Thermophysical Properties of InGaAs

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Abstract

The viscosity and thermal diffusivity of $In_xGa_{1-x}As$ with various compositions has been measured up to 1500 K. The double crucible method could be vilified its availabilities to measure the high vaporizing materials on both measurement. The thermophysical data of $In_xGa_{1-x}As$ (X=0.3, 0.5, 0.8) could be obtained for the first time. The temperature dependence of viscosity of molten $In_{0.8}Ga_{0.2}As$ was expressed as η (T)=0.213 exp (1.85 × 10^3/T) [mPa·s] by an oscillating cup method. The thermal diffusivity of molten $In_{0.8}Ga_{0.2}As$ was 11 mm^2/s at 1313 K and that of solid was 1.8 mm^2/s at 1273 K by a laser flush method.

1. Introduction

III-V compound semiconductors are promising material for optoelectronic devices. In these semiconductors, InGaAs is paid special attention in recent years as laser diodes emitting 1.3 μm light. For this advanced devices, the high quality substrate of $In_{0.3}Ga_{0.7}As$ with compositional homogeneity has to be grown [1].

Crystal growth is needed to optimize the growth conditions which are a temperature gradient at the growth interface, a traversing speed of sample, a crucible design, and so on. The crystal growth of semiconductor used to being performed by means of trials and errors. But the increasing of complexity requires another approach which is numerical simulation to search for the optimal condition. To carry out the highly precise simulation, the highly reliable thermophysical properties are essential. However, there are few data concerning InGaAs because it has a high melting point and a high vapor pressure of arsenic.

In this report, the measurements of viscosity and thermal diffusivity are mentioned and the results are discussed.

2. Experiment

2.1 viscosity measurement

An oscillating cup method was employed because the molten semiconductors

have relatively low viscosity and high temperature. This method has a big advantage which is adaptable to lower viscosity to about 0.3 mPa·s. In addition to that, a completely sealing container can be used for preventing vaporization from sample. It is quit important for a high precise measurement in arsenate compound with a high vapor pressure.

Figure 1 shows the schematic diagram of viscosity measurement system used in this study. This equipment consists of an oscillation detect part and a sample heating part. The container was hanged under torsion wire and the oscillation is initiated by giving a torsion force electrically induced to the disk that is located on middle part of the wire. The decay of oscillation is measured to detect the period of the laser light reflection form the mirror set on the wire. From its time interval and logarithmic attenuation, the viscosity was calculated using Roscoe's equation [2, 3]. In the case of cylindrical container, the relation between the viscosity η and attenuation of oscillation is expressed as follows:

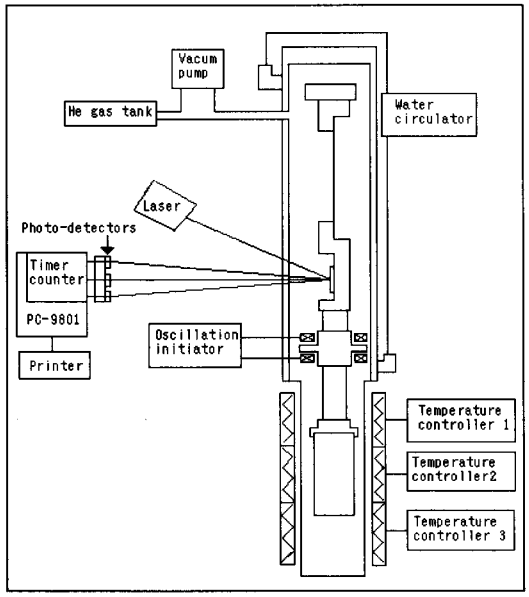

Fig.1 Schematic diagram of viscosity measurement facility by oscillating cup method

$$\eta = \frac{(I\delta / \pi R^3 HZ)^2}{\pi \rho \tau} \qquad (1)$$

$$Z = \left(1 + \frac{R}{4H}\right) a_0 - \left(\frac{3}{2} + \frac{4R}{\pi H}\right) / p + \left(\frac{3}{8} + \frac{9R}{4H}\right) a_2 / 2p^2 - \left(\frac{63}{128} - \frac{45R}{64H}\right) a_4 / 4p^4$$

$$p = \frac{1}{2} R\left(\frac{\pi \rho}{\eta \tau}\right)$$

$$a_0 = 1 - \left(\frac{3}{2}\right)\Delta - \left(\frac{3}{8}\right)\Delta^2 - \left(\frac{1}{16}\right)\Delta^3$$

$$a_2 = 1 + \left(\frac{1}{2}\right)\Delta + \left(\frac{1}{8}\right)\Delta^2 - \left(\frac{1}{16}\right)\Delta^3$$

$$a_4 = 1 + \left(\frac{1}{2}\right)\Delta - \left(\frac{3}{8}\right)\Delta^2 - \left(\frac{5}{16}\right)\Delta^3$$

$$\Delta = \frac{\delta}{2\pi}, \qquad \delta = \left(\frac{1}{n}\right) \ln\left(\frac{\theta_0}{\theta_n}\right)$$

where δ is the logarithmic attenuation, R the inner diameter of crucible, H the height of a molten sample in a crucible, ρ the density of sample, τ the oscillation period, θ the amplitude.

