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Mass Production of Large-Size GaAs Wafers at FREIBERGER

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Abstract

The paper presents FREIBERGER's recent achievements in mass production of 150 mm wafers both by LEC and VGF growth.

A simple biaxial stress test has been used to evaluate breakage behaviour of LEC and VGF wafers as well as the influence of laser marking on breakage.

INTRODUCTION

Forced by the rapid increase of the demand for 150 mm SI GaAs wafers, FREIBERGER has established mass production of LEC-based 150 mm wafers. Furthermore, the growth of low-epd 150 mm crystals by VGF-technique has also been developed in the meantime and integrated into the regular production. Main emphasis has been put on technical and technological measures for production cost reduction in order to realize in future prizes per area for 150 mm wafers which are equivalent to 100 mm wafers.

PRODUCTION FACILITY

Capacity limits of a production facility which was put into operation only in 1997 and has been designed for more than 3 million sq.in. polished wafer area per year have been reached earlier than expected. So, a new fab has been constructed which will be ramped up in spring/sommer this year. This construction stage will allow to triple the total output and increase fivefold 150 mm wafer production. Figure 1 gives the planned development of 150 mm wafer output subdivided into LEC and VGF material in 2001.

A completely new 150 mm line has been installed. It comprises separate high pressure furnaces for *ex-situ* synthesis with a capacity up to 50 kg per furnace, new-generation LEC crystal pullers, patented VGF furnaces, furnaces for boule heat treatment, ID and wire saws, single and double side polishing machines and equipment for surface conditioning, final cleaning and packaging.

The facilities are widely automated and interconnnected by transportation and handling systems taking into account heavier boules/wafers and cost reduction. Crystals and wafers are subject to an intensive inspection integrated into the technological line.

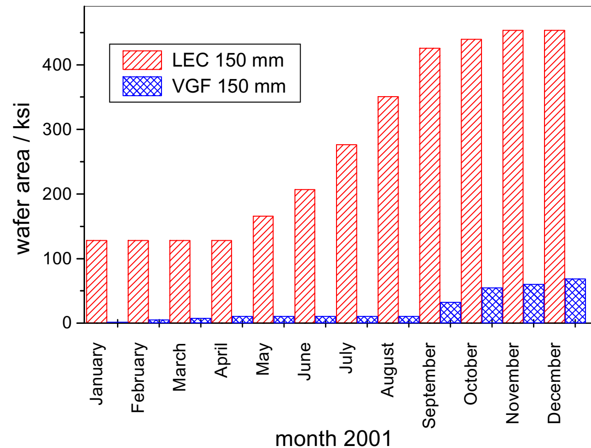

Fig. 1 Ramp up of 150 mm wafer production in 2001

CRYSTAL GROWTH

To realize FREIBERGER´s temperature gradient controlled LEC method [1, 2] the pullers are equipped with multi-heater systems. At present, 11 inch crucibles are used allowing a 28 kg process which may yield up to 160 wafers/boule. The extension to 16 inch crucibles and larger charges is under development. For reproducibility and reliability reasons a fully automated process and diameter control system is applied. Control of C- and O-potential in the Ar or Ar/N_2 growth atmosphere is carried on by a gas flow system at a total ambient pressure of 0.2 - 2 MPa. As demonstrated in fig. 2 the carbon content can be deliberately controlled in the range from $1x10^{13}$ to $2x10^{16}$ cm^{-3} in full correspondence with 3 or 4 inch crystals. The LEC pullers are suitable for the application of the VCz process as a low epd version of GaAs Czochralski growth [3]. LEC crystals are heat treated by a 2 step process to reduce residual stress and improve mesoscopic homogeneity.

Low epd SI GaAs crystals are grown by the liquid encapsulated VGF process in home made furnaces based on the design described in [4]. Crucibles from 3" to 150 mm diameter up to 360 mm length can be used. The axial temperature gradient at the solid/liquid interface is about 10 K/cm. Growth is performed under an

ambient Ar pressure of 0.2 - 1 MPa. The growth rate amounts to approx. 3 mm/h and is significantly lower as compared to LEC growth resulting in a lower productivity of the VGF process. 14 kg charges are used leading to 50 - 100 wafers/boule at present.

