MOTION OF ELECTRON-HOLE DROPS IN Ge

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MOTION OF ELECTRON-HOLE DROPS IN Ge

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Using a new experimental technique based on hysteresis, the
time development of the size of a localized packet of electron-
hole drops (EHD) in a spatially uniform free exciton gas near
threshold is measured for times $\approx 10^5$ sec. No significant
motion is found, determining an upper limit $D \leq 10^{-3} \text{cm}^2\text{sec}^{-1}$
to the possible EHD diffusion constant.

The transport of electron-hole drops (EHD) in Ge has been extensively
investigated in past years. A variety of experiments have shown
that EHD rapidly move $\sim 1$ mm from a localized excitation spot and form
a "cloud" of small droplets, apparently propelled by the "phonon
wind." Other experiments have shown that EHD can be easily moved by
an applied non-uniform strain or an electric field. However, the
persistence of hysteresis effects near threshold for times $\sim 10^4$ sec seemed to indicate that EHD could remain stationary for comparably long times. Using a new experimental technique we have discovered that EHD in suitably unperturbed crystals of ultrapure Ge are virtually immobile at 2K.

The experimental method is illustrated in Figs. 1 and 2. Using the
hysteresis effect, a spatially uniform free exciton (FE) gas is
produced inside a large ($8 \times 8 \times 4 \text{mm}^3$) crystal of ultra-pure Ge by volume
excitation with $1.5 \mu\text{m}$ wavelength radiation, as indicated in Fig. 1.
The excitation level ($P = 2.4 \text{ mW cm}^{-2}$ for Fig. 2) is chosen below the
threshold for EHD formation, but above that for drop breakup; thus
the presence of EHD depends upon the history of excitation. First
the volume excitation is monotonically increased to $P$, so the system
initially contains no EHD, as confirmed by spatially resolved scans
of the luminescence intensity $I_{\text{EHD}}$ and $I_{\text{FE}}$ vs. horizontal position $x$
inside the crystal, shown in Figs. 2a and 2b. A localized packet of
EHD is then produced by additional momentary stripe excitation from an
Ar ion laser as indicated in Fig. 1. During stripe excitation EHD are
ejected from the excited region as in earlier work ($P_{\text{stripe}} \sim 70 \text{ mW cm}^{-1}$) and form the cloud of droplets shown in Fig. 2c. After
stripe excitation has ceased, individual EHD remain due to hysteresis,
Fig. 1. Excitation geometry of Ge sample, to scale, showing spatial distribution of EHD and FE.

and give the spatial profile shown in Fig. 2d. Thus a localized packet of drops is produced in a spatially uniform system by a non-uniform history of excitation. Note that, in principle, individual EHD can survive indefinitely at any horizontal position x inside the crystal. From $I_{FE}$ and $I_{EHD}$ in Fig. 2 we estimate that the rate of decay of e-h pairs as EHD inside the packet is roughly ten times less than the decay rate of FE. Thus the presence of EHD is only a small perturbation on the system, unlike previous experiments on EHD motion. The very slow time development of the spatial distribution of EHD is obtained by repeatedly recording the spatial profile of the EHD luminescence for times $t \sim 2 \times 10^9$ sec.

A series of scans of the EHD luminescence profile at various times t following the end of stripe excitation is shown in Fig. 3; note that the horizontal scale is expanded and shifted by $\approx 4$ mm compared with Fig. 2. The most striking feature of this data is that the EHD spatial distribution at $t = 1.66 \times 10^4$ sec is nearly identical to that at $t = 660$ sec. During this time the peak intensity decreases
slightly, but neither the full width at half maximum $\Delta x(t)$ nor the horizontal position of the distribution changes by more than $\pm 20$ $\mu$m, roughly the limit of stability of our apparatus. If EHD undergo diffusion, one would expect the distributions in Fig. 3 to broaden in time according to

$$\Delta x(t)^2 = \Delta x(0)^2 + (16\pi n^2)Dt \quad (1)$$

where $D$ is the possible EHD diffusion constant. Using Eq. 1, we find from the data of Fig. 3 that $D \leq 10^{-3} \text{cm}^2\text{sec}^{-1}$ at 2.1K, a value 5 to 11 orders of magnitude smaller than previous experimental estimates. The extreme smallness of $D$ in this crystal indicates that EHD must be pinned to lattice defects in the absence of an applied force. The strongest damping mechanism other than defects, phonon scattering, is theoretically predicted to be $D_p \geq 10^{-4} \text{cm}^2\text{sec}^{-1}$ for EHD at 2K.\(^1\) Once sufficient force is applied to EHD pinned to defects, one expects that they break loose and travel through the crystal with a mobility corresponding to $D_p$ above, as observed by Alekseev et al.\(^5\)

The crystal used to obtain Figs. 2 and 3 was detector-quality ultrapure Ge, essentially free of deep traps for free carriers; the net concentration of shallow impurities was $|N_A - N_D| \approx 1.8 \times 10^{10} \text{cm}^{-3}$ and the dislocation density was $N_{\text{dis}} \approx 500 \text{cm}^{-2}$. In order to test the effectiveness of dislocations as pinning centers for EHD, an undislocated crystal was also investigated, with $|N_A - N_D| \approx 2 \times 10^{11} \text{cm}^{-3}$, due to 80 meV deep acceptor levels.\(^6\) This crystal gave results similar to Figs. 2 and 3, except that the EHD cloud created by stripe excitation was much wider ($\Delta x = 2.8$ mm for $P_{\text{stripe}} \approx 40 \text{ mW cm}^{-2}$) and exhibited structure due to anisotropies in the shape of the EHD cloud.
as discovered by Greenstein and Wolfe. As for Fig. 3, no significant
broadening or motion of the EHD cloud was observed for times up to
$1.6 \times 10^4$ sec, determining the upper limit $D \leq 10^{-6}$cm$^2$sec$^{-1}$ to the EHD
diffusion constant at 2.1K for this crystal. Thus the EHD pinning
centers are defects other than dislocations. The most likely candi-
dates are neutral impurity atoms, to which EHD theoretically bind by
5 to 7 meV per atom.

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