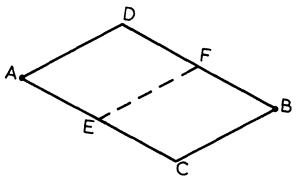

FIG. 1. Equilibrium shapes of dislocation at zero stress.

in the absence of any specific bend energy (which appears to be true in β brass). Under a small alternating stress the dislocation must flip from the equilibrium shape ADB when the stress is $+0$ to ACB when the stress is -0. It can do this at constant energy by passing through a sequence of Z-shaped configurations such as $AEFB$. In so doing the dislocation sweeps out the area of the parallelogram and so produces a jump in the macroscopic strain as the stress passes through 0. This strain jump is given by

$$\Delta\epsilon \sim \tfrac{1}{2}\rho b l \tan\tfrac{1}{2}\theta,$$

where ρ is the density of such dislocations, b is the Burgers vector, l is the distance between pinning points, and θ is the characteristic change in direction of the dislocation at a bend. For β brass which had been deformed 2% in tension, the total dislocation density was $\sim 10^{11}$ cm^{-2} of which about 10% were zig-zag dislocations.[2] If $\rho \sim 10^{10}$ cm^{-2}, $\theta = 59°$ (β brass), and, say, $l \sim 1000$ Å are taken as typical, then the macroscopic strain jump would be $\Delta\epsilon \sim 10^{-3}$.

The ideal stress-strain curve under a small alternating stress would have the unusual form of Fig. 2(a). In practice it would also be expected to show hysteresis [Fig. 2(b)], since even under quasistatic conditions some stress

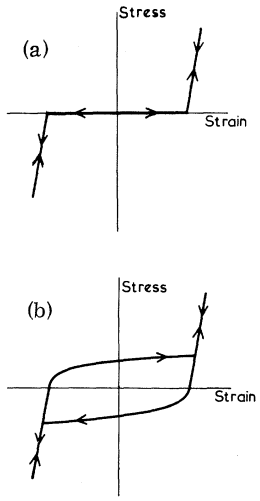

FIG. 2. Stress-strain behavior of a solid containing unstable dislocations: (a) static and (b) dynamic.

would probably be needed to flip the dislocations. The hysteresis would increase under dynamic conditions because of the finite transit time of the dislocation between the two zero-stress configurations.

Although β brass is so far the only material in which this type of dislocation has been observed, from known elastic constants it can be predicted that they are possible in iron, potassium, sodium, lithium, NiAl, AuCd, and LiMg alloys and the face-centered-cubic InTh alloy.[2] Any of these materials could show this abnormal mechanical damping for a reasonable density of unstable dislocations.

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DIRECT MEASUREMENT OF HOT ELECTRON-PHONON INTERACTIONS IN GaP*

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We report the determination of the mean free path for energy loss to phonons of energetic electrons in gallium phosphide. As will be described below, electrons in equilibrium in the conduction band drift into a narrow high-field region near the GaP surface. Their energy distribution is measured after they have passed through this region and have been emitted into vacuum.

The experiments were made with highly doped (0.01 Ω cm) p-type GaP grown from the vapor phase.[1] The experiments were carried out on the [110] face of crystals cleaved in ultrahigh vacuum.

In the following discussion refer to Fig. 1. When the surface of GaP is exposed to cesium, a dipole layer is formed in the region of the surface. Following the results in germanium and silicon,[2] we assume for the present that the Fermi level at the surface is pinned at the bottom of the conduction band. From the energy distribution of emitted electrons in the GaP and a photoemissive determination of the work function of the collector, we have determined that the work function of the cesiated GaP surface under consideration is 1.2 eV. Since the band gap is 2.2 eV, the bottom of the conduction band in the bulk material should lie 1.0 eV above the vacuum level. This result is consistent with the energy distribution of emitted electrons excited into the conduction band by light with energy close to the threshold of optical absorption, as will be described below.

The width of the region over which the bands are bent is controlled by the level of the doping. In our samples this region is calculated to be 130 Å wide. In deriving this result, it has been assumed that over most of the region of band bending the potential is parabolic, that the dielectric constant is 10, and that the hole mobility is 50 cm^2/V sec. From velocity-distribution measurements in high-resistivity GaP, Fischer[3] indicates that the Fermi level at the surface of cesium-covered GaP is located 0.85 eV below the bottom of the conduction band. In this case, the width of the bent-band region is 0.8 of the width cited above, and the scattering lengths which are reported here should be reduced correspondingly.

Electrons are excited into the conduction band by light incident from the vacuum interface with wavelengths close to the threshold of optical absorption. Since the absorption constant in this spectral range is less than 10^5 cm^{-1}, the electrons are generated much deeper in the material than the 130-Å bent-band region. Figure 2 shows the quantum efficiency of this material over the region of interest. From an analysis of the quantum efficiency in the threshold region, it is determined that the escape depth is 2000-2500 Å. Thus, most of the photoexcited electrons, which thermalize in a distance short compared with 2000 Å, reach

