Effect of microwave breakdown in germanium of the kinetics of electron-hole drops

A. A. Manenkov and S. P. Smolin

P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted March 31, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **25**, No. 9, 436–438 (5 May 1977)

A strong shortening of the luminescence kinetics of EHD as a result of microwave breakdown has been observed at $T = 1.3$ K. The effect is attributed to the influence exerted on the EHD by the phonon wind generated by the hot carriers during the time of the exciton breakdown.

PACS numbers: 71.35.+z, 78.55.Hx

Microwave breakdown of excitons in germanium in the presence of electron-hole drops (EHD) was investigated earlier.[1,2] Further study of this phenomenon has revealed a strong influence of the breakdown on the kinetics of the EHD. The experiment was performed with a setup similar to that described in[2], provided with a high-speed detector for the registration of the luminescence. Samples of pure germanium (concentration of residual impurities 10^{11} cm^{-3}) measuring $3\times3\times0.5$ mm were placed at the maximum of the electric field of a rectangular H_{102} microwave resonator parallel to the electric-field vector. The microwave source was a magnetron with wavelength 3 cm and power 3 W.

The electron-hole pairs were excited with light from a neon-helium laser of wavelength 1.15 μ, passing through a chopper placed at the focus of a lens. The pump pulse duration was 150 μsec at a rise time 1 μsec. The power of the light incident on the sample was approximately 20 mW, the dimension of the illuminated region was 3 mm. The experiments were performed at a temperature of 1.3 K.

The principal result of the present study was observation of a strong change in the kinetics of the EHD luminescence at the instant of the breakdown of the excitons. This change takes the form of a break in the curve with subsequent

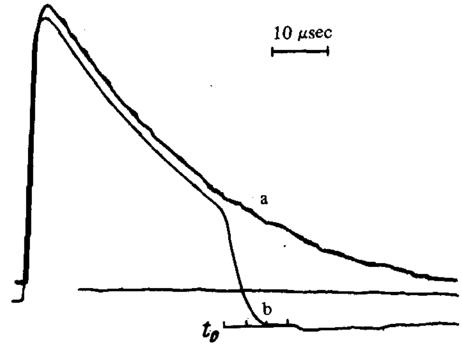

FIG. 1. EHD luminescence signal without exciton breakdown (a) and in the presence of breakdown (b), t_0 is the instant of breakdown.

decrease of the luminescence to zero within several microseconds (see Fig. 1). It is important to note that the entire post-breakdown kinetics is determined by the instant of the breakdown and not by the action of the microwave field after the breakdown. The duration of the action of the microwave field after the breakdown is not reflected at all in this picture. We note furthermore that a hundredfold increase of the microwave power level above threshold does not produce a noticable change in the kinetics of the process.

The foregoing facts can be explained by taking into consideration the action exerted on the EHD by the flux of phonons produced by the "hot" carriers during the breakdown time. This flux is powerful enough to drag all the EHD at a velocity close to that of sound towards the sample surface, where, as is well known, rapid carrier recombination takes place.

Let us make some estimates. The average phonon energy flux w near the sample surface is equal to P/S, where P is the microwave power absorbed in the course of the breakdown, and S is the sample surface area. In our case we have near threshold $P \sim 10^{-2}$ W (experimental and theoretical estimate, see[2]), and $S \approx 0.3$ cm^2, whence $w \sim 3\times10^5$ erg/sec cm^2. We estimate now the average wave vector of the phonon. It is known that the acoustic phonons radiated by the electrons have momenta of the same order of magnitude as the momenta of the electrons themselves. The energy of the hot electrons in the breakdown field is $\epsilon_e \sim 10$ K.[2] This yields $\bar{k} \sim \sqrt{2m\epsilon_e}/\hbar \sim 5\times10^5$ cm^{-1}, which is less than double the Fermi wave vector of the electron in the drop $k_0 = \pi(3n_0/\pi)^{1/3} \approx 2\times10^6$ cm^{-1}, where $n_0 = 2\times10^{17}$ cm^{-3} is the carrier density in the EHD. These phonons are effectively absorbed by the drop, to which they transfer their momentum. The force with which they act on the drop is given by[3]:

$$F_{\mathrm{ph}} = \frac{d^2 m^2 \bar{k}\, n_d\, w}{8\pi \hbar^3 \rho s^2},$$

where $d \approx 4$ eV is the deformation potential; $m \approx 3\times10^{-28}$ g is the average effective mass of the carriers in the drop, $\rho \approx 5$ g/cm^3 is the density of germanium, $s \approx 5\times10^5$ cm/sec is the speed of sound in germanium, and n_d is the number of carriers in the drop.

The friction force experienced by an EHD moving with velocity v_d is equal to

$$F_{\mathrm{fr}} = \frac{m n_d v_d}{\tau_r},$$

where $\tau_r \sim 10^{-8}$ sec is the drop momentum relaxation time.[3] Equating F_{ph} to F_{fr}, we obtain the velocity v_{d}. This, however, yields a value $\sim 10^8$ cm/sec. At such velocities, of course, the formula for F_{ph} becomes meaningless, since the phonon flux no longer accelerates the drop but, to the contrary decelerates it. It is therefore clear that all the EHD acquire velocities close to that of sound under the influence of the phonon wind of this force. On reaching the sample surface, the EHD apparently stick to the surface, because of the presence of surface levels that lie lower than the bottom of the conduction band, and rapidly recombine there.

In conclusion, we wish to mention an experiment performed by us, in which the sample was placed in the antinode of the resonator magnetic field. In this case we expected acceleration of the EHD in it because of the heating of the drop by the eddy current and because of the exciton evaporation. However, in microwave fields of intensity up to 1 gauss, no noticable influence of absorption of the microwave power on the kinetics of EHD luminescence was observed. Unfortunately, the great uncertainty in the quantities on which the heating of the EHD by the microwave field (conductivity, thermal contact with the lattice, dimensions of the EHD) does not permit a reliable estimate of this effect. The maximum value of the field was limited by the exciton breakdown as a result of the presence of an electric component at the sample location.

The authors take the opportunity to thank L. V. Keldysh for help in the interpretation of the experimental results.

[1] A. A. Manenkov, V. A. Milyaev, G. N. Mikhaĭlova, and S. P. Smolin, Pis’ma Zh. Eksp. Teor. Fiz. **16**, 454 (1972) [JETP Lett. **16**, (1972)].

[2] L. V. Keldysh, A. A. Manenkov, V. A. Milyaev, and G. N. Mikhaĭlova, Zh. Eksp. Teor. Fiz. **66**, 2178 (1974) [Sov. Phys. JETP **39**, 1072 (1974)].

[3] V. S. Bagaev, L. V. Keldysh, N. N. Sibel’din, and V. A. Tsvetkov, Zh. Eksp. Teor. Fiz. **70**, 702 (1976) [Sov. Phys. JETP **43**, 362 (1976)].