Development of Si-doped 8-inch GaAs substrates

M. Morishita[1], H. Takayama[1], S. Kaneko[1], H. Ota[1], T. Moriwake[1], S. Horikawa[2], K. Morishige[2], Y. Hagi[1, 2] and Y. Yabuhara[1, 2]

[1]Sumiden Semiconductor Materials Co., Ltd., 1-9-2 Takatsukadai, Nishi-ku, Kobe, Hyogo, 651-2271 Japan
[2]Sumitomo Electric Industries, Ltd., 1-1-1, Koya-kita, Itami, Hyogo, 664-0016 Japan
Phone: +81-78-990-1304, Fax: +81-78-990-1305, e-mail: takayama-hidetoshi@sei.co.jp

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Abstract

In this paper we report on newly developed Si-doped 8-inch GaAs substrates with low etch pit density (EPD) using the Vertical Boat (VB) method. We designed a new 8-inch VB growth furnace, optimized growth conditions to reduce crystal defects, and determined the required cooling rate. We successfully developed 8-inch GaAs substrates with high axial uniformity of EPD. Fig.1 shows picture of 3inch, 4-inch, 6-inch and 8-inch GaAs substrates.

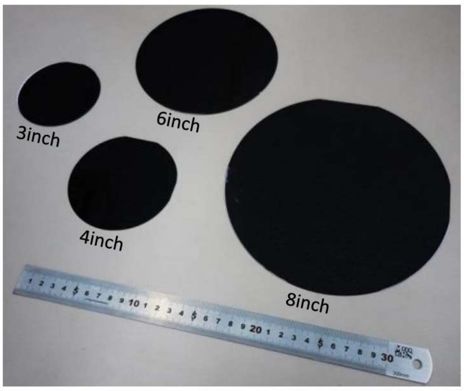

Fig. 1 Picture of 3-inch, 4-inch, 6-inch and 8-inch GaAs substrates.

INTRODUCTION

Demand for larger diameter GaAs substrates is growing rapidly, driven by the need to improve process efficiency and reduce production costs. Demand growth is expected continue and possibly accelerate as micro LEDs may be used in next-generation display applications, replacing liquid crystals and OLEDs. Large diameter GaAs substrates will need to have axial uniformity equal to or better than current substrates for key wafer characteristics such as carrier concentration and EPD.

Sumitomo Electric Industries (SEI) has been manufacturing 3-inch, 4-inch and 6-inch substrates for LED and LD from long crystal ingots with high in-plane uniformity of carrier concentrations, and in-plane and axial uniformity of EPD using the VB method. In this method, GaAs can be grown by moving the heater, which maintains the growth temperature profile (Fig.2). We have expanded our manufacturing technology for GaAs substrates for LEDs, moving to the growth of larger diameter crystals from which we have made 8-inch GaAs substrates. Fig.3 shows development history of GaAs substrates in SEI.

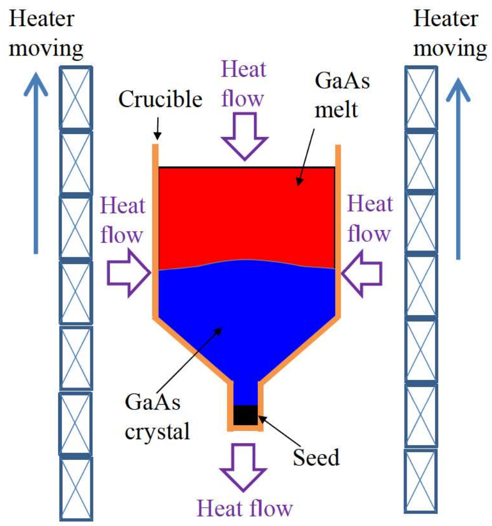

Fig. 2 Conceptual Diagram of the Vertical Boat (VB) Method

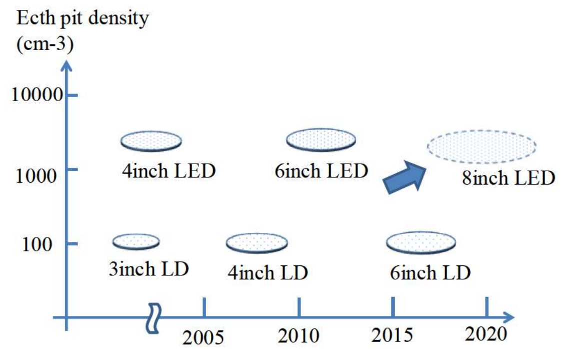

Fig. 3 Development history of GaAs substrates in SEI.

