Properties of 6-inch Semi-insulating GaAs Substrates Manufactured by Vertical Boat Method

by Tomohiro Kawase, Hiroaki Yoshida, Takashi Sakurada, Yoshiaki Hagi, Kazuya Kaminaka, Hideki Miyajima, Shigeru Kawarabayashi, Nobuo Toyoda, Makoto Kiyama, Shinichi Sawada and Ryusuke Nakai
Sumitomo Electric Industries, Ltd.
1-1-1, Koya-kita, Itami, Hyogo, 664-0016 Japan
Phone: +81-727-72-4581, Fax: +81-727-72-2440, e-mail: kawase@asd.sei.co.jp

INTRODUCTION

Cost reduction is the top priority of device manufacturers to overcome keen competition and obtain larger market share. The 6-inch process is the key technology in achieving the cost reduction goal.

However, the larger temperature difference in a 6-inch wafer in comparison to a 4-inch wafer increases the possibility of slip-dislocation generation and wafer breakage during high temperature processes. This prevents device manufacturers from succeeding with the 6-inch process. Enlarging the diameter from 4 inches to 6 inches also causes the increase of dislocation density and residual strain as well as difficulty in obtaining good reproducibility of the crystals.

Growth of 6-inch GaAs single crystals by LEC[1], VCZ[2] and VGF[3] methods have been reported and the manufacturing efforts continue. The 6-inch wafer production by the LEC method was reported at the GaAs MANTECH Conference in 1998[4].

We have successfully developed the Vertical Boat (VB) method for mass production of GaAs substrates with low dislocation density and low residual strain. This is the first report on the properties of 6-inch semi-insulating GaAs substrates manufactured by the VB method.

CRYSTAL GROWTH

Furnace configuration and temperature profile of the VB method are schematically drawn in Fig.1 for comparison with the LEC method. GaAs pre-synthesized polycrystals are charged in a pBN crucible. The crucible is mounted on a crucible support, and heated in a vertical furnace. Polycrystals are melted, and the crucible is moved downward relative to the furnace, resulting in the growth of <100> seeded 6-inch GaAs single crystals. The crystals are doped with carbon to obtain semi-insulating properties.

6-inch crystals up to 20kg and over 100 wafers from one boule have been obtained with good reproducibility. There is no barrier to grow the crystal up to 40kg.

Table 1 shows the comparison of productivity for 6-inch GaAs crystals between VB and LEC methods. One of the most notable characteristics of VB method is the growth under a low temperature gradient, which makes it possible to obtain the crystal with low dislocation density and low residual strain. Large residual strain in LEC crystals sometimes causes cracks in the crystals, an issue which is eliminated utilizing the VB method.

The controllability and reproducibility of the temperature profile of the VB furnace are superior to those of the LEC furnace, because of the very simple configuration of the VB furnace. An additional benefit to VB crystals is that they have the identical shapes when solidified in the crucible. The two advantages of the VB method mentioned above enable us to achieve good reproducibility of 6-inch GaAs crystals. In addition, the price of a VB furnace is much lower than a LEC furnace, because pulling rod and diameter control systems are not necessary.

As mentioned above, the VB method is the most productive and promising technique for growth of 6-inch diameter GaAs single crystals.

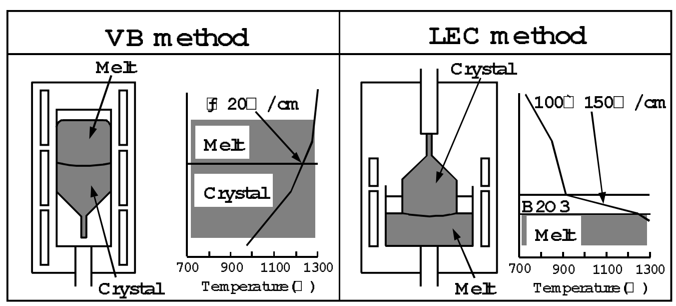

Fig.1. Furnace configuration and temperature profile of VB and LEC methods.

