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# Dynamic characteristics of dislocations in indium-doped gallium arsenide crystal

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Characteristics in the motion of dislocations generated from scratches in GaAs doped with In at a concentration of $2\times10^{20}$ atoms/cm$^3$ are investigated and are compared with those in undoped GaAs. $\alpha$ dislocations in In-doped GaAs are found to be immovable under stress lower than 10 MPa in the temperature range 350–750 °C. Such immovability under low stress is not found for $\beta$ dislocations in In-doped GaAs and for both $\alpha$ and $\beta$ dislocations in undoped GaAs.

GaAs is attracting keen interest as the material for high-speed and optical devices. Owing to its softness in mechanical strength, bulk crystals of GaAs grown by the boat technique or the liquid encapsulated Czochralski (LEC) technique are usually dislocated at densities of about $10^4$–$10^5$ cm$^{-2}$. Dislocations act as effective gettering centers for impurities and microdefects around them and cause spatial inhomogeneities in electrical and optical properties of a crystal. Thus, GaAs crystals free from dislocations or with dislocations of extremely low densities are required in device production. It has been reported that doping with certain impurities is effective in reducing the density of grown-in dislocations.[1] Jacob *et al.*[2] have shown that the density of grown-in dislocations in a GaAs crystal is greatly reduced by the doping of isovalent impurity In at a concentration as high as an order of $10^{20}$ atoms/cm$^3$. The Nippon Telegram and Telephone group has succeeded in growing dislocation-free crystals of GaAs 2 in. in diameter by the LEC technique with the doping of In of the above concentration and protecting the surfaces of the grown crystals from evaporation of As at high temperature.[3] The measurement of the dislocation mobility in In-doped GaAs crystals has been done by Matsui *et al.*[4] and no detectable difference in the dislocation velocities has been found between undoped GaAs and In-doped GaAs. This seems to suggest that In atoms dissolved in a GaAs crystal do not offer appreciable resistance to the dislocation motion. On the contrary, we have found a remarkable difference in the dynamic characteristics of dislocations in undoped GaAs and In-doped GaAs. This letter reports such characteristics.

Specimens were prepared from two kinds of crystals: one is an undoped crystal grown by the boat technique with impurity Si at a concentration of order of $10^{13}$ atoms/cm$^3$ and the other a crystal doped with In at a concentration of $2\times10^{20}$ atoms/cm$^3$ grown by the LEC technique. Specimens were in a rectangular shape approximately $2\times3\times15$ mm$^3$ in size and with the long axis along $[1\bar{1}0]$ and the top and side surfaces parallel to (111) and $(11\bar{2})$, respectively. The surface of the specimen was finished by chemical polishing with a reagent of $3H_2SO_4$:$1H_2O_2$:$1H_2O$ at 70–80 °C.

A scratch was drawn on the (111) or $(\bar{1}\bar{1}\bar{1})$ surface of the specimen along the $[1\bar{1}0]$ direction at room temperature with a diamond stylus. Such a scratch acted as a preferential generation center for dislocations upon stressing the specimen. The specimen was stressed at elevated temperatures by means of three-point bending with the bending axis parallel to the $[11\bar{2}]$ direction in a vacuum better than $10^{-3}$ Pa. Usually, the bending direction was such that the As $(\bar{1}\bar{1}\bar{1})$ surface was in tension. The displacement of dislocations generated from the scratch during the stressing was determined by the observation of dislocation etch pits on the As $(\bar{1}\bar{1}\bar{1})$ surface developed by the RC-1 etchant.[5] The type of dislocations under observation was determined by following the technique adopted by Mihara and Ninomiya.[6]

