Watson and Freeman,[12] we obtain the s part $\alpha_j^2 = 0.08$, the p part $\beta_j^2 = 0.92$ with 80% of the total wave function accounted for on the four nearest-neighbor P atoms. In the perfect lattice the bonding is tetrahedral sp^3, i.e., 0.25 s-like and 0.75 p-like. Thus, while the data indicate *no distortion* from T_d symmetry at the Ga site, there is evidence for *lattice relaxation* of each neighbor to more sp^2 (planar) bonding with the three remaing Ga neighbors with a predominantly p orbital left in the broken bond.

Electrical properties of radiation-induced defects in GaP have been studied by dc transport[13] and deep-level transient spectroscopy.[14] Infrared absorption[15] and luminescence[16] have also been studied. The vacancy may be a nonradiative center which degrades the performance of light-emitting diodes. Correlations between EPR and these other techniques are planned to shed light on these issues.

In conclusion, the Ga vacancy in electron-irradiated GaP has been identified through EPR. At 77 and 4.2 K, it exhibits some lattice relaxation but retains the full T_d symmetry of the lattice site. The EPR-active charge state is doubly negative.

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Acceleration of Electron-Hole Drops in Germanium by a Radiation Field: Evidence for Phonon Wind

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By heating the droplet cloud in Ge with infrared radiation, we increase the low-frequency phonon emission rate of the droplets. By measuring the resulting velocity increase, we give convincing evidence that this "phonon wind," powered by Auger decay, is the cause of droplet motion, as originally proposed by Keldysh.

The subject of the interaction of electron-hole drops (EHD) with acoustic phonons in Ge was initiated by Keldysh[1] and expanded theoretically[2-5] and experimentally[6-9] by many authors. It is now well established that this interaction with low-frequency phonons ($|q| \leq 2k_F$, where k_F is the Fermi wave vector of the liquid) is the main determinant of droplet motion. For example, the short droplet momentum relaxation time τ (10^{-8}–10^{-9} sec at 2 K), determined by thermal phonons, implies that only a flux of nonthermal phonons ("phonon wind") has the strength required to move the EHD in the observed fashion.[10] Up to now, the phonon wind was considered to have a number of different origins:

(1) A copious amount of high-frequency phonons are liberated during the thermalization of the hot photogenerated e-h pairs. We have given a rather direct experimental demonstration of the irrelevance of these particular phonons by showing that EHD velocities are independent of excitation wavelength.[11] We have argued[11,12] that the time scales involved in downconversion of these phonons into phonon wind ($|q| \leq 2k_F$) are such that high-frequency phonons escape the droplet cloud without affecting EHD velocities.

(2) The same argument applies to the zone-edge phonons which are emitted from the droplets during the phonon-assisted recombination of pairs.

(3) The third mechanism was originally proposed by Keldysh[2,5] and is powered by Auger decay. By virtue of the fast carrier-carrier interaction, a fraction of the band-gap energy (βE_g, where β is an efficiency coefficient less than 1) is transferred to the drop as a whole and results in Auger heating. This energy is finally released by the EHD in the form of low-frequency phonons capable of moving the droplets. In this paper, we quantitatively demonstrate this effect for the first time, by further heating the droplets with infrared radiation, and measuring the EHD velocity increase.

The sample used in this experiment was of high-purity Ge ($|N_A - N_B| \leq 3\times10^{10}$ cm^{-3}) immersed in superfluid He maintained at 2 K. The surface excitation consisted of 50 mW of 1.06-μm radiation uniformly distributed over a 1-mm-diam spot on the Syton-polished face of the sample. The output from a He-Ne laser operating at 3.39 μm was scattered by the droplets and frequency analyzed. The Doppler-shift spectra thus obtained, one of which is shown at the top of Fig. 1, are direct replicas of the velocity distribution in the probed region of the sample. Experimental details can be found in Ref. 10.

