# Photograph of an Electron-Hole Drop in Germanium*

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We present the first photograph of an electron-hole drop in germanium.

We have previously shown that, in suitably stressed disks of pure Ge, a single large electron-hole drop may be stably formed.[1,2] The evidence is based on the observation of Alfvén resonances within the drop correlated with detailed studies of the drop recombination luminescence at 709 meV (1.75 $\mu$m). Using a lapped and etched Ge disk of 4 mm diam and 1.4 mm thickness which is nonuniformly stressed along the ⟨110⟩ axis, we have extended the previous experiments to obtain a photograph of the drop, Fig. 1.

This is the image of the drop obtained by focusing its luminescence onto the surface of an infrared-sensitive vidicon image tube.[3] The incident light is confirmed to be radiation at the drop-luminescence wavelength by passing it through an interference filter which selects out the 1.75-$\mu$m luminescence. The figure is a photograph of the video-monitor display from the image tube.

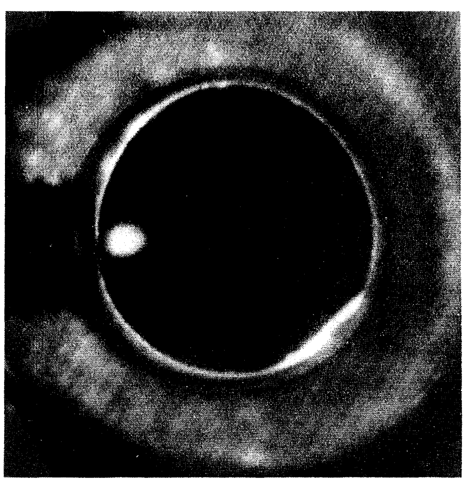

FIG. 1. Photograph of a long-lived electron-hole drop in a 4-mm disk of pure germanium. The sample is mounted in a dielectric sample holder (Ref. 2, Fig. 3) and stressed by a 1.8-mm-diam screw discernible on the left. The drop is the intense spot adjacent to the screw. The bright ring is drop-luminescence light scattered from the sample boundary. The bright line along the lower right crystal rim is scattered luminescence from an orientation mark along the ⟨100⟩ axis. The outer gray ring is the dielectric holder made visible by external illumination.

An Ar-Kr-ion laser is focused on the back surface of the Ge crystal and the drop is produced by this optical excitation. The laser light is filtered through an $H_2O$ bath to remove all pump light at 1.75 $\mu$m. The maximum power absorbed into the germanium is approximately 80 mW. The crystal is immersed in superfluid helium at 1.8 K. The drop of radius $R \approx 0.3$ mm is located at approximately a point of minimum drop energy (approximately the maximum stress point) in the crystal at about 0.4 mm from the stressed surface.[4] The radius is observed to decrease with decreasing laser power. To obtain the maximum drop radius, the laser beam is focused at the point of drop formation, as in Fig. 1. When the laser spot is translated to the center of the crystal a nearly identical photograph is obtained, showing the drop at the same point of minimum drop energy, with slightly smaller radius.

By adjusting the lens to give a larger image on the vidicon we have obtained the photograph of Fig. 2 at our highest pump level (80 mW). In this picture the laser pump spot was located at the center of the sample, approximately 1.6 mm away from the drop. This picture clearly displays a nonspherical drop away from the crystal

FIG. 2. Magnified image of the drop. The width of the photo corresponds to 1.5 mm on the crystal.

surface. At levels below ≈ 40-mW absorbed power, the drop has a nearly spherical shape. The resolution in this picture is limited by the scanning raster to ~ 10 μm on the crystal.

The lifetime of the drop in this crystal (sample CR15) has been measured to be 490 μsec from the decay of the total luminescence intensity from the entire crystal after the laser is switched off.[2,5] The long lifetime is a consequence of the reduced density of electron-hole pairs in the drop under stress. Alfvén-wave experiments for this sample geometry have determined the drop radius to be of order 0.3 mm at the same laser power. Most recently we have performed time-resolved slit-scanning experiments[5] which agree well with the Alfvên-wave data, as well as the photographs reproduced here. We regard the Alfvên-wave results as strong evidence that the image we have photographed here is that of a single drop and not a cloud of small drops. For unstressed Ge we observe a much weaker and more diffuse video image, which translates with the laser spot, consistent with a cloud of small drops having a much lower average electron-hole density.