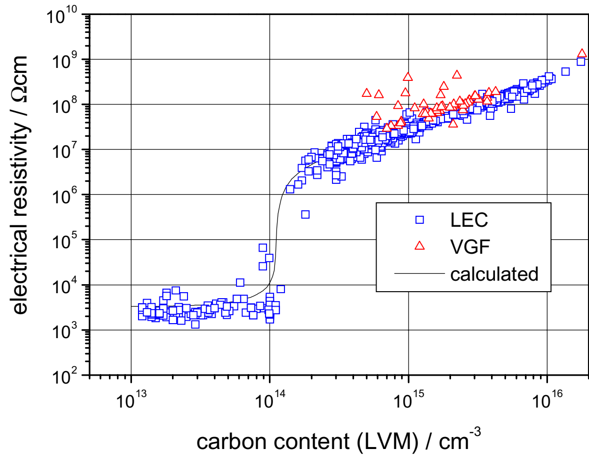

Fig.2 Electrical resistivity of 150 mm crystals in dependence on carbon concentration

The development of the heater/insulation system and other furnace details as well as the crystal growth technology has been supported by in-house computer modelling using advanced computer codes [5] which include turbulent gas convection.

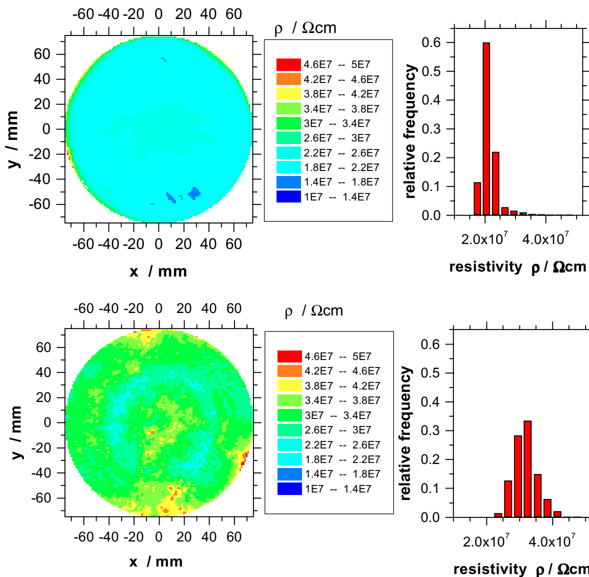

Fig. 3a./b Typical TDCM mappings of 150 mm LEC (above) and VGF wafers (below)

To define EL2 concentration and to improve mesoscopic homogeneity a combined *in-* and *ex-situ* annealing procedure is performed for VGF crystals. Average epd is typically 10,000 cm^{-2}. Dislocations are arranged in fragmented cellular structure with approx. 2 mm cell size. As demonstrated in fig.2 $\rho \propto [C]$ holds for VGF-crystals, too. The slightly higher resistivities are caused by a smaller average EL2-concentration and an acceptor-like intrinsic defect, probably a Ga-vacancy which is known to be an acceptor. Content of residual impurities is equivalent for both materials.

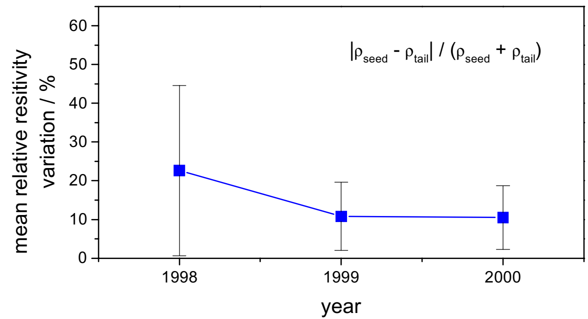

Fig. 4 Improvement of axial homogeneity of 150 mm LEC crystals

TDCM mappings of seed and tail end wafers of each crystal are used to control radial homogeneity of the crystals. Examples for LEC and VGF material are given in fig. 3a/b. The standard deviation of radial electrical resisitivity is typical < 20 % and 30 % for LEC and VGF crystals, respectively. Axial homogeneity is characterized by < 20 % for LEC crystals. It has been continuously improved as shown in fig. 4 where $|\rho_{seed} - \rho_{tail}| / (\rho_{seed} + \rho_{tail})$ is given for the 150 mm crystals grown in the last three years. Axial homogeneity of LEC crystals is significantly better as compared to < 80 % typical for 150 mm VGF crystals at the present stage of development.

WAFERING

The wafer line is capable to produce 150 mm or 100 mm , respectively. By extensive R&D work state-of-the-art equipment tools have been modified to achieve high throughput and yield. Main emphasis was given to highly automated steps. Key issues are high speed ID-sawing procedure, fundamental investigations in wire sawing technology, elimination of lapping, optimization of double side polishing, mounting prior to final polishing and cleaning. It has to be noted that FREIBERGER has the capability to use ID sawing and wire sawing technique for 150 mm alternatively.