The furnace consists of three zone heaters to keep the highly homogeneous temperature distribution in sample and to suppress the buoyancy convection. The temperature at the sample was measured by two thermocouples positioned at upper and lower parts of crucible.

As mentioned above, molten InGaAs dissociates the vaporized arsenic. Furthermore, when the InGaAs solidifies, its volume increases. Therefore, the crucible should be contrived to prevent from rupturing. Double crucible was used as shown in Fig. 2. A quartz tube, which was 15 mm inner diameter and 70 mm height, was used to avoid the reaction with InGaAs as inner crucible.

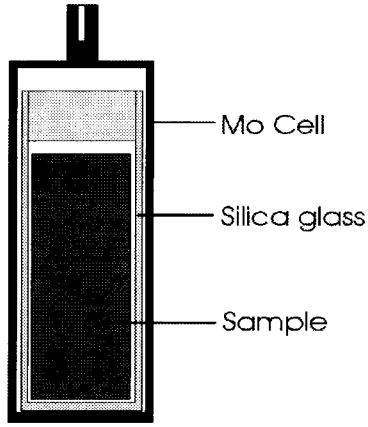

Fig.2 Double contained sample for viscosity measurement

Bulky $In_xGa_{1-x}As$ with hopeful composition was inserted in quartz crucible and then it was sealed under the vacuum condition. A molybdenum tube, which inner diameter was 21 and height was 75 mm, contained the inner crucible because the quartz became soft and was expanded by inner pressure above the melting temperature of InAs.

The X value of In_xGa_{1-x} As were changed as follows; X = 0.3, 0.5, 0.8, 1.

2.2 thermal diffusivity measurement

To measure the thermal diffusivity, the laser flush method was employed. Laser Flash Thermal Constants Analyzer TC-700H/melt made by ULVAC-RIKO inc. was used as Experimental equipment.

The principal of laser flush method is that the thermal diffusivity can be estimate by measuring the temperature variation at the bottom of the sample after the pulsive laser beam heats the surface. It was necessary to set the well absorbing layer because the surface of InGaAs has a high reflectivity. In the case of melt, the surface could not be colored black directly. Therefore, the melt was sandwiched between graphite sheets (ϕ 10 mm × 0.2 mm thickness). Moreover, the

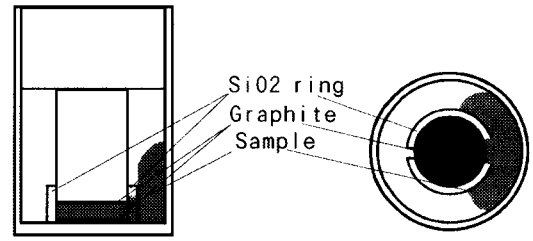

Fig.3 Sample cell for thermal diffusivity measurement

sample was enclosed with a quartz container to avoid the dissociation of arsenic as shown in Fig. 3. The crucible was sealed under the vacuum condition of 10^{-6} Torr.

The sample consisted of five layers. However, if the thickness of quartz layer is enough, it can be ignored. Therefore, the analysis for three layers sample was used to calculate the thermal diffusivity by a multi-layer analyzing method. This method can calculate a thermal diffusivity form the measured half time of temperature response curve at the bottom of sample. The correlation in a width of laser pulse, a distribution of laser power, and heat loss to sidewall of crucible was done based on ref. 4.

3. Result and Discussion

3.1 Viscosity

At first, the viscosity measurement of silver was done as the reference data to check the validity of the double crucible up to 1500 K. The results agreed with the past measurement [5, 6] within ± 5 % dispersion as shown in Fig. 4. Accordingly the double structure of the crucible did not affect the measurement.