The distance traveled by the leading dislocation in an array of dislocations generated from a scratch during a given stress pulse was measured as the measure of the mobility of dislocations. Such arrays of dislocations developed by stressing are shown in Fig. 1. In the undoped crystal both $\alpha$ and $\beta$ dislocations are observed to move at 450 °C under any stress down to about 1 MPa. The travel distance of $\alpha$ dislocations under any stress is found to be much larger than that of $\beta$ dislocations, showing that $\alpha$ dislocations move more easily than $\beta$ dislocations. This result is consistent with the data published so far by other authors.[7-10] The travel distances of both $\alpha$ and $\beta$ dislocations in the In-doped crystal under a shear stress of 20 MPa at 450 °C during a given stressing duration are smaller than those in the undoped crystal by a factor of about 2. Also in this case, the mobility of $\alpha$ dislocations is found to be higher than that of $\beta$ dislocations. An interesting fact is found when the applied stress is low. Namely, $\alpha$ dislocations generated from the scratch show no displacement under stresses lower than 10 MPa at 450 °C

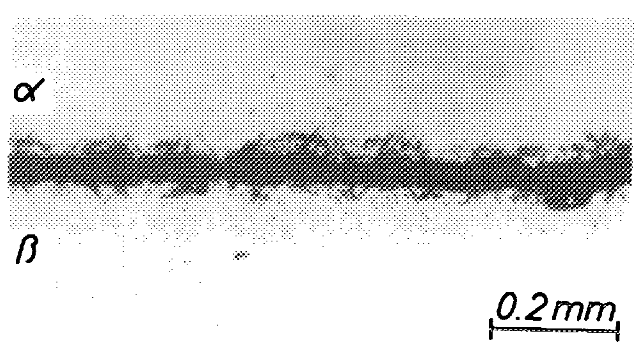
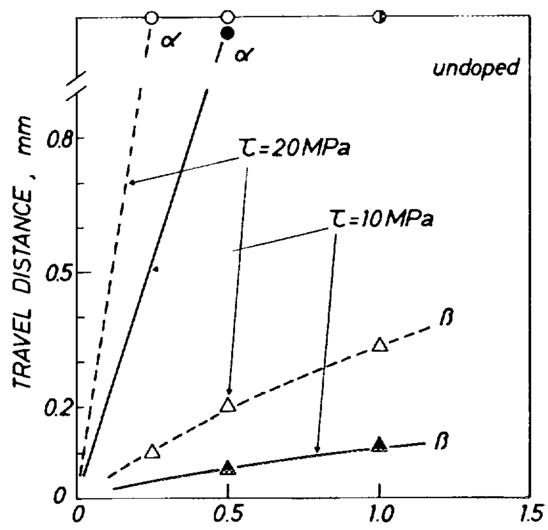
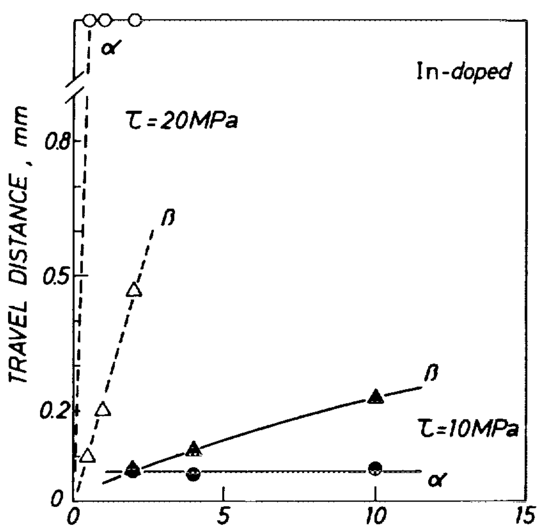



FIG. 1. Etch pits of dislocation arrays emitted from a scratch in an In-doped GaAs crystal.



(a)



(b)

FIG. 2. Travel distances of $\alpha$ and $\beta$ dislocations at 450 °C in the central part of the specimen plotted against the stressing duration under shear stresses $\tau$ of 20 and 10 MPa. (a) Undoped GaAs; (b) In-doped GaAs.

while $\beta$ dislocations are observed to move under the same condition.

