# Anisotropy of the dislocation uhf conductivity of *n*-Ge

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It is shown that the dislocation uhf conductivity, previously discovered,[1-3] exhibits an anisotropy, the magnitude of which agrees with the anisotropy of the dislocation structure.

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In Refs. 1–3 it was found that Ge and Si crystals with dislocations exhibit an appreciable uhf conductivity at such low temperatures when there are no free charge carriers in the bands. Therefore a hypothesis was proposed that this conductivity is due to the motion of charge carriers along the nuclei of the dislocations (dislocation conductivity). Such a mechanism should lead to a conductivity anisotropy. The results of experiments, designed to test this assumption, are presented below. The specimens for the deformation were cut in the form of parallelepipeds with dimensions of $3\times4\times20$ mm$^3$ along the $[1\bar{1}0]$, [001] and [110] directions, respectively. Dislocations were introduced by bending the specimen.[2] A scratch, made in the middle of the wide face along the [110] direction, served as the source of the dislocations. The dislocation structure, produced by this manner of deformation, has been described in detail in Ref. 4. If, in our experiments, the source of the dislocations was only the scratch, then a specimen could be prepared in which the dislocations lay only along the $[1\bar{1}0]$ direc-

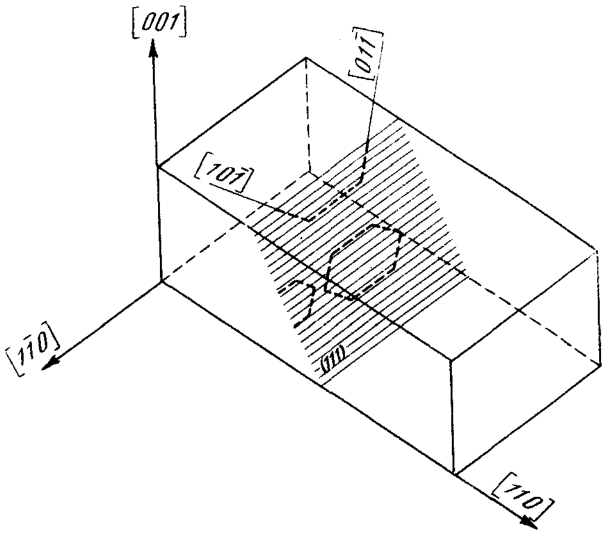

FIG. 1. Assumed dislocation structure of the sample. Only the one slip plane (111) is depicted.

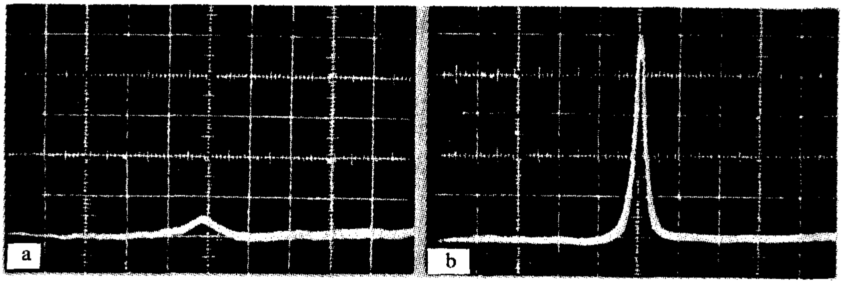

FIG. 2. a—Resonance curve for electric field directed along $[1\bar{1}0]$; b—the same, but with the field directed along [110]. The uhf oscillator power was the same in both cases.

tion. In this case etch pits should be observed only on the $(1\bar{1}0)$ face (Fig. 1). However, we also observed etch pits on the (110) face. Therefore we assume that sources of dislocation loops were operating within the volume of the specimen (Fig. 1). The lateral portions of the loops, lying along the $[10\bar{1}]$ and $[0\bar{1}1]$ directions, perturbed the ideal anisotropy of the dislocation structure. The densities of the dislocations, lying along different directions, can be determined by computing the density of etch pits on the following faces: $(1\bar{1}0)$ and (110)—$N_D^{(1\bar{1}0)}$ and $N_D^{(110)}$. If the uhf conductivity occurs along the dislocations, then it can be shown that the ratio of the conductivities along the $[1\bar{1}0]$ and [110] directions is equal to

$$\frac{\sigma^{[1\bar{1}0]}}{\sigma^{[110]}} = 2\,\frac{N_D^{(1\bar{1}0)}}{N_D^{(110)}}$$