TABLE 1
COMPARISON OF THE PRODUCTIVITY FOR 6-INCH GAAS CRYSTALS

	VB	LEC	Remarks
Dislocation density	Good	Poor	Temperature gradient
Residual strain	Good	Poor	Temperature gradient
Single crystal	Good	Very Good	Reaction to crucible
Lot size	Good	Good	
Material loss	Good	Med.	Crystal shape
Reproducibility	Good	Med.	Configuration
Price of furnace	Low	High	Pulling rod Diameter control

DISLOCATION DENSITY AND RESIDUAL STRAIN

Dislocation density was investigated as etch pit density (EPD) revealed by molten KOH etching. Radial profiles of EPDs on 6-inch VB-GaAs substrates cut from seed side and tail side are plotted in Fig.2. The average EPDs of 6-inch VB substrates are about 4,000cm^{-2}, which is one order of magnitude lower than that of the 6-inch LEC substrate. The average EPDs of several boules are shown in Fig.3. The

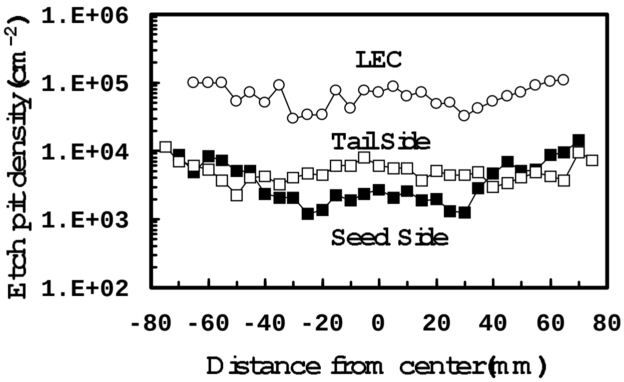

Fig.2. Radial profiles of EPDs on 6-inch GaAs substrates.
EPDs

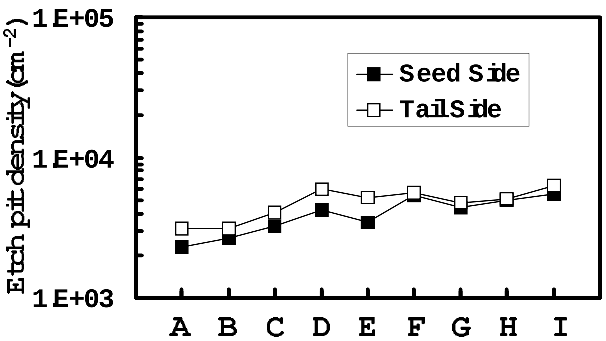

Fig.3. Average EPDs on 6-inch VB-GaAs substrates from several boules (A – I).
of all 6-inch boules are between 3,000 and 6,000cm^{-2}, which

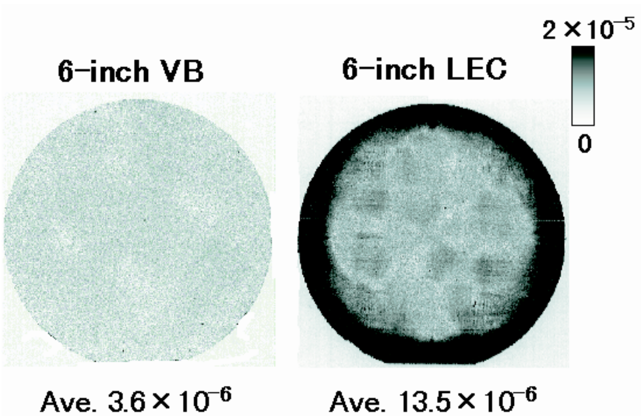

Fig.4. Two-dimensional maps of residual strain.
shows excellent reproducibility.
Residual strain in the GaAs substrate was measured by the scanning infrared polariscope developed by M. Yamada[5]. Two-dimensional maps of residual strain are shown in Fig.4. Dark color regions on the maps show the regions having high residual strain. The residual strain of the 6-inch VB substrate is less than half of that of the 6-inch LEC substrate.The average dislocation density and the residual strain along the growth axis are plotted in Fig.5. Low dislocation density and low residual strain are obtained in the whole ingot.

It is confirmed that VB substrates with low dislocation density and low residual strain have high resistance against breakage and slip generation.