Figures 2(a) and 2(b) show the distances traveled by leading dislocations of $\alpha$ and $\beta$ types at the central part of the specimen plotted against the stressing duration for the undoped and the In-doped crystals, respectively. The magnitudes of the stress shown in the figure are those of the shear stress at the center of the specimen. The data points located on the top of the figure mean that the dislocations generated from the scratch have left the specimen. The slope of the curve may be regarded as the apparent velocity of the leading dislocation.

Figure 3 shows how the distance traveled by the leading dislocation of $\alpha$ type varies along the length of the specimen in the undoped and the In-doped crystals when the maximum stress at the specimen center is 20 MPa at 450 °C. The stressing duration is 15 s for the undoped crystal and 30 s for the In-doped one. In the bottom of the figure the variation of the shear stress along the length of the specimen is shown.

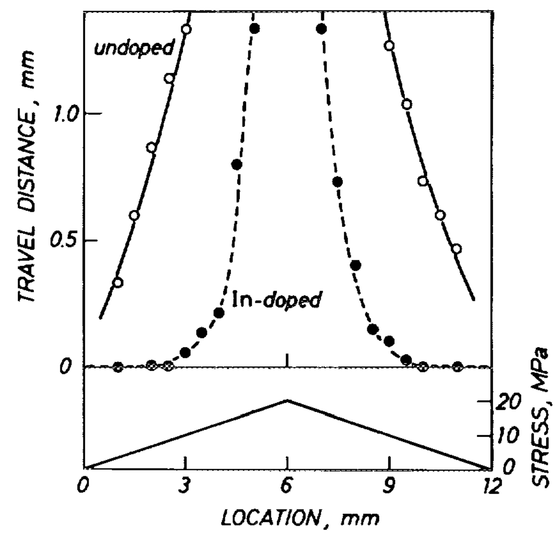



FIG. 3. Variations in the travel distances of leading $\alpha$ dislocations at 450 °C along the specimen length in the undoped and In-doped GaAs. The lower part of the figure shows the variation of the applied shear stress.

The stress decreases linearly with the distance from the specimen center. The variation of the travel distance along the length is quite different between the undoped crystal and the In-doped crystal. The motion of $\alpha$ dislocations in the In-doped crystal is known to be impeded drastically under low stresses. They are practically immobile under stresses lower than 10 MPa. Such immobilization under low stresses is not observed for $\beta$ dislocations. The above characteristics in the dislocation motion have been observed commonly over the temperature range 350–750 °C that is adopted in the present investigation. The details of the results of measurements on dislocation mobility in the In-doped GaAs crystal in comparison with those in the undoped crystal or in crystals doped with other kinds of impurities will be published elsewhere soon.

Dislocation immobility under a low applied stress in the presence of impurities has been found in silicon crystals doped with oxygen or nitrogen by means of *in situ* x-ray topography.[11] The effect has successfully been interpreted in terms of locking of dislocations by impurities due to the development of impurity clusters at the dislocation core. In the case of In-doped GaAs, only $\alpha$ dislocations suffer strong locking due to impurity In. Thus, it is natural to think that $\alpha$ dislocations in a GaAs crystal have strong interaction with In atoms by some means that is absent for $\beta$ dislocations. Possibly, the core structure is important in developing clusters of In atoms there.

The density of dislocations in a GaAs crystal is thought to increase at the time of crystal growth mostly by means of multiplication of dislocations that are generated at some irregularities in the grown crystal under thermal stress. The multiplication process needs the motion of all the types of dislocations included in a loop as easily visualized in the Frank–Read mechanism. If a dislocation of any orientation is immovable, the whole process does not work and leads to no increase in the dislocation density. We propose that the success in growing so-called dislocation-free crystals of In-doped GaAs by the LEC technique is due to the pinning of $\alpha$ dislocations due to In atoms under a reduced thermal stress that prevents the dislocation multiplication.

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