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Two-Dimensional High-Resolution EL2 Topography in Thin Semi-Insulating LEC-Grown GaAs Wafers

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Two-dimensional near-infrared absorption maps of commercial 2" GaAs wafers with a spatial resolution up to 100x100 μm^2 are compared with X-ray topographs. In undoped wafers of high dislocation density (10^4-10^5 cm^{-2}) taken from the seed end of the crystal the EL2 distribution is strictly correlated with grown-in dislocation networks even on a microscopic scale. In-doped wafers have a uniform EL2 concentration in the dislocation-free central part. At peripheral slip bands gettering effects of EL2 are observed.

The importance of GaAs substrate quality for integrated circuit (IC) applications has been pointed out by several groups of workers. Variations of threshold voltages of field-effect-transistors (FET) seem to be correlated with the local dislocation environment.[1-4] However, there is increasing evidence that spatial concentration fluctuations of the deep donor EL2 responsible for the semi-insulating properties of undoped GaAs crystals have a strong influence upon electrical device parameters.[5,6]

From the point of view of a device producer a definite correlation between device parameters and crystal defects is needed. Therefore, as a

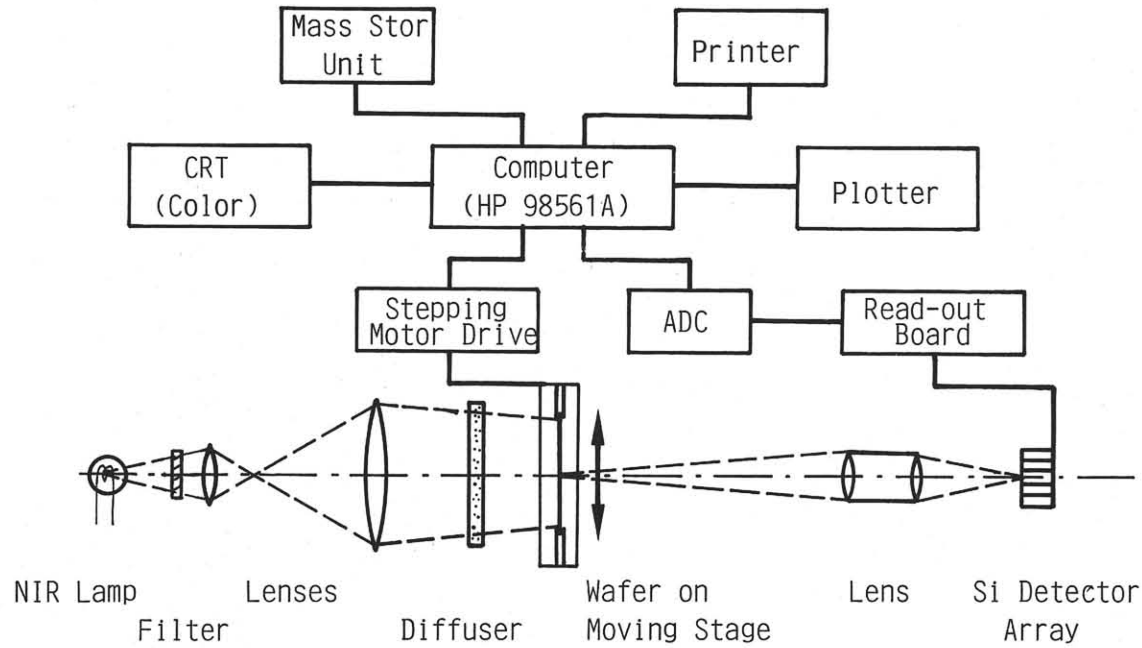

Fig. 1 Schematic drawing of the NIR absorption measurement system.

first step a quantitative comparison between the EL2 defect density and the dislocation networks in commercial wafers - both measured with high spatial resolution - is highly desirable. In this paper high-resolution and extremely sensitive quantitative measurements of the EL2 distribution in semi-insulating LEC-grown (100) GaAs wafers (300-500 μm thickness) are reported and compared with X-ray topography.

For this purpose an experimental set-up was developed which is shown schematically in Fig. 1. Based on a Si-diode array as detector element[7] absorption values at 1000 nm are determined using a scanning technique. A spatial resolution of 100x 100 μm^2 is possible for a 2" wafer. Using the calibration of Martin[8] the neutral EL2 concentration is calculated. Special efforts are made to obtain quantitative absorption data. For this purpose the diode dark current is subtracted and erraneous intensities due to stray light and multiple reflexions from the wafer surface and optical lenses are carefully suppressed. Spatial inhomogeneities of the illumination are eliminated by taking the ratio of the transmitted intensity and the reference intensity measured for each diode.

Thus by moderate statistical averaging it is possible to detect EL2 variations of $5x10^{14}$ cm^{-3} in wafers of 400 μm thickness. The absolute accuracy of the absorption values has been checked by comparison with a grating spectrometer. A systematic error of less than 10 % was found.

