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MODULATION OF BALLISTIC PHONON FLUXES IN Ge BY A He GAS FILM AT A SOLID/SUPERFLUID INTERFACE

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Abstract.—A He gas bubble may be formed at the surface of a sample which is immersed in a superfluid He cooling bath and subject to intense optical excitation. We have discovered that this bubble oscillates at 1-10 KHz, under steady state optical excitation, and this leads to a modulation of the ballistic phonon flux intensity into the sample.

Focused laser excitation is commonly used to generate free carriers and phonons in crystals at low temperatures. For samples immersed in superfluid He and under high optical excitation density (100 W/cm²), a small He gas film or bubble may be formed at the excitation point. The existence of He gas films created by ohmic heating has been previously noted [1]. This paper deals with how the photo-produced gas bubble modifies the ballistic phonon flux into the sample. We have observed similar bubbles on Ge, Si, As, Au, but here we concentrate on pure crystalline Ge. We have used time resolved light scattering, phonon flux detection, and infrared luminescence imaging to study this He gas bubble, its modulation of the ballistic phonon flux and the effect of the bubble on the transport of electron-hole droplets in Ge.

The most intriguing aspect of the bubble is its tendency to oscillate in size under steady state excitation conditions. The dynamic properties of the bubble may be exposed with a simple time resolved light scattering technique. An Ar⁺ laser (5145 Å) is used to create the bubble, while the light from a low power He Ne probe laser (6328 Å) is scattered off of the bubble. The scattered light is detected with a fast photodiode. The oscillation of the bubble is shown in Fig. 1 as a function of incident Ar⁺ laser power for focused (100µm) excitation at T = 1.74 K. Here, the Ar⁺ laser is chopped at 1 KHz to synchronize the bubble oscillations for display and to show the relative magnitude of the oscillatory effect on the scattered light signal. In fact, such oscillations are also observed for steady state Ar⁺ excitation.

The maximum bubble diameter may be measured by scanning the He Ne probe laser. The relationship between oscillation frequency and bubble diameter was obtained as a function of Ar⁺ excitation power, as shown in Fig. 2. The bubble frequency depends on diameter as \( v \propto D^{-3/4} \); therefore larger bubbles oscillate more slowly.
What is the cause of this oscillation? The dependence of $v$ on $D$ argues against simple capillary modes for which $v \propto D^{-3/2}$. To resolve this issue we have devised a stroboscopic imaging technique (to be reported elsewhere) that reveals a gradual growth and sudden collapse of the bubble diameter as a function of time. We therefore conclude that the oscillations arise from a mechanical instability of the bubble in the superfluid bath.

Optical excitation of Ge at low temperatures produces a ballistic phonon flux which can be detected with a superconducting bolometer. To measure the effect of the bubble on this flux, two coincident laser beams are used: A cw Ar$^+$ laser creates the bubble, and a Q-switched YAG: Nd laser provides a reference (57W, 250 ns) heat pulse for comparison of intensity. The detected phonon signal from this experiment is shown in Fig. 3. The inset shows the heat pulse that sets the intensity scale. The phonon flux intensity modulations caused by the bubble are observed in the tail of the heat pulse. These modulations are about 1% of the heat pulse intensity.

Optical excitation of Ge at liquid He temperatures also produces a cloud of electron-hole droplets. The size and shape of the droplet cloud in Ge are determined by a "phonon wind" produced indirectly by optical excitation [2].

A modulation of the electron-hole droplet cloud size by the bubble is observed in a spatial profile of the cloud. The cloud profile is recorded by passing a focused infrared image of the recombination luminescence ($\lambda = 1.75\mu m$) across the spectrometer slit. By defocusing the laser, the excitation density can be reduced below the 100W/cm$^2$ optical power density threshold for the bubble. A hysteresis is observed in the power density required for the bubble to come on and to go off.

This hysteresis effect is used to isolate the effect of the bubble on the cloud size for a given optical power. Figure 4a shows for reference a cloud profile for focused (100$\mu$m) excitation. The remaining traces are for a
500µm excitation spot diameter. Trace b) is obtained in the hysteresis region with the bubble on. Trace c) is then obtained after momentarily blocking the laser to remove the bubble. The cloud penetrates 1.4 times as far into the sample with the bubble present. The spatially integrated total luminescence remains unchanged, indicating that this is truly a spatial redistribution.

We conclude that the bubble reduces the phonon transmission into the bath, increasing the flux reflected back into the sample and thus increasing the total phonon flux.

In Fig. 4, traces a), b), c) were recorded slowly with a 0.15s time constant, so no oscillatory phenomena was observed. In Fig. 4d) we see that the cloud shape does actually oscillate in time, synchronous with the bubble. Here the cloud profile is digitized in one quick sweep with a 100µs time constant. This is a novel demonstration of the fundamental role that ballistic phonons play in the spatial distribution of electron-hole droplets.

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