EXPERIMENT

In order to produce 8-inch GaAs crystals, we modified the technology for the VB crystal growth method currently used in SEI's 6-inch substrate production. We designed a furnace of the optimum structure. In the growth of large diameter GaAs crystal, it is very difficult to control the thermal environment in the direction of the growth axis. Thermal control is crucial to keep the optimum interface shape, and maintain that shape stably through the growth of the entire crystal ingot. Through the use of simulations, we improved the technique for the use of multiple zone heaters further and optimized the number of zones, zone width and temperature profile. We control the thermal environment in the growth axis with only the side heaters. Fig.2 shows conceptual diagram of thermal environment. Fig.4 shows the results of simulation. We confirmed the conditions to obtain an interface shape equivalent to 6-inch. It is important to maintain this interface shape during crystal growth period.

Growth is carried out by filling the crucible with raw materials and the Si dopant, melting these materials in a furnace, and then solidifying the melt starting from the seed crystal. The temperature in the furnace is controlled to maintain an optimum solid/liquid interface shape so that the in-plane distribution of carrier concentration and EPD is reduced. The crystal is solidified while keeping the furnace temperature at the optimum conditions. After the crystal has been fully solidified, the crystal is cooled in a furnace in which the temperature distribution in the axial direction is uniformity adjusted so as not to cause slip defects due to temperature non-uniformity during cooling. Finally, 8-inch GaAs crystal is produced.

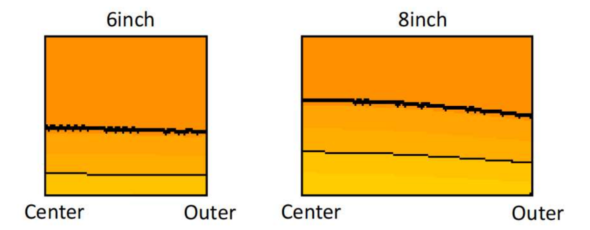

Fig. 4 The interface shape in GaAs growth simulation

RESULTS

The characteristics of 8-inch, 6-inch for LED and 6-inch for LD GaAs substrates are shown in Table I. EPD, Carrier concentration, and TTV of 8inch GaAs substrates are similar to those of 6inch GaAs substrates. Warp of 8inch substrates is higher than that of 6inch substrates, but we will improve it by optimization of slicing and polishing conditions.

Fig 5 shows the carrier concentration distribution of 8-inch and 6-inch GaAs substrates for LED. The in-plane distribution of carrier concentration of 8-inch is equivalent to 6-inch. Fig 6 shows the correlation between carrier concentration and mobility of 8-inch and 6-inch GaAs substrates. The correlations of 8-inch are the same as that of 6-inch, which means that both substrates have the same electrical properties caused by impurities.

TABLE I Characteristics of GaAs substrates

Wafer size	8" LED	6"LED	6" LD
Etch pit density (/cm3)	≦5000	≦5000	≦500
Carrier concentration (atm/cm3)	0.3-4.0E18	0.3-4.0E18	0.8-4.0E18
TTV (um)	≦15	≦15	≦7
Warp(um)	≦20	≦15	≦10
Surface	Double side polished	Double side polished	Double side polished