Macroscopic properties

Control of resistivity is an important issue for producing semi-insulating GaAs substrates. Resistivity depends on the carbon and EL2 concentrations. The resistivity dependence on carbon concentration is shown in Fig.6. 6-inch VB substrates have the same dependence of 4-inch LEC

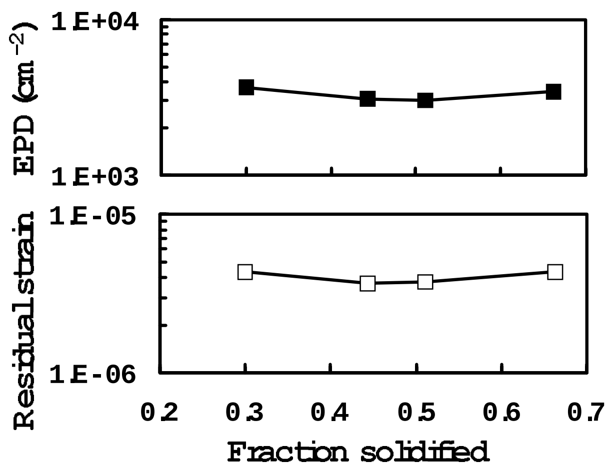

Fig.5. Average dislocation density and residual strain along the growth axis of a 6-inch VB-GaAs single crystal.
substrates. A newly

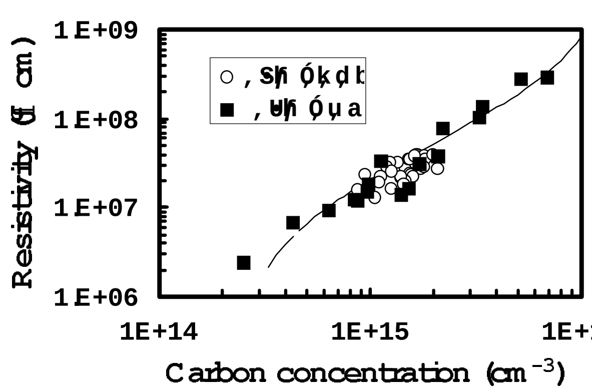

Fig.6. Resistivity dependence on carbon concentration.

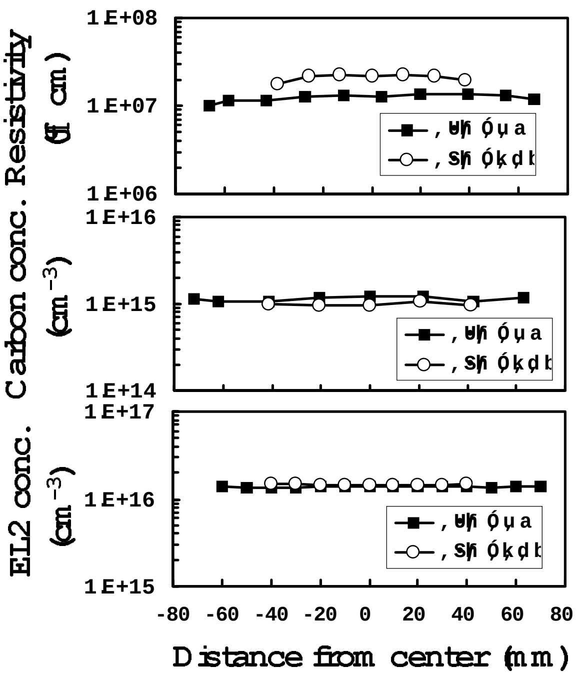

Fig.7. Profiles along the radial direction of resisitivity, carbon and EL2 concentrations.

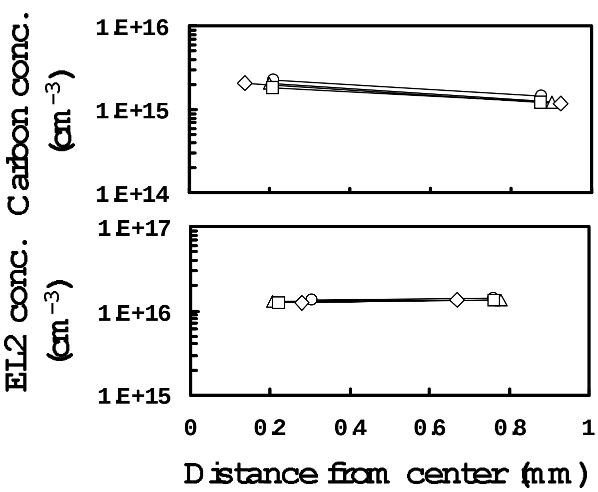

Fig.8. Carbon and EL2 concentrations along the growth axis of several 6-inch VB GaAs crystals.

developed carbon doping technique made it possible to achieve the wide range control of resistivity from 1E6 to 5E8• cm on 6-inch VB substrates.

