (TMA) were used as sources of column III materials and 100 % arsine (AsH_3) were used as

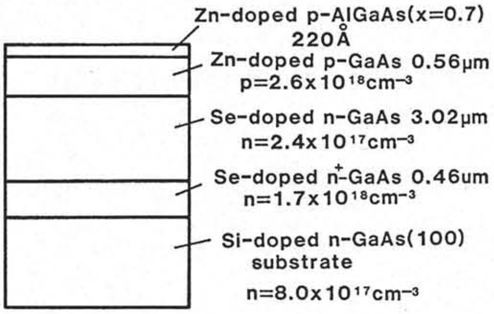

Fig. 2. The cross-sectional structure of epitaxial layer (solar cell structure). Each thickness and carrier concentration denotes average values.

source of element As. The doping of n- and p-type layers were carried out by employing hydrogen selenide (H_2Se) and diethylzinc (DEZ), respectively. The susceptor was rotated with a speed of 5 RPM.

The thicknesses of GaAs layers were estimated by measuring the stain-etched cross-section with an optical microscope, and those of thin AlGaAs layers were measured with alpha step (Tencor Instruments) by selectively etching the AlGaAs layers. The carrier concentrations of Se- and Zn-doped GaAs layers were determined by C-V and Hall measurements, respectively.

3. Uniformity in thickness and carrier concentration

The distribution in thicknesses of GaAs layers and carrier concentrations of Se- and Zn-doped GaAs layers among twenty wafers are shown in Figs. 3(a) and 3(b), respectively. Each thickness and carrier concentration in Fig. 3 is the value obtained at a center of each wafer. The variation in thicknesses of GaAs layers was 7.7 %. Those in carrier concentrations of Se- and Zn-doped GaAs layers were 24.0 % and 34.1 %, respectively. The variation is defined as 100 x $\sigma/\bar{x}$ (%) ($\bar{x}$: average, σ: standard deviation). The distribution in thicknesses of GaAs and AlGaAs layers, and carrier concentrations of Se- and Zn-doped GaAs layers along the gas flow direction are shown in Figs. 4(a) and 4(b), respectively. The variation in thicknesses of GaAs layers was 4.8 %, and that of AlGaAs layers was 10.7 %. The thickness of AlGaAs is so thin that the measurement error for thickness makes the variation large. The variation in carrier

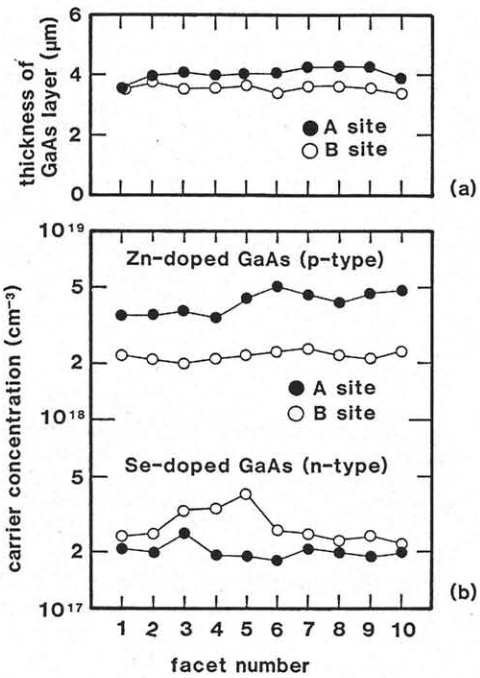

Fig. 3. The distribution in thicknesses of GaAs layers (a) and carrier concentrations of Se- and Zn-doped GaAs layers (b) among twenty wafers.

