Development of Laser Diode Grade Si-doped 8-inch GaAs Substrates

K. Shibata[1], K. Aoyama[1], M. Nishioka[1], K. Hashio[1], F. Adachi[1], S. Fujita[1,2]
Y. Hagi[1, 2] and T. Morishita[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: shibata-kazuya@sei.co.jp

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Abstract

In this paper, we report on newly developed Laser Diode (LD) Grade, Si-doped 8-inch GaAs substrates using the Vertical Boat (VB) method. We optimized crystal growth conditions to reduce dislocations. We have successfully developed LD Grade 8-inch GaAs substrates with very low dislocation density and high radial uniformity of carrier concentration.

INTRODUCTION

The demand for larger diameter GaAs substrates is growing rapidly. This growth is expected to accelerate with the introduction of Micro LEDs, which may replace LCDs and OLEDs in next generation displays. 8-inch GaAs substrates for Micro LEDs will require low dislocation density and radial carrier concentration uniformity equal to or better than current 4-inch and 6-inch substrates. Specifically, it is critical for these parameters to be equal to that required by LD substrates.

Sumitomo Electric Industries (SEI) has been a leading manufacturer of 3-inch, 4-inch and 6-inch GaAs substrates for LD applications. In addition, we have experience to manufacture LED grade 8-inch GaAs substrates [1]. With further improvements in SEI's capabilities, we have succeeded in the development of LD grade 8-inch GaAs substrates.

EXPERIMENT

Fig. 1 shows a schematic of SEI's VB crystal growth furnace. GaAs pre-synthesized polycrystal and Si dopant are charged in a crucible as raw materials. After melting raw materials, a single crystal was grown along the <100> direction from a seed crystal mounted at the bottom of the crucible by moving a heater.

A flat solid-liquid interface (growth interface) is essential for low dislocation density and high radial uniformity of carrier concentration. To realize an optimally flat growth interface shape, we optimized each zone setting of a multi-zone heater and controlled the temperature profile precisely throughout whole crystal growth. Since the cooling process after solidification also affects the dislocation density, we optimized cooling conditions. This allows for a successful 8-inch GaAs crystal production process.

The 8-inch GaAs crystal was cut and polished in the same manner as 6-inch substrates are manufactured. (Resulting in a prime quality, double side mirror 8-inch GaAs substrate.)

RESULTS

-Crystal property

Dislocation densities are evaluated as Etch Pit Densities (EPDs) measured at 5mm pitch. Fig 2 shows EPD map of 8-inch GaAs substrates for LD (8-inch LD) comparing to typical 6-inch LD and conventional 8-inch LED GaAs substrates.

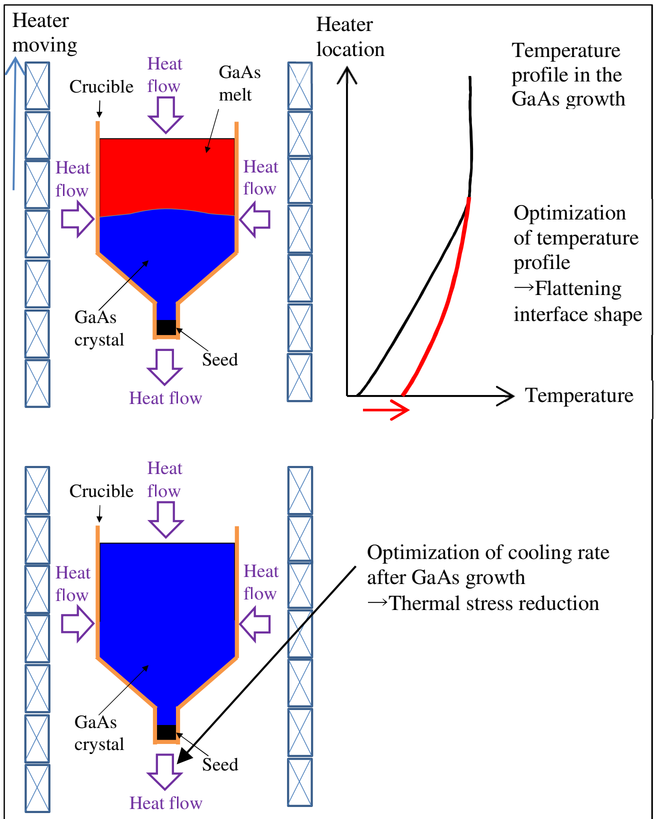

Fig. 1 VB Crystal growth furnace and conceptual diagram of optimizing growth conditions for 8-inch GaAs substrate with lower EPD.