The droplets were heated with the output from an ABC-YAlG[13] laser, operating at 2.1 μm. This radiation was chopped at about 500 Hz, and its effect on the velocity distribution was monitored using a lockin technique. A typical recorder trace is shown in the bottom of Fig. 1, where it is seen that the scattering intensity is decreased

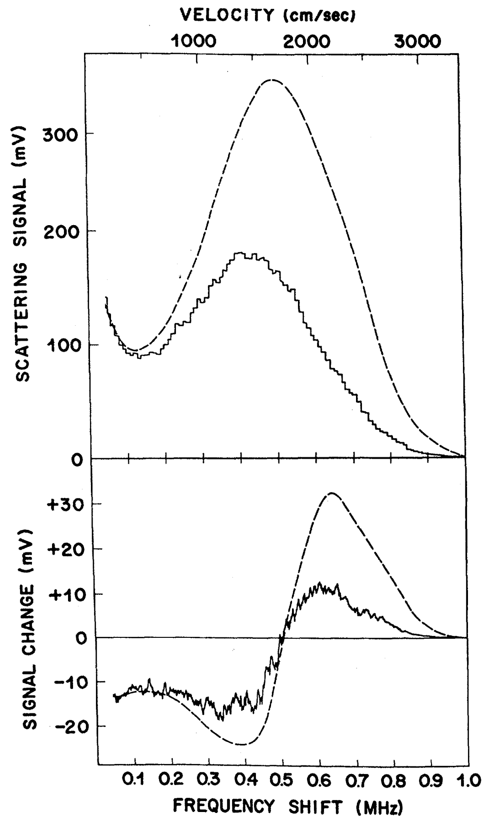

FIG. 1. EHD velocity distribution (top) and its change under the influence of the 2.1-μm radiation. The relevant parameters (inside the sample) were as follows: depth 300 μm, heating beam power density 220 W/cm^2, scattering angle 0.025 rad. The dotted line represents the raw data (noisy lines) corrected for the finite frequency response of the detector/amplifier.

on the low-velocity side of the peak, and increased on the high-velocity side, while the integrated intensity has remained essentially unchanged. The net effect is that the distribution has been shifted towards higher velocities. Figure 2 shows that the increase in mean velocity, obtained from sets of spectra similar to those shown in Fig. 1, is proportional to the incident power density, which could be varied over more than an order of magnitude.

Note that the time scales involved in our experiment are long compared to the momentum relaxation time τ; we thus observe steady-state velocity responses Δv to external forces f as follows:

$$\Delta v = f\tau / V n_c m, \qquad (1)$$

where V is the droplet volume, n_c the condensate density, and m some appropriate electron mass.

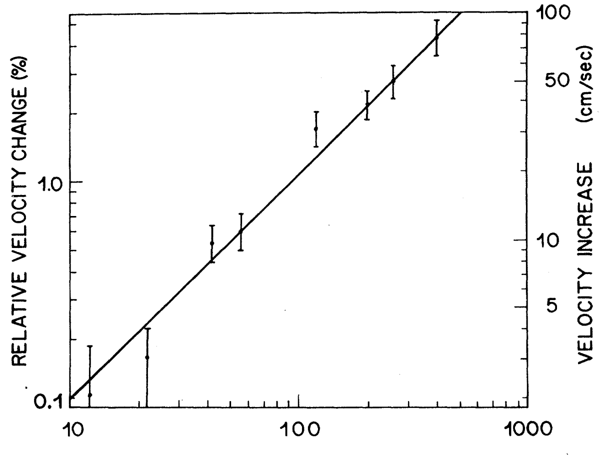

FIG. 2. Velocity responses as a function of incident power density of 2.1-μm radiation. The horizontal scale has to be multiplied by 0.55 to account for reflection losses. The error bars have been estimated from spread obtained in several runs.

This permits us to discuss the possible effects of the 2.1-μm radiation in terms of such forces.

(1) *Radiation pressure.*[14]—We can estimate the velocity responses to radiation pressure from scattering ($\Delta\nu_s$) and from absorpiton ($\Delta\nu_a$). The optical mismatch between the droplets and the unperturbed lattice is sufficiently small[15] that we can use the Rayleigh-Gans approximation to the Mie scattering theory.[16] We can write

$$\Delta\nu_s = 2\pi a^2 \frac{I_0 n_0}{c} A^2\left(\frac{n}{n_0} - 1\right)^2 \frac{\tau}{V n_c m}, \quad (2a)$$