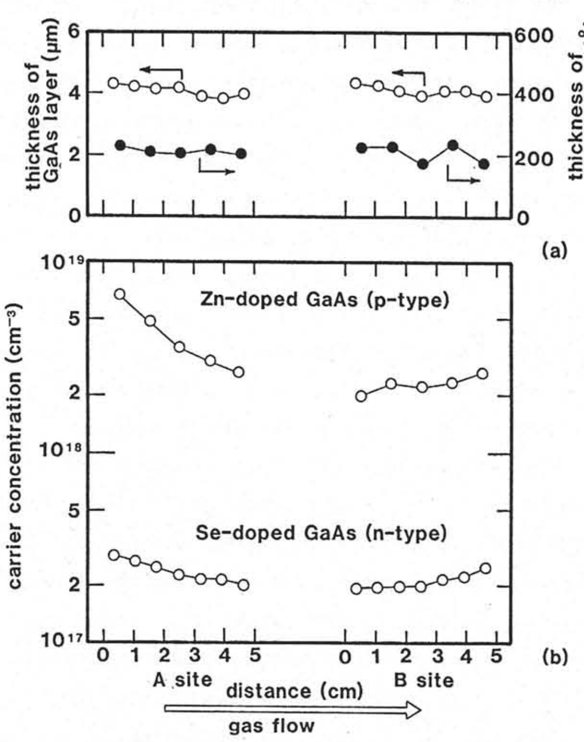

Fig. 4. The distribution in thicknesses of GaAs and AlGaAs layers (a) and carrier concentrations of Se- and Zn-doped GaAs layers (b) along the gas flow direction within two wafers.

concentrations of Se- and Zn-doped GaAs layers were 13.3 % and 45.5 %, respectively.

The uniformity in thicknesses of GaAs layers is good in whole wafer as shown in Figs. 3(a) and 4(a), and the variation in thicknesses is less than that in carrier concentrations. The growth rate is expected to be mainly affected by the flow rate of carrier H_2 gas. In previous paper[4], we have reported that the flow rate of carrier H_2 gas seriously influenced the growth rate and the uniformity in layer thicknesses drastically varied with the flow rate. Our results in Figs. 3(a) and 4(a) indicate that the flow rate of carrier H_2 gas 70 SLM used in the present growth is the good condition for uniform growth in a large area. On the other hand, the variation of the carrier concentrations along the gas flow direction is caused by the ununiformity of the substrate temperature. Keil et al. have reported that the doping efficiency of H_2Se and DEZ in GaAs was very sensitive to the substrate temperature[5]. We also have observed that the carrier concentration increases drastically even with a small decrease of the substrate temperature. In the light of this, our result in Fig. 4(b) suggests that the temperature of the susceptor is highest at the center. The maximum of the temperature difference along the gas flow direction was estimated to be about 15 °C from the data of doping efficiency for the temperature. To obtain better uniformity in carrier concentration, it is required to modify the reflection panel pattern, which has an effect on the distribution of the susceptor temperature. We confirm that the temperature difference on the susceptor can be improved below 10 °C by the modification of the pannel pattern.

4. Uniformity of solar cell efficiency

Forty three solar cells with an area of 20x20 mm^2 were fabricated from eleven epitaxial wafers to examine the uniformity around the susceptor, and sixteen solar cells with an area of 10x10 mm^2 were fabricated from two wafers to examine the uniformity along the gas flow direction. The distribution in efficiencies at AM0 of 20x20 mm^2 solar cells around the susceptor is shown in Fig. 5, and the histogram of efficiencies is shown in Fig. 6. The variation in efficiencies was 8.3 %. The maximum and average values of the efficiencies were 17.1 % and 15.0 %, respectively. The average of open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) were 0.971 V and 25.5 mA/cm^2,

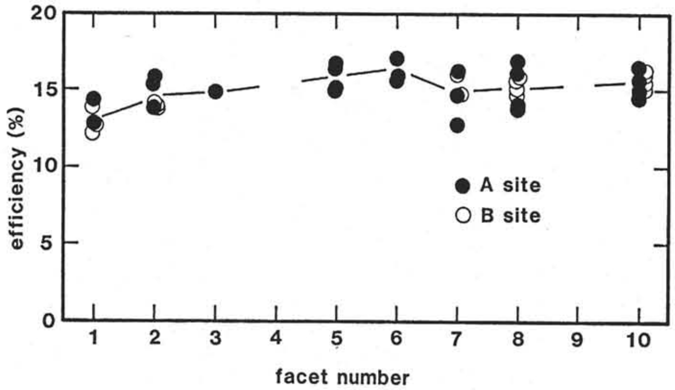

Fig. 5. The distribution in efficiencies at AM0 of solar cells with an area of 20x20 mm^2 around the susceptor.