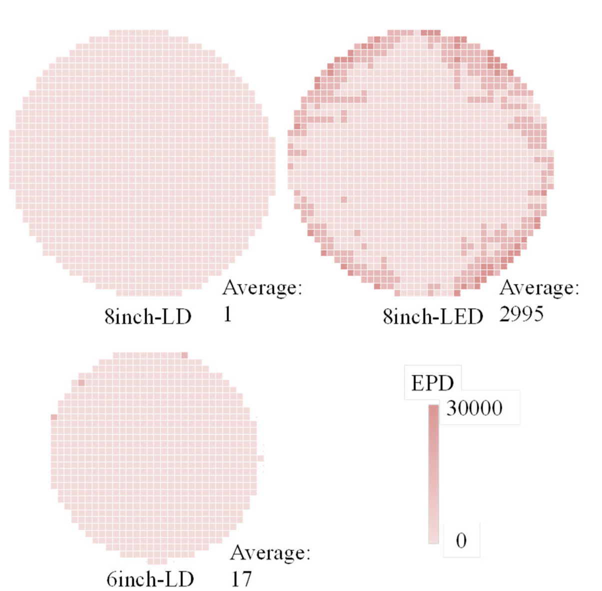

Fig.2 EPD map of GaAs substrates

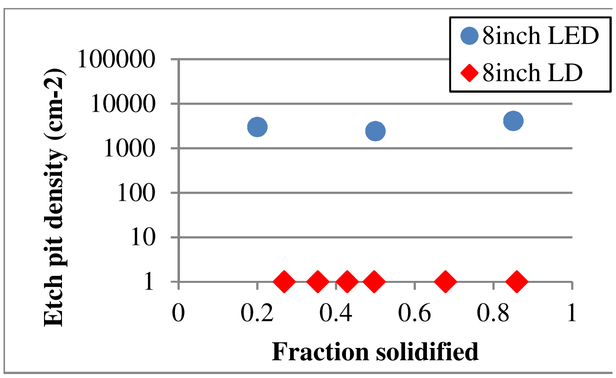

Fig. 3 EPD along the growth direction of GaAs crystals

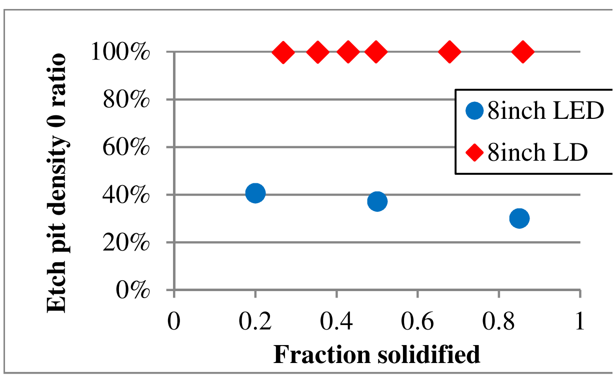

Fig. 4 EPD 0 ratio along the growth direction of GaAs crystals

Fig 3 shows the axial distribution of EPD and Fig4 shows the axial distribution of EPD 0 ratio which means percentage of EPD 0 point out of total EPD measurement point. The EPD of 8-inch LD is almost dislocation free and equivalent to 6-inch LD.

Fig 5 shows the radial distribution of carrier concentration of 8-inch-LD in comparison to the 8-inch LED and 6-inch GaAs substrates. 8-inch LD exhibits a flatter distribution than the 8-inch LED substrate. The radial uniformity of each substrate is also exhibited for comparison in Table I.

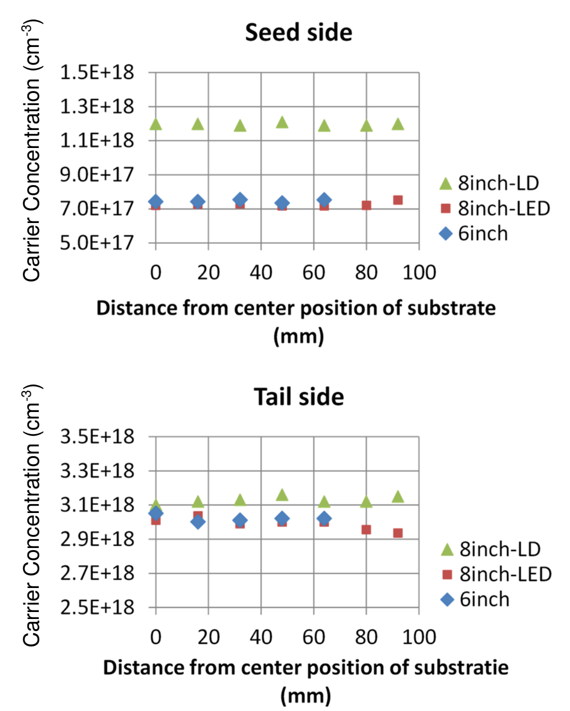

Fig. 5 In-plane uniformity of carrier concentration of GaAs substrates

	8inch-LD		8inch-LED		6inch-LD	
	Seed side	Tail side	Seed side	Tail side	Seed side	Tail side
average (cm^{-3})	1.20E+18	3.13E+18	7.27E+17	2.99E+18	7.46E+17	3.02E+18
σ (cm-3)	7.45E+15	2.00E+16	1.12E+16	3.13E+16	7.33E+15	1.67E+16
(Max-Min) /Average	3.7%	1.2%	4.7%	3.3%	2.7%	1.7%

TABLE I Carrier concentration of GaAs substrates

Fig.6 shows residual strain distribution of 8-inch LD, LED and 6-inch LD GaAs substrates. LED substrates have a little residual strain due to dislocations around substrate periphery. On the other hands, LD substrates have almost no residual strain due to the absence of dislocations. The substrate for 8-inch LDs has low residual strain, which is expected to suppress slip line generation in the epi-process.