Figure 7 shows the profiles along the radial direction of resisitivity, carbon and EL2 concentrations. Resistivitiy along the radial direction on a 6-inch VB substrate has a very uniform profile similar to that on a 4-inch LEC substrate. Such a uniform profile of resisitivity is attributed to the uniform profiles of carbon and EL2 concentrations along the radial direction.

The carbon and EL2 concentrations along the growth axis of several 6-inch VB GaAs crystals are plotted in Fig.8. The small variation between lots as shown in Fig 8 confirms the good reproducibility of resisitivity.

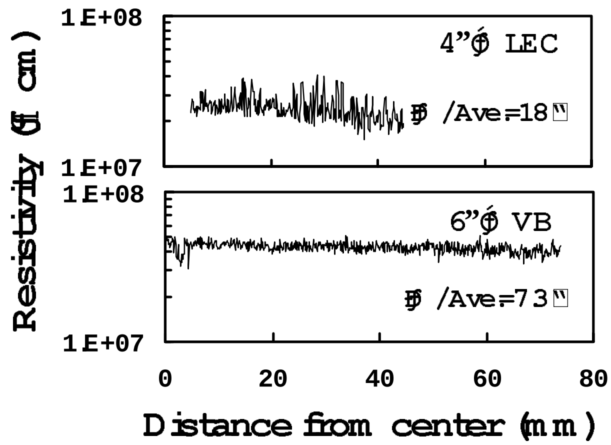

Fig.9. Resistivity profiles, measured at 100• m pitches from the center to the periphery.

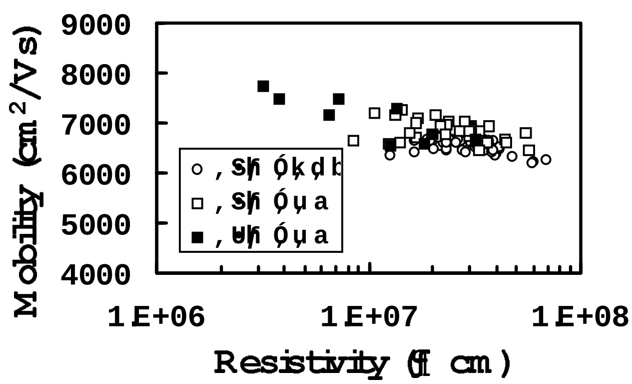

Fig.10. Electron mobility in 4-inch and 6-inch VB substrates and 4-inch LEC substrates

MICROSCOPIC PROPERTIES

Figure 9 shows the resistivity profiles, measured at 100• m pitches from the center to the periphery, on a 6-inch VB substrate and a 4-inch LEC substrate. The variation of microscopic resistivity on the 6-inch VB substrate is much smaller than that of the 4-inch LEC substrate. Surely, such excellent homogeneity of microscopic resisitivity on the 6-inch VB substrate is attributed to the excellent microscopic homogeneity of impurity and EL2. Kaminaka, et al.[6] suggested that microscopic homogeneity affects the electron mobility in GaAs substrates produced by the LEC method. The electron mobility in 4-inch and 6-inch VB substrates is slightly higher than that of 4-inch LEC substrates, as shown in Fig.10. This is due to VB's better microscopic homogeneity, which is proved by smaller variation of microscopic resistvity.

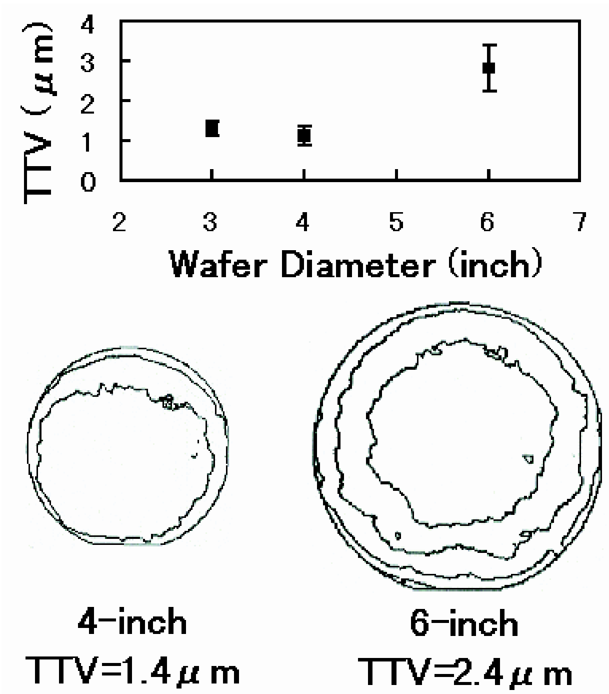

Fig.11. TTVs and two dimensional maps of 4-inch and 6-inch VB wafers.