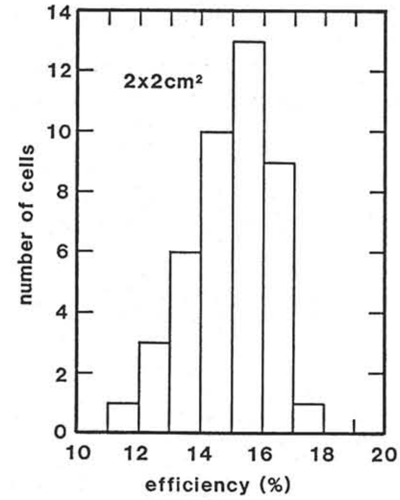

Fig. 6. The histogram of efficiencies at AM0 of forty three solar cells with an area of 20x20 mm^2.

respectively. The variation in efficiencies at AM0 of 10x10 mm^2 solar cells was 4.3 %. The maximum and average were 18.0 % and 16.8 %, respectively. The cell efficiency in this experiment is a little low compared to the maximum efficiency of 19.7 % (V_{oc}=1.01 V, J_{sc}=31.5 mA/cm^2, for a 10x10 mm^2 cell), which we have achieved by the same barrel-type MOCVD reactor[6]. This degradation of cell efficiency is considered to be mainly due to the poor properties of p-AlGaAs/p-GaAs hetero-interface or p-GaAs layer, i.e. life time reduction of electrons. The solar cell efficiency strongly depends on the carrier concentrations of n- and p-GaAs layers as described in previous work[7,8]. The distribution in cell efficiencies as shown in Figs. 5 and 6 is expected to be correlated with that in carrier concentration of p-GaAs layers. This is confirmed in Figs. 7(a) and 7(b), where

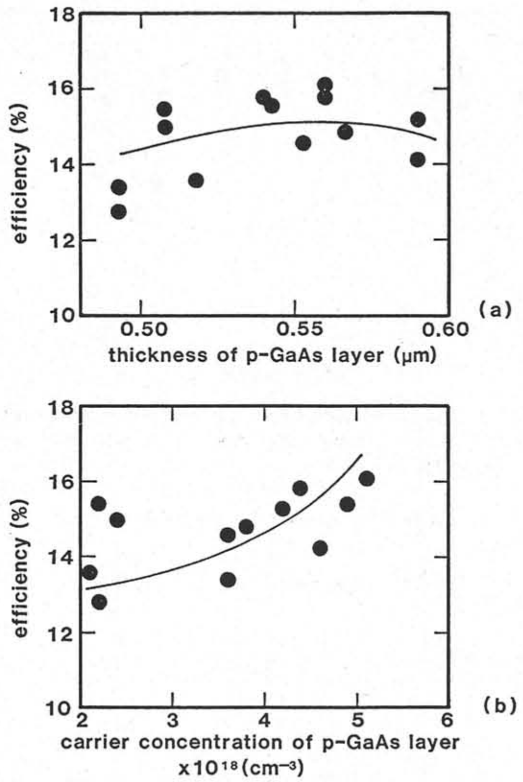

Fig. 7. The efficiency at AMO of solar cells with an area of 20x20 mm^2 as a function of thickness (a) and carrier concentration (b) of p-GaAs layer, respectively.

the cell efficiency is plotted for the thickness (a) and for the carrier concentration of p-GaAs layer (b), respectively. The cell efficiencies are almost independent of the thickness of p-GaAs layers in the range shown in Fig. 7(a). In contrast, the cell efficiencies are increased with increasing the carrier concentration of p-GaAs layer. The thickness and carrier concentration of n-GaAs layer do not probably much influence the variation of the solar cell efficiency, because n-GaAs layer is thick enough and the distribution in carrier concentrations of n-GaAs layers is less than that of p-GaAs layers.

5. Summary

The uniformity of AlGaAs/GaAs hetero-epitaxial layers grown by a barrel-type MOCVD reactor on thickness, carrier concentration and solar cell efficiency has been investigated.

The uniformity in thickness was excellent in twenty 50x45 mm^2 wafers and the variation in thicknesses was less than 8 %. The high uniformity in thickness was achieved by optimizing the flow rate of carrier H_2 gas. For carrier concentration, the uniformity was poor compared to that in thickness. The variations were 24.0 % and 34.1 % in Se- and Zn-doped GaAs layers, respectively. Those large variations in carrier concentrations were caused by the ununiformity of the susceptor temperature. The maximum of temperature difference was estimated to be about 15 °C.

In solar cells fabricated from these epitaxial layers, the maximum efficiency at AM0 of 17.1 % was obtained at 20x20 mm^2 cell size, and the variation was 8.3 %. The cell efficiency was correlated with the carrier concentrations of p-GaAs layers. By improving the uniformity of the susceptor temperature, it is possible to make the cell efficiency more uniform in a large number of solar cells.

Acknowledgments

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