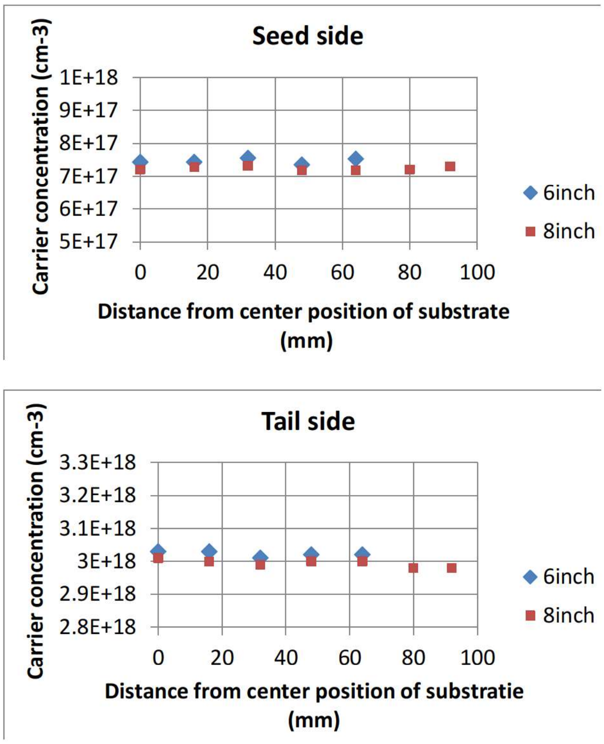

Fig. 5 In-plane uniformity of carrier concentration of GaAs substrates

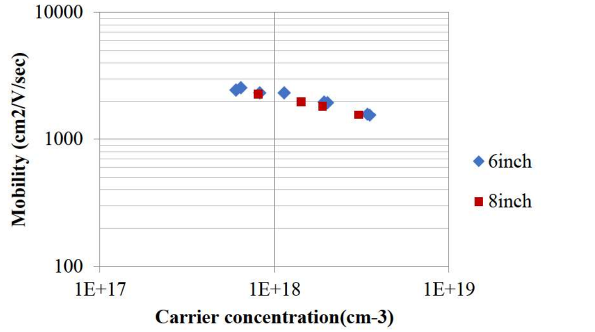

Fig. 6 The correlation between carrier concentration and mobility of 8-inch and 6-inch GaAs substrates.

Fig 7 shows EPD map of 8-inch, 6-inch for LED, and 6-inch for LD GaAs substrates. The in-plane distribution of EPD of 8-inch is equivalent to 6-inch for LED. We could realize the EPD of 6-inch GaAs substrates for LD due to improving two growth conditions of 6-inch GaAs substrates for LED. First is flattening interface shape of growing GaAs caused by optimization of temperature gradient around the growth interface. Second is thermal stress relaxation caused by optimization of cooling rate after GaAs growth. Fig. 8 shows conceptual diagram of First and Second improvement. We further believe that by optimizing the thermal environment we can also produce low EPD 8-inch GaAs substrate similar to 6-inch for LD.