$$\Delta\nu_a = \sigma \frac{I_0 n_0}{c} \frac{\tau}{m}, \quad (2b)$$

where I_0 is the power density, a the droplet radius, and A a correction factor containing the details of the scattering pattern. The real index n of the EHD has been estimated from the value measured[15] at 3.39 μm and extrapolated to 2.1 μm using the Drude formula. The absorption cross section σ per e-h pair was obtained by measuring the ratio $\sigma_{2.1\,\mu\text{m}}/\sigma_{3.39\,\mu\text{m}}$ in a separate *in situ* experiment. Using $a = 2.5$ μm, $I_0 = 100$ W/cm^2, $n_0 = 4$, $A^2 = 15$,[17] $n/n_0 - 1 \approx -4\times10^{-4}$, $\tau = 2\times10^{-9}$ sec, $m = 0.91\times10^{-27}$ g, $n_c = 2\times10^{-17}$ cm^{-3}, and $\sigma = 6\times10^{-19}$ cm^2,[18] we obtain $\Delta\nu_s \approx 10^{-2}$ cm/sec and $\Delta\nu_a \approx 10^{-1}$ cm/sec. We conclude that both forms of radiation pressure are too weak to account for the observed increase in velocity of 40 cm/sec (see Fig. 2).

(2) *Droplet heating and phonon wind.*—We here consider the effect of *energy* transfer between the radiation field and the droplets. The mechanisms discussed so far involve the exchange of momentum and the velocity responses are therefore limited by the strong phonon damping. This will not be the case in this section, as phonons will be shown to be responsible for the motivating force as well. We have shown[11] that in Keldysh's model, the droplet velocities are proportional to the rate of phonon emission which is given by $\beta E_g V n_c/\tau_0$, where τ_0 is the droplet recombination lifetime. (For the sake of discussion we set $\beta = \frac{1}{2}$, which is certainly an upper limit, but not an unreasonable one.)

The additional power absorbed by the irradiated droplets and released as phonon wind is given by $\sigma I_0 V n_c$; thus we can write

$$\frac{\Delta\nu}{\nu} = \frac{\sigma I_0 \tau_0}{\beta E_g}. \quad (3)$$

With $E_g = 0.74$ eV, $\tau_0 = 40$ μsec, and $\nu = 1600$ cm/sec from Fig. 1, we find $\Delta\nu = 64$ cm/sec for $I_0 = 100$ W/cm^2, in excellent agreement with the measured value of 40 cm/sec. The remaining discrepancy can probably be accounted for by the fact that the phonon emission is not isotropic, but tends to be channeled in the [111] crystallographic direction[8,19] away from our probing point which was in the [110] direction from the region of optical excitation on the sample surface.

Before ending the discussion, we would like to note that the secondary field heats up the droplets in our experiment by about 1 to 20 mK. Experiments have been reported[20] where the droplets are heated close to the critical temperature of the liquid. Under such conditions, the phonon wind should become so large as to accelerate the droplets close to the sound velocity, leading to very short transit times through the small crystals used in these experiments, and possibly explaining the puzzling instabilties observed in the microwave absorption. Further experiments along these lines should prove of interest, as the viscous coupling of the drops to the lattice has been predicted to increase by orders of magnitude at such high drift velocities.[3,4]

In conclusion, the experiment reported here confirms that phonons are responsible for droplet motion. The nature of the effect shows, for the first time, that phonons emitted by the drops themselves contribute to droplet motion, thereby giving support for the idea of phonon wind. Furthermore, the magnitude of the effect is in excellent agreement with the assumption that the phonon wind is entirely responsible for the droplet motion. Finally, we feel that the results reported here, together with those reported in Ref. 10, where we showed that high-frequency phonons do not participate in phonon wind, give convincing evidence for the validity of Keldysh's model.

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Magnetic Properties of Liquid Pd, Si, and Pd-Si Alloys

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The magnetic susceptibility χ of liquid Pd, Si, and Pd-Si alloys was measured. For crystalline semiconducting Si, χ changes at the melting point T_M from diamagnetic to paramagnetic values in good agreement with existing theoretical calculations for the liquid state. For liquid Pd, χ is discussed within the Stoner-Wohlfarth and Edwards models. The data obtained for liquid Pd-Si alloys provide an understanding of the diamagnetism of the metallic glass $Pd_{81}Si_{19}$ and will be discussed in the light of recent density-of-states data obtained by photoemission.

The aim of this Letter is twofold. *Firstly*, we are interested in the magnetic properties of the pure liquid metals, Pd and Si. Up to now no experimental data have been available on χ of liquid Pd. On the other hand Pd, in the solid state, is an example where many attempts have been made