The flatness data of more than 100,000 100 mm and 150 mm wafers (fig. 5) indicate the successful development of the 150 mm double side polishing technology in the years 1996 - 2000. In contrary, single side polished wafers remain on a significant worse flatness level indicating limitations for their usage for critical applications.

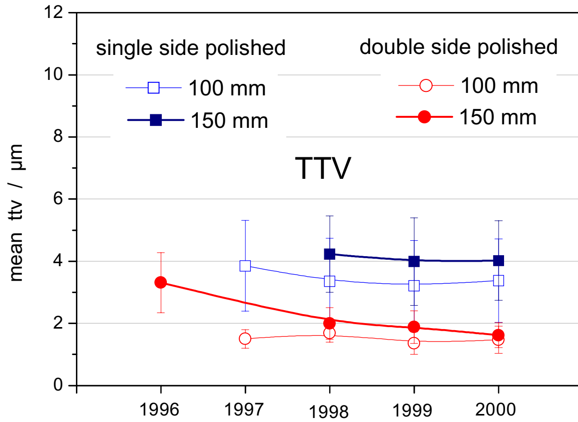

Fig. 5 Statistical data of global flatness parameter ttv for 100 mm and 150 mm single and double side polished wafers

Results are shown in fig. 6 for the LTV_{max} distribution for a data basis of more than 28,800 wafers.

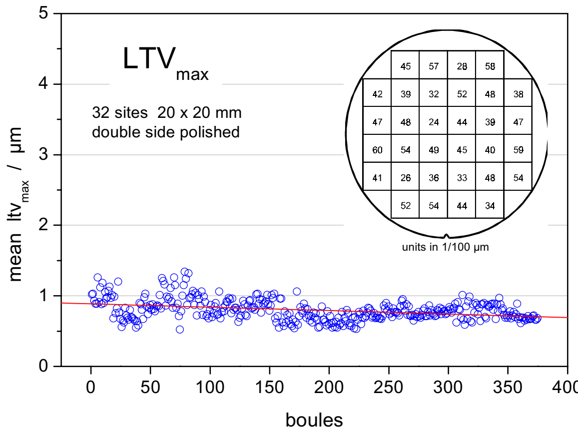

Fig. 6 Mean maximum local thickness variation LTV_{max} for 375 boules with several specifications

There is no difference in the wafering behaviour of VGF crystals in comparison to LEC crystals.

Special Issue: Fracture Strength

To evaluate surface quality and residual damage of GaAs wafers a fracture strength test has been introduced and applied for regular spot checks. The "ring-on-ring biaxial strength test" according to DIN 52 292 [6] has been modified to the effect that a small diameter ball (1/8", steel or teflon) is used to centrally load the wafer similar to [7]. Herewith, alignment problems which might arise from a double-ring arrangement were avoided. Wafer support is realised by a PTFE ring having an inner diameter of 142 mm and a flat supporting area. The tests were carried out in a conventional testing machine at T = 20°C and a cross head speed of 1 mm/min. As maximum bending at fracture is much larger than wafer thickness linear approaches are inappropriate to describe the load – displacement behaviour. Therefore, FEM analyses were performed to calculate maximum fracture strength. Statistical evaluation of the data has been done by means of Weibull distribution analysis [8].

Weibull plots of maximum load at breakage for two sets of 150 mm LEC and VGF wafers taken from different boules are represented in fig. 7. The front side of the wafers has been tested for tension.

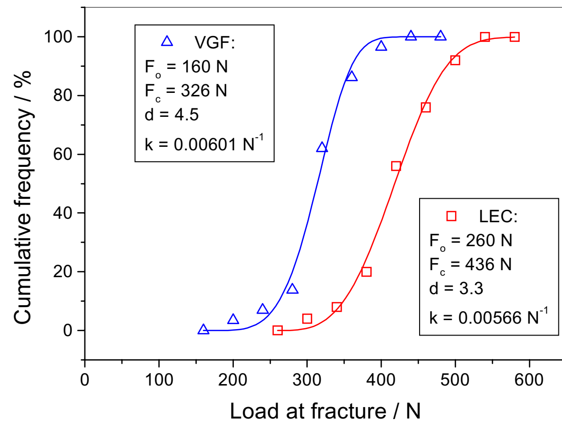

Fig. 7 Weibull plot of load at fracture for LEC and VGF wafers

The inserts indicate the threshold load F_o, the 63.2 % probability Weibull fracture load F_c and the Weibull exponent d. From the rather high Weibull exponent follows that the tested volume is representative for the whole wafer. Comparing the two wafer sets slightly higher loads at fracture have been observed for LEC wafers which are under further investigation. It follows that dislocation density and residual stress level which are surely higher for LEC wafers do not influence the breakage behaviour of wafers.