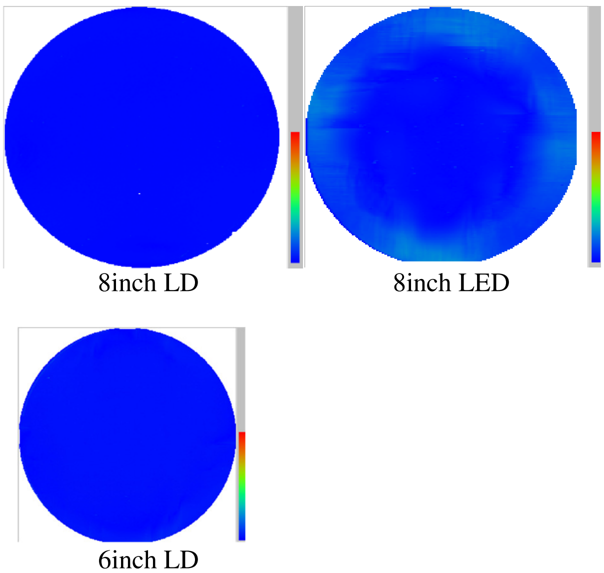

Fig. 6 Residual strain distribution of GaAs substrates

WAFER PROPERTIES

Fig.7 shows the comparison of warp and total thickness variation (TTV) between 6-inch and 8-inch GaAs substrates. The WARP and TTV of 8-inch are slightly higher than on 6-inch and we are working on improvement.

Fig.8 shows the comparison of surface roughness between 6-inch and 8-inch GaAs substrates measured by AFM. The surface roughness of the substrate is an important parameter because it is involved in the epi-surface roughness when epitaxial growth is performed. The surface roughness (Ra) of the 8-inch substrate is 0.26 nm, which is equivalent to the surface roughness of the 6-inch substrate of 0.25 nm.

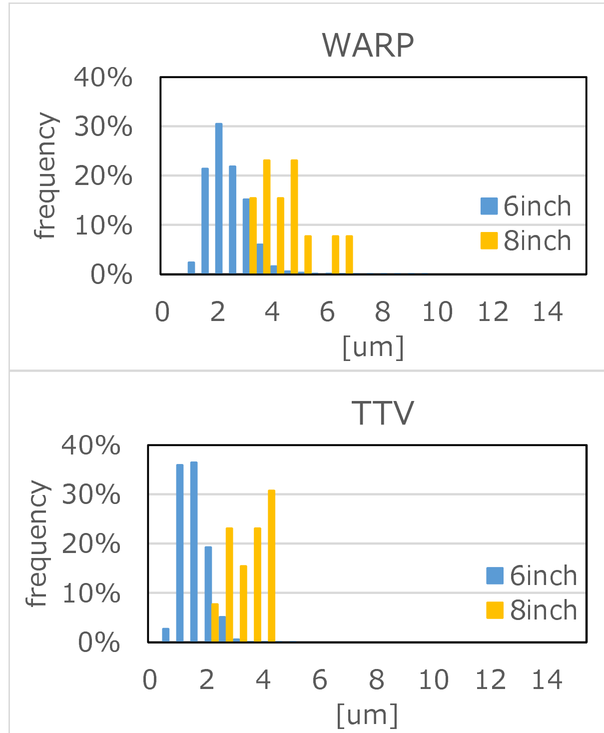

Fig. 7 Warp and TTV histogram for 6-inch and 8-inch GaAs substrates

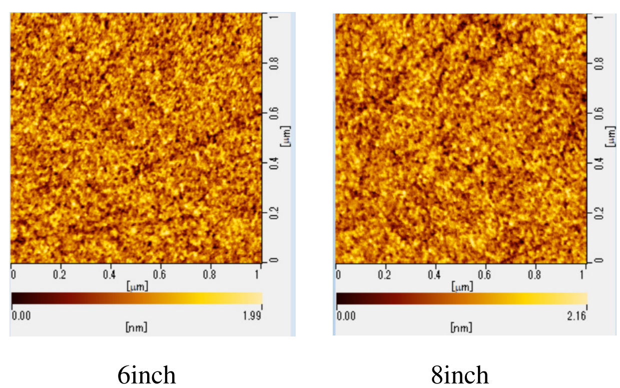

Fig. 8 Surface roughness of GaAs substrates

Conclusions

SEI has successfully developed Si-doped 8-inch GaAs substrates with very low dislocation density and high radial carrier concentration uniformity. In addition, the wafer properties are almost equivalent to 6" in terms of flatness and surface roughness. These substrates have comparable quality to commercially available 6-inch substrates used for LDs. Furthermore, SEI has demonstrated and confirmed reproducibility for all 8-inch LD substrate parameters. Therefore, we believe that our development of high quality 8-inch GaAs substrates suitable for Micro LEDs and LDs will contribute to the progress of this device market.

References

[1] M. Morishita, 2018, CS ManTech, Development of Si-doped 8-inch GaAs substrates