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[1]R. S. Markiewicz, J. P. Wolfe, and C. D. Jeffries, Phys. Rev. Lett. 32, 1357 (1974), and 34, 59(E) (1975).

[2]J. P. Wolfe, R. S. Markiewicz, C. Kittel, and C. D. Jeffries, Phys. Rev. Lett. 34, 275 (1975).

[3]The vidicon has a Pb-salt photoconductive surface sensitive at 1.75 μm.

[4]It is known that contact stresses of this sort produce a maximum shear stress below the surface, as discussed by J. P. Wolfe, S. M. Kelso, R. S. Markiewicz, and J. E. Furneaux, to be published.

[5]Wolfe *et al.*, Ref. 4.

# Localization and the Minimum Metallic Conductivity in Si Inversion Layers

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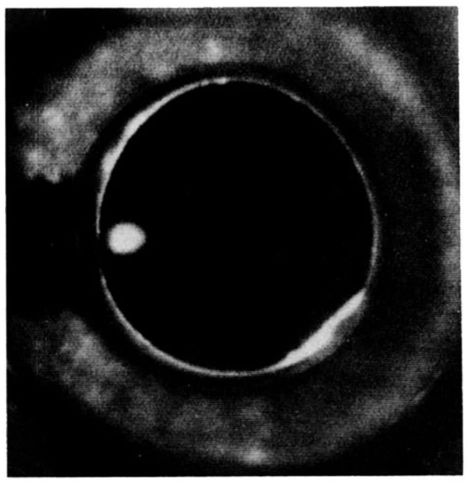
We observe the "minimum metallic conductivity," $\sigma_m$, to be a decreasing function of surface-state charge density, $Q_{ss}$, near the Si-$SiO_2$ interface. This dependence of $\sigma_m$ on $Q_{ss}$ is contrary to Mott's concept of minimum metallic conductivity, but explains the large differences in $\sigma_m$ reported in the recent literature.

Carriers in Si inversion layers constitute a two-dimensional (2D) electronic system whose density $n_s$ can be varied by more than two orders of magnitude. Several recent papers have reported carrier localization in this system at low temperatures.[1-7] This phenomenon, which has been called Mott-Anderson localization, is characterized by a transition from metallic conduction at high $n_s$ to thermally activated conduction at low $n_s$ [this transition occurs at $n_s \sim 10^{12}/\mathrm{cm}^2$ for an $n$-type (100) inversion layer] and its cause has been attributed to potential fluctuations at the Si-$SiO_2$ interface. Although all the reported data agree on the qualitative features of this transition, there exist large differences in the value of the reported minimum metallic conductivity, $\sigma_m$, below which the conductivity becomes thermally activated. In particular, while we reported in Ref. 2 the value $\sigma_m \sim 6\times10^{-4}\ \Omega^{-1}$, Pepper *et al.* reported $\sigma_m \sim 2\times10^{-5}\ \Omega^{-1}$ which is an order of magnitude lower than other reported values.[3-6] Mott's concept of minimum metallic conductivity,[8] applied to a 2D system, requires that $\sigma_m$ be relatively insensitive to material parameters and parameters characterizing the potential fluctuations. Since the wide variation of $\sigma_m$ reported in the literature seriously questions the concept of a minimum metallic conductivity, it is important to establish this variation on a firmer experimental footing.

We have chosen surface-state charge density, $Q_{ss}$, near the Si-$SiO_2$ interface[9] as a convenient parameter to characterize potential fluctuations at the interface and studied the dependence of $\sigma_m$ on $Q_{ss}$. It is the purpose of this Comment to report results from this study and to point out that the differences in $\sigma_m$, as reported in recent literature, are consistent with the $Q_{ss}$ dependence of



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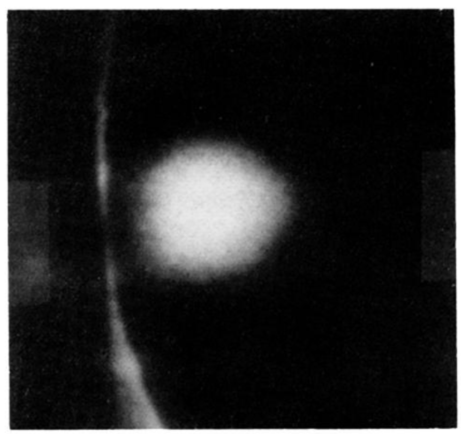

FIG. 2. Magnified image of the drop. The width of the photo corresponds to 1.5 mm on the crystal.