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The Growth of an InGaAs-InP Superlattice by the Chloride VPE

J. Komeno, K. Kodama, M. Takikawa, and M. Ozeki Fujitsu Laboratories Ltd.

rajiesa haboracorres hea.

1677 Ono, Atsugi, Kanagawa 243-01, Japan

 $In_{0.53}Ga_{0.47}As$ -InP superlattices have been successfully grown by the chloride transport vapor phase epitaxy (chloride VPE). The grown superlattices were evaluated by several measurements. The thickness of the heterointerface region was measured by Auger electron spectroscopy, and is determined to be less than 30 Å. X-ray measurements show satellite diffractions which demonstrate uniformity in period of the superlattice. Optical absorption and photoluminescence measurements give the evidence for the formation of the quantum wells in InGaAs layers.

Recently, many works have been published¹⁻³⁾ on the ternary alloy $In_{0.53}Ga_{0.47}As$ (InGaAs in the following) because of its promising properties for device applications. Indeed, InGaAs is an important material for long-wavelength optical communication devices. Moreover, its high bulk mobility at room temperature and high drift velocity make this material very attractive for high-speed field-effect transistor (FET) applications.

We report here the first successful growth of InGaAs-InP superlattices using the chloride VPE method which uses $AsCl_3$ and PCl_3 as the sources of the Group V elements. The $AsCl_3$ -Ga-In-H₂ and the PCl_3 -In-H₂ systems have been used for the growth of InGaAs and InP, respectively. The motivations for employing the chloride VPE method are that this technique is safer than MOCVD which uses dangerous AsH_3 , PH_3 , and metalorganic compounds, that the chloride method offers lower cost and higher yield of production compared with MBE, and besides that InGaAs and InP layers of very high purity can be grown by the chloride VPE.

In the case of chloride VPE growth of InGaAs, arsenic trichloride first reacts with H_2 at high temperature, yielding a gaseous mixture of As₄ and HCl. Next, this HCl reacts with III-V compound crust formed on the Group III metal source, which is saturated with arsenic, according to the following reactions:

GaAs(s) + HCl(g) = GaCl(g) + $\frac{1}{4}$ As₄(g) + $\frac{1}{2}$ H₂(g),(1)

 $InAs(s) + HCl(g) = InCl(g) + \frac{1}{4}As_4(g) + \frac{1}{2}H_2(g). (2)$ For simplicity, we have not included those compounds which at the growth temperature (670°C) are only present as minor species. Above reactions are reversed at a low temperature, causing deposition of the III-V compound on the substrate. We can, therefore, regard the deposition of $In_XGa_{1-x}As \text{ as the deposition of a mixture of InAs}$ and GaAs, as shown by the following equation:

x InAs +
$$(1-x)$$
 GaAs = $In_xGa_{1-x}As$. (3)

Thus, controlling of alloy composition requires control of the composition of the gas mixture of InCl and GaCl, formed by reactions (1) and (2). The reactor system that we use for VPE growth of InGaAs on InP substrates is designed to permit such control. A schematic diagram of this reactor is shown in Fig.1, together with a temperature profile used here. The flow rates of H2 + AsCl3 over Ga and In sources were 150 and 300 cm³/min, respectively. Total H2 flow rate at growth region was 950 cm³/min. The reactor system adopts the dual-growth-chamber method. 4) That is, the reactor tube is divided into two chambers, the upper one is for InGaAs growth and the lower for InP growth. An abrupt InGaAs-InP heterojunction is obtained by transferring a substrate from one chamber to the other with a transfer time of less than a few seconds. To reduce the growth rates of InGaAs and InP is also essential for obtaining



Fig.l Schematic diagram of the reactor and temperature profile for chloride VPE growth of InGaAs-InP heterostructure.

abrupt heterointerfaces. Controlling the partial pressure of HCl in equation (1) and (2), we have succeeded in decreasing the growth rate of InGaAs to about 3 Å/s and that of InP to about 12 Å/s. As shown in Table 1, these growth rates are comparable to that of molecular beam epitaxy (MBE) $^{5,6)}$. Therefore, extremely abrupt heterointerfaces can easily be realized and superlattice structures can be prepared.

	InGaAs	AlGaAs
MBE	~4 Å/s	3-6 Å∕s
VPE	~3 Å/s	

Table 1 Growth rates of ternary alloys in MBE and VPE.

Figure 2 is a micrograph of the angle-beveled cross section of an InGaAs-InP superlattice grown by the chloride vapor phase epitaxy. The twelve layers of InGaAs (~ 80 Å) appear as the lighter lines while the eleven darker lines are InP layers (~ 140 Å).

Figure 3 shows an Auger profile of phosphorus measured on a beveled superlattice surface. This figure shows that phosphorus content varies periodically. The valleys and the peaks in the profile correspond to InGaAs layers and InP layers, respectively. The thickness of the heterointerface region was estimated and found it to be less than 30 Å.



Fig.2 Angle-beveled cross section of an InGaAs-InP superlattice grown by chloride VPE. The twelve InGaAs layers (~ 80 Å) appear as the lighter lines while the eleven InP layers (~ 140 Å) are the darker material.



Fig.3 Auger profile of phosphorus measured on a beveled InGaAs-InP superlattice grown by chloride VPE. The valleys and the peaks correspond to InGaAs and InP layers, respectively. The measured chemical-interface widths of the heterojunctions are less than 30 Å.

The InGaAs-InP superlattices grown by the chloride VPE were also evaluated by X-ray diffraction measurements. The result is shown in Fig. 4. In the case of superlattice structure, the satellite diffractions appear and this demonstrates uniformity in period of the superlattice.

Photoluminescence and optical absorption measurements were made, using PbS photoconductive cells as detectors, to investigate the InGaAs-InP multiple-quantum-well (MQW) structures.

was observed in the AlGaAs-GaAs structures. 7-8)



Fig.4 X-ray diffraction pattern from an InGaAs-InP superlattice grown by chloride VPE. Satellite diffractions are observed in the vicinity of the main diffraction.

The photoluminescence was measured at 4.2 K, using the 4880 Å line of an Argon laser. The excitation intensity was kept sufficiently low in order to prevent an increase of the sample temperature. The absorption measurements were also made at 4.2 K. The under surfaces of InP substrates were mirror-polished for the measurement. It was checked that there was little effect of optical interference on the absorption spectrum.

Figure 5 shows the dependence of photoluminescence peak energy on the thickness of InGaAs well layer. As the thickness of quantum well is decreased, the peak energy shifts toward higher energy. This is quite natural when a quantum well structure is formed.

Typical absorption spectra of InGaAs-InP MQW samples are shown in Fig.6. In the figure, also shown is a spectrum obtained on an InGaAs bulk sample of about 5000 Å thick. The MOW samples have absorption edges at shorter wavelength than that in the bulk sample and complicated structures can be observed in the spectra. Such structures are not recognized in the spectrum of the bulk sample. The arrows in the figure indicate calculated transition energies from hole subband to electron subband, and show good agreements with these spectra. This means that the quantum wells are formed in InGaAs layers of the present structure. It also means that these structures are free from alloy clustering which



Fig.5 The dependence of PL peak energy on the thickness of InGaAs well layer. PL measurements were carried out at 4.2 K using the 4880 Å line of an Argon laser.



Fig.6 Optical absorption spectra of the bulk and the MQW samples. The arrows indicate calculated transition energies from hole subband to electron subband.

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