Figure 5 shows the viscosity of InGaAs. To compare with another data measured by Glasov [7] and Kakimoto [8]

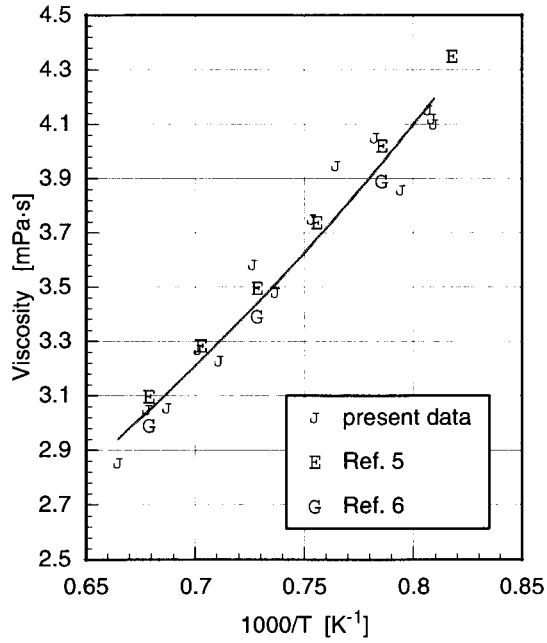

Fig.4 Viscosity of silver [5,6]

which data are about end composition such as InAs or GaAs. The temperature dependence of viscosity was expressed as follow in the case of molten $In_{0.8}Ga_{0.2}As$.

$$\eta(T) = 0.213 \exp\left(\frac{1.85\times10^{3}}{T}\right) \quad [\mathrm{mPa\cdot s}] \qquad (2)$$

The horizontal axis was rescaled by melting temperature, Tm, to (T-Tm)/Tm in order to compare with the different composition materials. The values of this study agreed well with reference 7 and 8 except for Glasov's GaAs data as shown Fig. 6.

The composition dependency of viscosity was shown in Fig. 7. The dependency was small because the difference between the each marginal composition, InAs and GaAs, was small.

3.2 Thermal diffusivity

To check the validity of measurement method using sealing cell, the thermal diffusivity of Gallium was measured because the available reference data exist.

