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# Characterization of Semi-Insulating GaAs Substrates for GaAs ICs

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Semi-insulating (100) GaAs is used as a substrate for direct ion implantation in the manufacture of GaAs MESFET ICs. Although the ion implantation has an advantage of controllability in fabricating a thin active channel layer of MESFET in the substrate, activation efficiency, Hall mobility and FET performances, as well as controllability of threshold voltage for E- and D-FETs are strongly dependent on crystal quality and homogeneity of the substrate.

Recent progressive activity in GaAs ICs is attributed to the availability of a great variety of semi-insulating GaAs single crystals by either Liquid Encapsulation Czochralski (LEC) or horizontal Bridgman (HB) techniques. Particularly, round shaped and large sized ( 2 and 3 inches), intentionally and unintentionally Cr-doped, semi-insulating (100) wafers are successfully obtained by LEC technique[1,2]. On the other hand, 2 and 3 inch (100) round wafers doped with Cr have been available by HB technique. This variety of GaAs substrates is very promising for the manufacture of GaAs ICs. From this point of view, this paper reviews characteristicfeatures of undoped and Cr-doped, semi-insulating GaAs (100) wafers grown by both LEC and HB techniques.

Several kinds of undoped and Cr-doped (100) wafers are characterized before and after annealing with plasma-enhanced CVD cap followed by Si ion implantation. Hall measurements are carried out after annealing, and activation efficiency of implanted dose is considered from the viewpoint of Cr concentration and growth techniques. Homogeneity of wafers is investigated by measuring electrical performances of MESFETs on the whole area of the wafers.

For substrates suitable for direct ion implantation, uniform resistivity over the entire wafer is required. Leakage current $I_L$ corresponding to sheet resistance varies sinusoidally over an LEC-grown undoped substrate, and it is inversely correlated with dislocation density distribution[3], as shown in Fig.1. This result suggests that dislocation-free crystal may be indispensable to investigate a semi-insulating mechanism of undoped crystal.

Crystal defects, such as dislocations, should be considered, especially in LEC-grown, undoped and relatively low Cr-doped substrates for evaluating FET performances, because dislocation density in LEC-grown

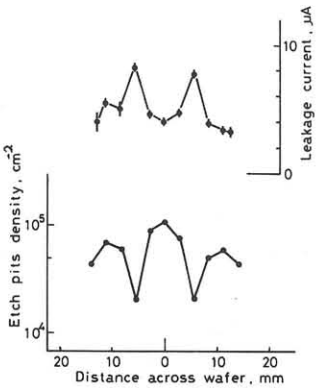


Figure 1
Correlation between leakage current and etch pit density along <100> direction on an LEC-undoped (100) wafer.

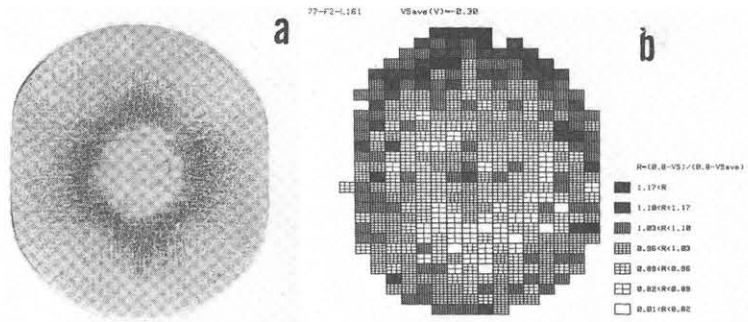


Figure 2
Correlation between (a) etch pit density distribution and (b) threshold voltage $V_{th}$ distribution (see Text).

crystal is higher and more inhomogeneous than that in HB-grown crystal. Dislocation density across a wafer varies sinusoidally from $\sim 10^5$ to $\sim 10^4$ $cm^{-2}$ (see Fig.1). This inhomogeneous distribution apparently affects threshold voltage of FET. Figure 2 shows an example, where (a) is a macroscopic etched pattern showing etch pit density variation, and (b) shows threshold voltage distribution for FETs fabricated over a substrate adjacent to the substrate (a). $V_{th}$ for FETs fabricated on higher dislocation density area (bright area on (a)) is lower than that for FETs on lower dislocation density area (dark area on (a)). Resultant standard deviation $\sigma V_{th}$ was estimated to be about 100 mV for $V_{th}$= -0.3 V averaged on 372 FETs. On the other hand, dislocation density and its distribution in HB-grown substrate are less than in LEC-grown substrate. However, since the semi-insulating mechanism of HB-crystal is mainly Cr-dominant, $V_{th}$ variation is dependent on Cr concentration distribution over the wafer, and that in LEC-grown Cr-doped crystal is close to a solid-liquid interface shape during crystal pulling[5].

With regard to activation efficiency and Hall mobility in Cr-doped substrates, LEC-grown substrates are much superior to HB-grown substrates. In the case of HB-technique, it is necessary to dope with Cr more than a few tenths wt.ppm in order to maintain high resistivity. Cr concentration along the <111> growth axis varies according to the well-know normal freeze equation, and then Cr concentration over the (100) wafer cut by $54.7^{\circ}$ from the <111> grown boule is not uniform, but varies gradually from one edge to the other. This inhomogeneity becomes serious as the wafer size increases. In application to ICs, Cr doping concentration should be reduced to avoid this concentration inhomogeneity. It can be said that the final goal for the HB-crystal is attaining an undoped, semi-insulating crystals.

The effect of dislocations on FET performances is not clear yet, but it is emphasized that LEC-growth of dislocation-free crystals and/or elimination of dislocations[6] are quite important. The future of GaAs ICs is now widely acceptable for high-speed integrated circuits, but further improvement is needed in crystal quality, as well as in device processing.

References

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