Laser marks are often discussed as an origin for crack nuclei. To study their influence on breakage behaviour, a modified fracture test has been performed in dependence on the laser marking conditions and the corresponding geometrical features of the marks.

Standard double side polished 150 m LEC wafers were lasermarked in the middle of the front side, of the back side, with single dot, double dot and triple dot density, each. Additionally, sets of front and back side softlasermarked wafers were tested, too. Details are given in table 1. Softmarked wafers have a maximum depth of 1 µm whereas on standard wafers (hardmarked) the depth reaches approx. 20 to 40 µm. The back side of all wafer sets has been tested for tension.

TABLE 1
EXPERIMENTAL SETUP FOR DIFFERENT LASERMARKING SETS

Sample no.	Type	Density	Location	Wafer polish
R	-	-	-	DSP
1	H	1DD	Front	DSP
2	H	1DD	Back	DSP
3	H	2DD	Front	DSP
4	H	2DD	Back	DSP
5	H	3DD	Front	DSP
6	H	3DD	Back	DSP
7	S	2DD	Front	DSP
8	S	2DD	Back	DSP
9	H	1DD	Back	SSP
10	S	2DD	Back	SSP

H – Hardmarking
S – Softmarking
1DD – single dot density
2DD – double dot density
3DD – triple dot density
Front – front side
Back – back side
R – Reference (no marking)
DSP – double side polished
SSP – single side polished

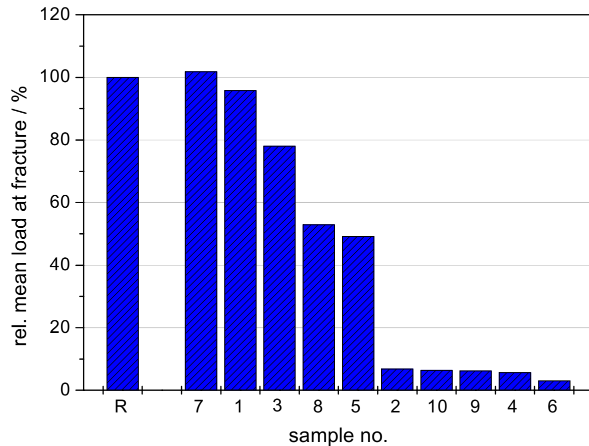

Fig 8 Dependence of load at fracture from lasermarking depth (soft vs. hardmarking), lasermarking features (single vs. double vs. triple dot density), lasermarking location (front vs. back side) and polishing condition of back side (polished vs. cut/etched) in a fracture strength test

Results given in fig. 8 (mean values for a sample size of 10 per set) show four different groups in comparison to unmarked reference wafers:

- Softmarking on front side and hardmarking with single dot density on front side do not incfluence the breakage behaviour
- Hardmarking with double dot density on front side reduces load at fracture by approx. 25 %
- Hardmarking with triple dot density on front side and softmarking on back side reduce load at fracture by approx. 50 %
- Hardmarking with single, double or triple dot density on back side, soft- or hardmarking on back side of single side polished wafers reduce load at fracture by more than 90 %

According to SEMI-Standard M12 lasermarking on 150 mm wafers has to be applied on front side with single dot density. The results of the above investigation show that different marking features and/or marking on back side dramatically reduce the load at fracture thus possibly resulting in yield losses. Softlasermarking on front side is an excellent alternative to hardmarking. With respect to breakage (and for flatness reasons) single side polished 150 mm wafers are worse compared to double side polished wafers.

SUMMARY

The production of 150 mm SI GaAs wafers at FREIBERGER now is entering an industrial scale on a high quality level with a strong increase in volume, currently. LEC and VGF growth techniques are available whereas VCz is under development depending on market demand. Wafers show excellent flatness data for double side polished conditions. Special attention has been paid on breakage behaviour of LEC and VGF wafers. No influence of dislocation density and residual stress was observed on load at fracture. Furthermore, investigations on the influence of different lasermarking types and locations on breakage reveal strong tendency for reduction by back side lasermarking.

ACKNOWLEDGEMENTS

Financial support by the Bundesministerium für Bildung und Forschung (01BM404A/6) is greatfully acknowledged.

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