The transmission X-ray topographs were taken with a rotating anode (Rigaku, 25 kW) using $MoK\alpha_1$-radiation and the (220) reflexion. The bow of the wafer vertical to the scanning direction was automatically corrected.

Results from two (100) LEC-grown GaAs wafers obtained from different suppliers are presented: Wafer #1 comes from a conventional undoped crystal with a dislocation density of 10^4-10^5 cm^{-2}. Wafer #2 is In-doped (In concentration: $1.2x10^{20}$ cm^{-3}) and has a low dislocation density of less than 10^2 cm^{-2} in the central area. Both samples were cut from the seed end of the crystals.

Wafer #1 exhibits fluctuations of the EL2 concentration up to 60 % with an average value of $1.9x10^{16}$ cm^{-3}. This value should be considered as

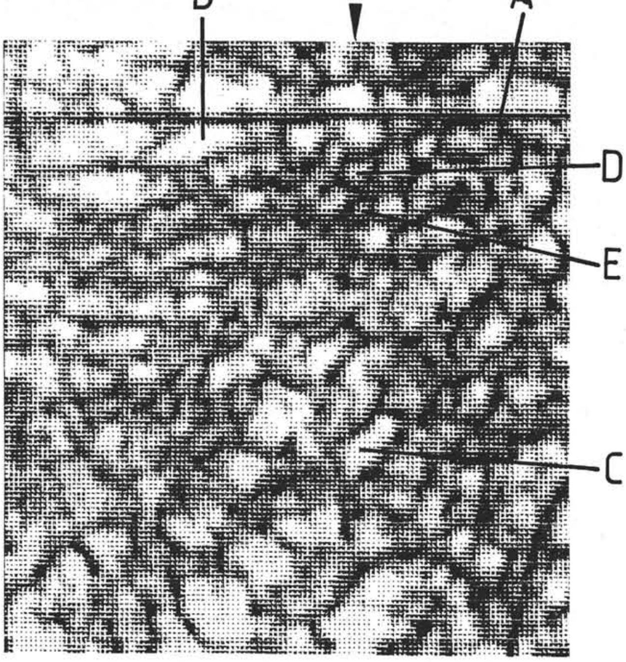

Fig. 2 EL2 topography of wafer #1 (central area, 12x12 mm^2). Spatial resolution is 100x100 μm^2. In this 10-step grey-scale plot white pixels correspond to EL2 concentrations of $<1.46x10^{16}$ cm^{-3}, black pixels of $>2.39x10^{16}$ cm^{-3}, and each graduation denotes a rise of $0.12x10^{16}$ cm^{-3}.

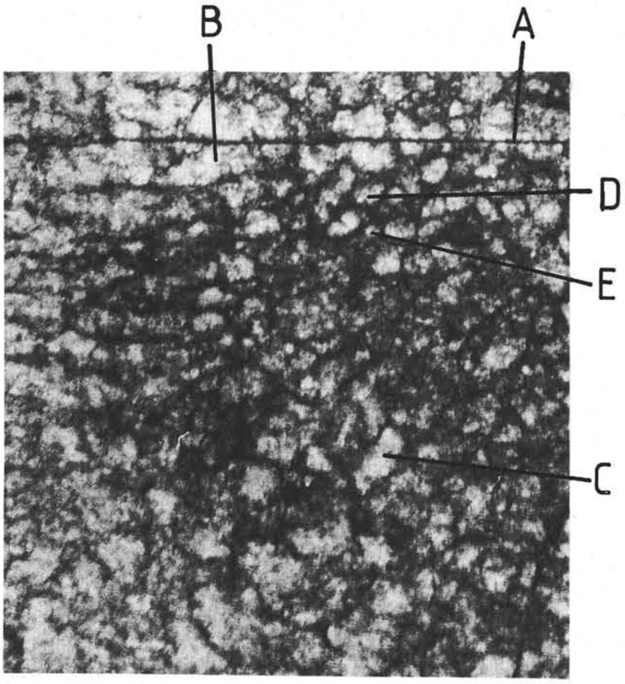

Fig. 3 X-ray topography of wafer #1 (same area as in Fig. 2).

an upper limit as any residual absorption in the same spectral region due to other defects would lead to concentrations being too high. The typical cellular and linear structures[9)] are found identically both for the EL2 distribution and the dislocation density.

Even locally a qualitative one-to-one correlation exists (Figs. 2,3): Linear structures (A), larger (B,C) and smaller cells (D,E) appear in both Figs. Due to the small wafer thickness and the high density of data points the spatial resolution in Fig. 2 is much better than the typical width of a cell. It is obvious that high EL2 defect densities (black areas) are confined to a band of less than 150 µm thickness around the highly dislocated cell boundary.