TABLE I.

| Sample No. | Donor density, cm$^{-3}$ | $N_D(1\bar{1}0)$, cm$^{-2}$ | $N_D^{(110)}$, cm$^{-2}$ | Conductivity anisotropy (calculation) | Conductivity anisotropy (experiment) |
|---|---|---|---|---|---|
| 1 | $10^{13}$ | $3 \cdot 10^6$ | $1 \cdot 10^6$ | 6 | $10 \pm 3$ |
| 2 | $2 \cdot 10^{13}$ | $3{,}5 \cdot 10^5$ | $7 \cdot 10^4$ | 10 | $11 \pm 3$ |
| 3 | $2 \cdot 10^{13}$ | $4 \cdot 10^6$ | $7 \cdot 10^5$ | 11 | $11 \pm 3$ |
| 4 | $10^{14}$ | $5 \cdot 10^6$ | $1{,}5 \cdot 10^6$ | 6.6 | $7{,}8 \pm 0.5$ |
| 5 | $10^{14}$ | $6 \cdot 10^6$ | $1{,}3 \cdot 10^6$ | 9 | $7 \pm 0.5$ |

The factor of 2 in this expression results from the spatial orientation of the lateral portions of the loops. Disks with a diameter of ~3 mm and a thickness of ~0.7 mm were cut from the deformed specimens for the measurements. The samples were placed in a cylindrical "through-going" cavity in which the $TE_{111}$ oscillation was excited at a frequency of 9500 MHz.

The cavity consisted of two parts—upper and lower—with these parts joined along the lines of the current flowing along the cavity walls. The specimen was placed at the center of the cavity on a thin Teflon disk, fastened to the lower part of the cavity. Slots for coupling the cavity to the uhf oscillator and to the detector, the signal from which was fed to an oscilloscope, were located in the upper part. The oscillator operated in the frequency-modulation regime and a resonance curve was observed on the oscilloscope screen. The lower part of the cavity with the sample could be turned with respect to the upper part; this, of course, did not alter the direction of the electric field in the cavity, but changed the angle between the field directon and the direction of the dislocation lines. The measurements were made at $T = 4.2$ K. It was found that the $Q$-factor of the cavity, and this means also the conductivity of the sample, depends on the relative orientation of the dislocations and the electric field. By rotating the sample we found the orientations with the highest and lowest $Q$-factors of the cavity. It was always found that the minimum $Q$-factor (maximum conductivity) is observed when the electric field is directed along $[1\bar{1}0]$. The maximum $Q$ was observed when the field was perpendicular to the $[1\bar{1}0]$ direction. Typical resonance curves, observed for these two orientations of the sample, are shown in Figs. 2a and 2b, respectively. By measuring the width of the resonance curves, we find $\sigma^{[1\bar{1}0]}$ and $\sigma^{[110]}$. The results are given in Table I. Table I contains data on the anisotropy of the dislocation structure, the anisotropy of the uhf conductivity at 4.2 K and the concentration of impurity donors in the original samples. It is seen that the data on the expected conductivity anisotropy, calculated on the basis of information on the anisotropy of the dislocation structure, agree well with experiment. We also measured the ratio $\sigma^{[1\bar{1}0]}/\sigma^{[110]}$ for samples 4 and 5 at a temperature of 1.4 K. It was found that with a lowering of the temperature the values of the conductivities $\sigma^{[1\bar{1}0]}$ and $\sigma^{[110]}$ each decreased by almost a factor of three, whereas their ratio remained the same as before. This fact also indicates that the anisotropy of the uhf conductivity is determined only by the anisotropy of the dislocation structure.

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