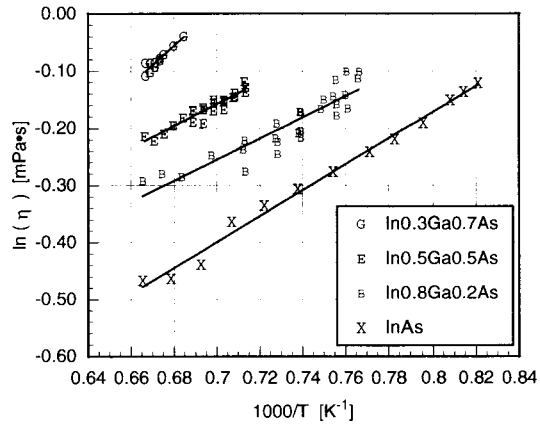

Fig. 5 Temperature dependence of viscosity

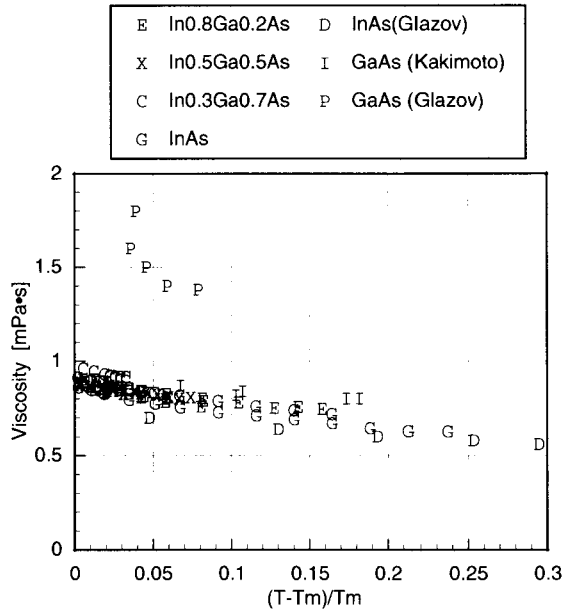

Fig. 6 Viscosity of molten InGaAs rescaled by melting temperature

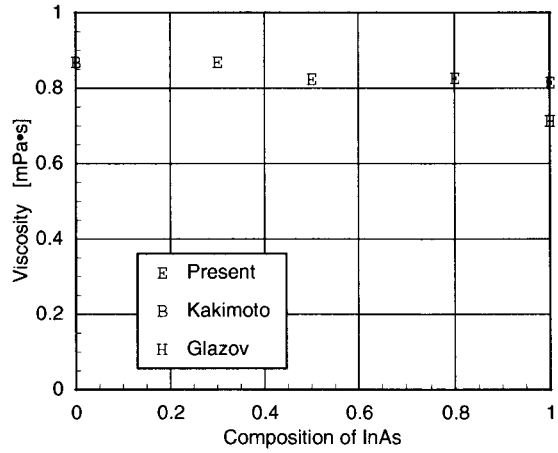

Fig. 7 Compositon dependency of visocosity at $(T-T_m)/T_m = 0.05$

The thickness of the bottom of a quartz crucible was kept constant 4 mm. On the other hand, the thickness of the sample was selected 1.2, 2.0, and 2.8 mm. The temperature dependence of the thermal diffusivity is shown in Fig. 8 [9,10]. The dispersion was within ± 10% and the influence of sample thickness did not exist. Therefore, the measurement of InGaAs was performed using 1.5 mm thickness sample. The X values of $In_xGa_{1-x}As$ were selected 0.3, 0.5, and 0.8. The measurement was carried out after the sample was completely melted at 1250 °C. The thermal diffusivity as a function of temperature is shown in Fig. 9. The temperature dependency was linear in this range and the composition dependency was small. In Fig. 9, the values of InAs and GaAs, which were estimated by Wedemann-Franz low, is also plotted.

The thermal diffusivity of molten $In_{0.8}Ga_{0.2}As$ was 11 mm^2/s at 1313 K and that of solid was 1.8 mm^2/s at 1273 K (Fig. 10). The thermal diffusivity of molten state was about 6 times lager than solid state. So this means that the heat from melt will not easily escape into crystal when a crystal growth is performed. As the result, it might produce the difficulties to design the optimal thermal condition

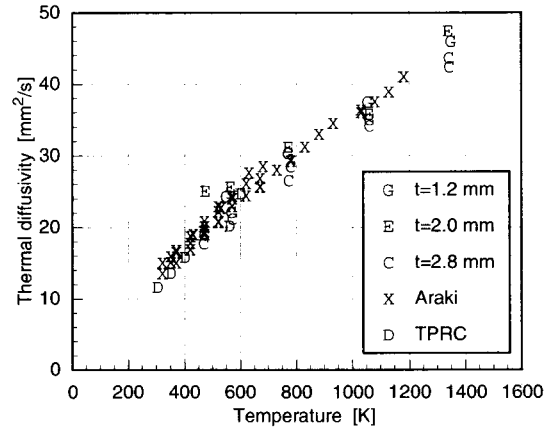

Fig. 8 Thermal diffusivity of Gallium [9,10]

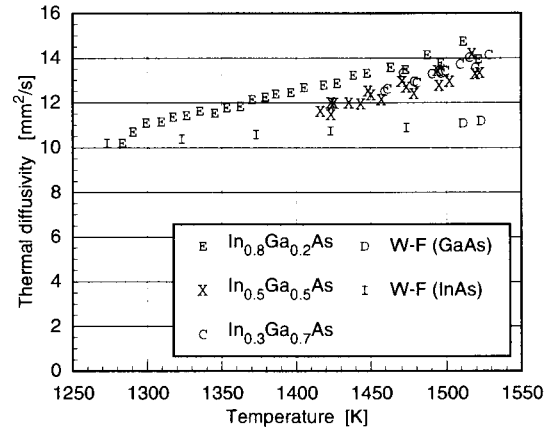

Fig. 9 Temperature dependence of thermal diffusivity of molten InGaAs

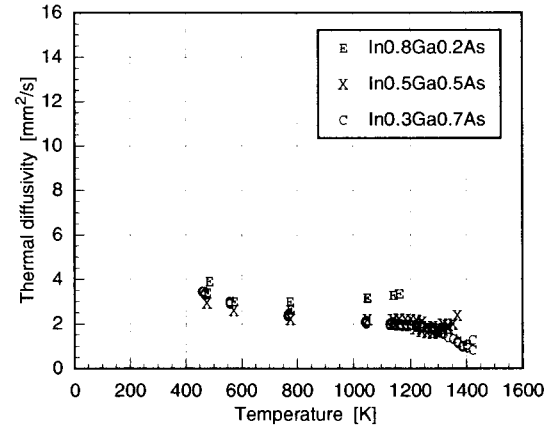

Fig. 10 Temperature dependence of thermal diffusivity of solid InGaAs

4. Summary

The viscosity and thermal diffusivity of $In_xGa_{1-x}As$ with various compositions has been measured up to 1500 K. The double crucible method could be vilified its availabilities to measure the high vaporizing materials on both measurement. The thermophysical data of $In_xGa_{1-x}As$ (X=0.3, 0.5, 0.8) could be obtained for the first time.

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