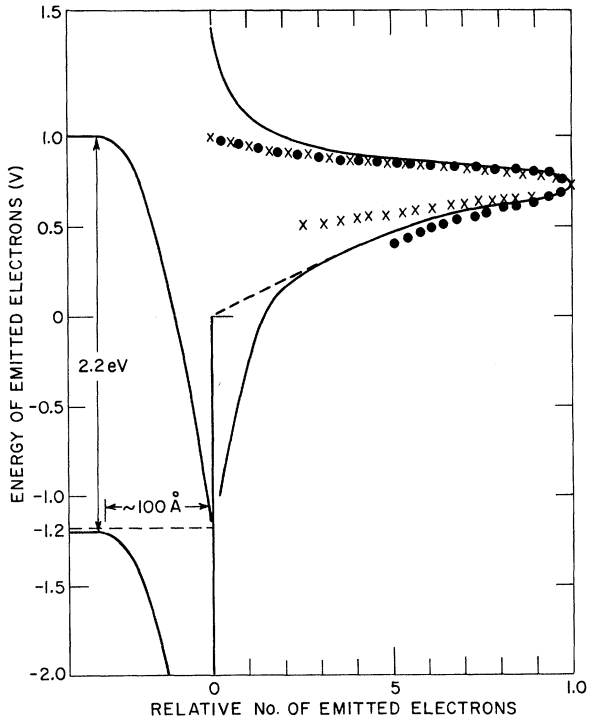

FIG. 1. The energy distribution of emitted electrons superimposed on a band diagram showing the band bending at the surface of cesiated p-type GaP. The dots represent the solution of the transport equation with $l = 25$ Å. The crosses show the solution for the ballistic model with $l = 22$ Å.

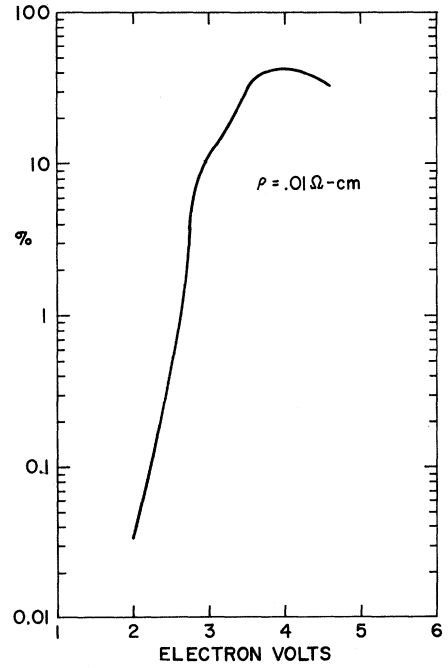

FIG. 2. The quantum efficiency in percent as a function of incident-photon energy. The high yield where the absorption constant is low indicates an escape depth of 2000-2500 Å.

the region of band bending with a distribution which is kT or 0.025 eV wide. After crossing the bent-band region, the electrons with energy greater than the electron affinity can be emitted into vacuum. The energy distribution of the emitted electrons provides information on the phonon-interaction parameters.

Figure 1 shows the energy distribution of electrons excited by 2.8-eV photons. The high-energy tail in the distribution is caused by electrons which are emitted before they can thermalize, approximately 15% of the total yield. For incident photon energies of 2.6 eV or less, there is no detectable emission above the theoretical curve shown in the figure. The fraction of the emission in the long low-energy tail diminishes considerably when higher incident-photon energies are used. The effect of the field on the energy distribution has been calculated for two limiting cases. First, assuming the field to be uniform, the solution of the transport equation has been obtained by retaining only the first two terms in the spherical harmonic expansion of the density function. This solution has been given by Bartelink, Moll, and Meyer[4] for the case where $E_0 = e^2F^2l^2/3E_p \ll 2E$. In this equation F is the electric field, l is the mean free path for phonon collisions, E_p is the energy loss per collision, and E is the electron energy in eV. We have obtained a solution for $E_0 \gg E$. In the intermediate region of interest here, the two solutions give essentially the same curves for the energy distributions of the emitted electrons.

Second, the electron-phonon interaction was considered ballistically with the electrons scattered in the direction of the field. This assumption is reasonable considering the large magnitude of the electric field (2×10^6 V/cm on the average). An expression for the electron energy distribution was derived in this case by use of a recursion relation given by Kane.[5]

The expressions obtained are as follows:

$$J(\Lambda) = \text{const}\left(\frac{\varphi^2}{\Lambda^2}-\frac{\varphi}{\Lambda}\right)\exp\frac{-\varphi^2}{4E_0\Lambda},$$

$E_0 \gg 2E$ transport solution; (1)

$$J(\Lambda) = \text{const}\left(\frac{\varphi^2}{\Lambda^2}-1\right)\exp\left(\frac{-\varphi^2}{4E_0\Lambda}-\frac{\varphi}{2E_0}+\frac{3\Lambda}{4E_0}\right),$$

$E_0 \gg E$ transport solution; (2)

and

$$J(\Lambda) = \text{const}\left(\frac{x}{l}\right)^{\Lambda/E_p}\frac{1}{(\Lambda/E_p)!}e^{-x/l},$$

ballistic solution. (3)

In these expressions, φ equals Fx, and x is the width of the bent-band region. Λ is the energy lost to phonons; $\Lambda = \varphi - E$.

Figure 1 shows the experimental energy distribution with the distribution curves derived from the transport equation for $l = 25$ Å and from the ballistic solution for $l = 22$ Å. In each of these solutions, it has been assumed that the energy loss per collision is 0.050 eV.[6]

The mean free path for energetic electron-phonon interactions has been derived from electron-multiplication experiments by Logan and Chynoweth.[7,8] These values lie between 32 and 140 Å. The present experiment is a more direct measurement of this mean free path, since it depends only on the magnitudes of the ionized-impurity density and the energy loss per collision, which are reasonably well known.

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