WAFER PRODUCTION

Flatness defined as total thickness variation (TTV) is one of the most important factors which affect the yield of device manufacturing. Typically, when increasing the wafer diameter it is difficult to maintain an acceptable level of flatness. However, we have achieved an acceptable level of flatness, even in 6-inch wafers.

TTVs and two dimensional maps of the 4-inch and 6-inch VB wafers are shown in Fig,11. Although the TTV value of 6-inch wafers is slightly larger than the 4-inch, it is acceptable. We are confident that the TTV of 6-inch wafers will soon be equal to that of 4-inch wafers, through continuous improvements in the production process.

ION IMPLANTATION

The properties of the ion-implanted layer of the 6-inch VB substrates were evaluated. Silicon atoms were implanted into VB and LEC substrates at the energy of 90keV with a dosage of $3.0\times10^{12}cm^{-2}$. The relationship between the carbon concentration in the substrates and the sheet carrier concentration (Ns) of the ion-implanted layer are shown in Fig.12. Ns of the 6-inch VB substrate shows the same dependence on carbon concentration as 3-inch LEC and 4-inch VB substrates. This result suggests that the same condition of ion-implantation can be applied for both LEC and 6-inch VB substrates.

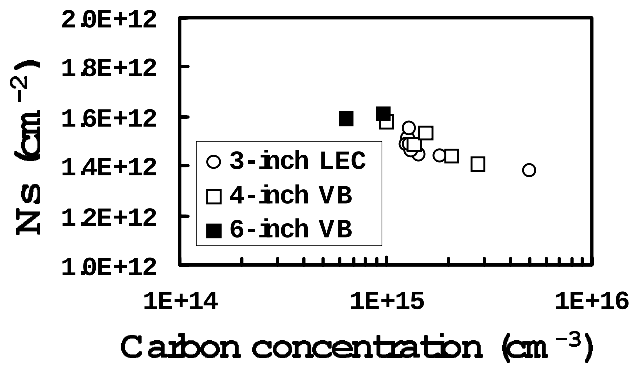

Fig.12. Relationship between the carbon concentration in the substrates and the sheet carrier concentration (Ns) of the ion-implanted layer.

SUMMARY

The mass production of 6-inch semi-insulating GaAs substrates with superior properties has been achieved by the VB method. The properties are as follows.

1. Low dislocation density and low residual strain in 6-inch VB substrates along the growth axis and their excellent reproducibility between lots.
2. Good uniformity of carbon and EL2 concentrations, and uniform resistivity along the radial direction.
3. Good reproducibility of carbon and EL2 concentrations between lots.
4. Excellent homogeneity of microscopic resisitivity and high electron mobility.

In addition, the flatness of the wafer is acceptable for device production. Properties of the ion-implanted layer of 6-inch VB substrates are consistent with those of LEC substrates. This suggests that 6-inch VB substrates can be used with the same conditions as that of LEC substrates for device fabrications.

REFERENCES

[1] M. Shibata, T. Suzuki, S. Kuma, J. Crystal Growth 128 (1993) 439.
[2] T. Kawase, S. Fujiwara, K. Hashio, M. Tatsumi, T. Shirakawa and K. Tada, Proc. of 19th Int. Symp. on GaAs and Related Compounds, Karuizawa, (1992) 13.
[3] • -• s Review No.8 Vol.6 (1995) 14.
[4] T. Flade, W. Fliegel, R. Hammer, M. Jurisch, A. Kiesel, A. Kleinwechter, A. Köhler, U. Kretzer and B. Weinert, Int. Conf. on GaAs MANTECH, Seattle, (1998) 123.
[5] M. Yamada, Rev. Sci. Instrum. 64 (1993) 1815.
[6] K. Kaminaka, H. Morishita, M. Kiyama, A. Kawasaki, M.

Yokogawa, K. Fujita and S. Akai, Proc. of 7 th Conf. on
Semi-insulating • -• Materials, Ixtapa, (1992) 307.