In general, the EL2 concentration decreases with an increasing distance from the next boundary reaching an approximately constant value in very large cells. This can be illustrated performing a line scan across cells of different size (Fig. 4). The cells C, D, and E have a diameter of about 1, 0.75, and 0.5 mm, respectively. The

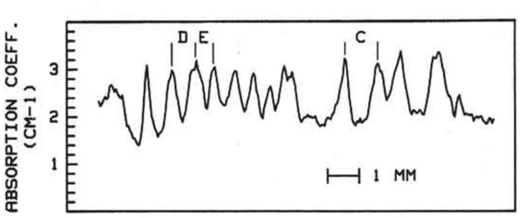

Fig. 4 Line scan from top to bottom of Fig. 2 beginning at the point marked by an array. Spatial resolution is 50 µm. The positions of the cells C, D, and E which are crossed in the center are indicated.

absorption minimum in the center is lower in larger cells whereas the absorption maximum at the corresponding walls remains essentially constant. It is, therefore, believed that in this crystal the generation of EL2 defects is related with the formation of dislocation networks.

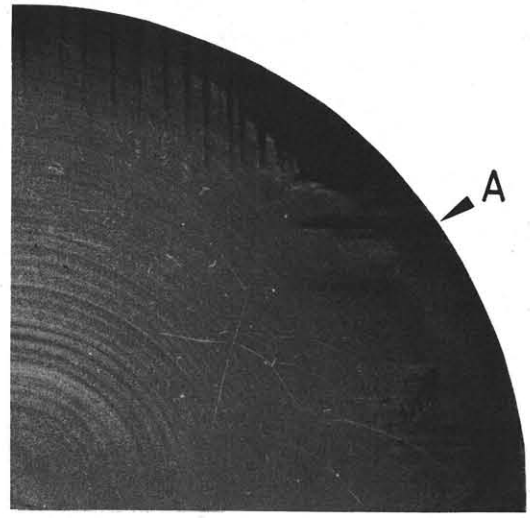

Fig. 5 X-ray topography of the In-doped wafer #2. (one quarter).

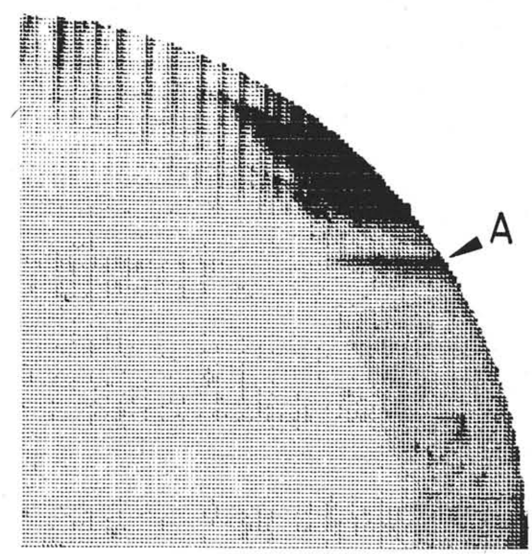

Fig. 6 EL2 topography of wafer #2 (same area as in Fig. 5). White pixels: EL2 concentration $<0.78\times10^{16}$ cm^{-3}, black pixels: $>1.48\times10^{16}$ cm^{-3}, graduation: 0.08×10^{16} cm^{-3}.

Wafer #2 doped with indium gives no contrast in X-ray topography (Fig. 5) in the central area of about 40 mm in diameter aside from growth striations. Strong slip line patterns, however, are observed in a peripheral ring of about 5 mm width. The central area of the EL2 map (Fig. 6) displays essentially a constant absorption corresponding to a concentration of EL2 of 0.95×10^{16} cm^{-3}. It is interesting to note that the striations are not accompanied by visible periodic fluctuations of EL2. Therefore, if there is any influence on the EL2 distribution it must be below the detection limit of about 5 %.

At the edge of the wafer the same features due to slip bands are found as in X-ray topography. In addition, there exists a ring near the edge of the wafer with an increased EL2 concentration (≃10-20 %). Obviously, an interaction between the ring and the slip bands can be established: Strong slip bands are leading to a reduction of the EL2 density in the neighbourhood. This can be seen most distinctly at the slip line marked by "A" in Figs. 5,6. At this position the absorption within the above-mentioned ring is lowered to a value comparable to the inner part of the wafer.

A similar observation was made previously[10] in an undoped crystal: Sheets along ⟨110⟩ were surrounded by regions of reduced EL2 absorption. This was tentatively attributed to gettering of EL2 to dislocation clusters. Our results substantiate that this mechanism is also active near peripheral slip bands in indium doped crystals.

In conclusion, we observed in undoped GaAs wafers coming from the seed end of a crystal with a high dislocation density a one-to-one correlation between the EL2 distribution and dislocation networks. This is in agreement with the model that EL2 is created during dislocation climb. In Indium doped crystals with a low dislocation density in the central area the EL2 concentration of $\simeq 1 \times 10^{16}$ cm^{-3} is probably determined by a high-temperature thermodynamic equilibrium value. A gettering effect at strong peripheral slip bands was detected.

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