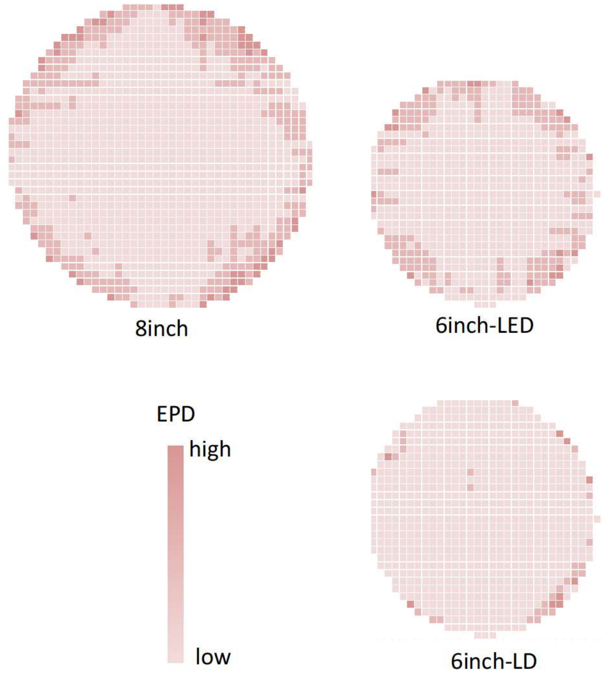

Fig. 7 EPD map of GaAs substrates

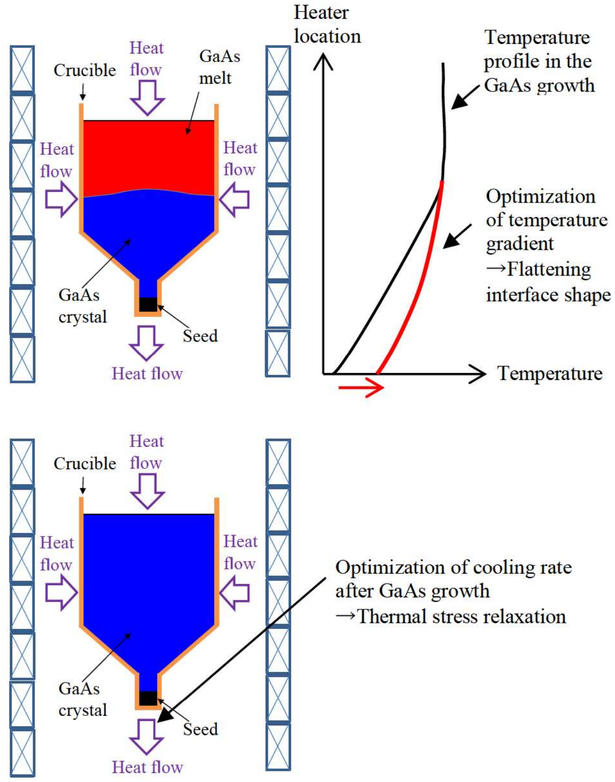

Fig. 8 Conceptual diagram of optimizing growth conditions for 6-inch GaAs substrate with lower EPD.

Fig 9 shows the axial distribution of EPD. The EPD is uniform in the axial direction similar to 6-inch LED substrate. This result shows that the difference between wafers is small and the controllability is good.

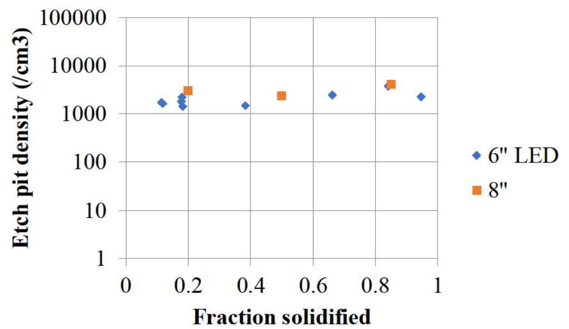

Fig. 9 EPD axial distribution of GaAs substrates

Fig.10 shows residual strain distribution of 6-inch and 8-inch GaAs substrates. Both substrates have a little residual strain due to slip dislocations around substrate circumference. But both residual strains are low on the whole, and the distribution make no difference.

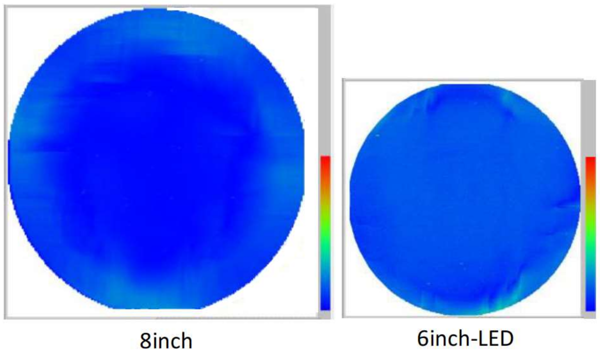

Fig. 10 Residual strain distribution of GaAs substrates

CONCLUSIONS

SEI has developed Si-doped 8-inch GaAs substrates which have good uniformity of EPD in the axial direction. Uniformity of in-plane distribution of carrier, EPD, and residual strain are as good as for 6-inch LED substrates. We expect these substrates will find use in an evolving LED device market.