Thermal Pinching in Electron-Hole Plasma. II

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The appearance of extrusions at the ends of thermal pinch channels in electron-hole plasma as reported in a previous paper is measured as a function of time relative to the onset of pinching. They occur after the power input to the pinch has been turned off. A model is proposed which takes into account the diminished volume of the liquid phase compared with the solid.

INTRODUCTION

THE occurrence of thermal pinching in electron-hole plasma was reported in an earlier paper,[1] hereafter referred to as I. An attendant effect was noted: the appearance of conical extrusions immediately adjacent to the current contacts on the indium antimonide samples after pinching at the highest power levels. Photographs of typical "squirts" are shown in I, Fig. 7. Because indium antimonide shrinks approximately 10% in volume upon melting,[2] further experiments about the origin of these extrusions were undertaken and the results are reported here.

EXPERIMENTAL

In order to determine at what time the extrusions occur relative to the onset and cessation of pinching, a simple detection probe was devised. The experimental arrangement and some results are illustrated in Figs. 1 and 2. The indium antimonide samples used to produce the data recorded on these figures were single crystals cut from adjacent parts of a boule and had the following properties at 77°K, the temperature at which the experiments were performed: $\sigma=8(\Omega\ \text{cm})^{-1}$; $n=8\times10^{13}\ \text{cm}^{-3}$; $\mu=6\times10^{5}\ \text{cm}^2/\text{V sec}$, and area$=0.5$ mm$\times0.5$ mm. Gold wire of diameter$=0.075$ mm was soldered to the samples with indium producing joints approximately twice the diameter of the wire. A square wave current pulse of 4-μsec duration produced a total current of $I_T=22$ A in the first passage of current through sample No. 1, Fig. 1, and an $I_T=23.5$ A during the second passage. Small platinum plates were located very near ($\sim5\times10^{-2}$ mm), but not in contact with the current-carrying contacts. These were biased at 6 V so that an extrusion near the contacts could close the detection circuit producing a deflection on the oscilloscope. Two μsec after the first passage of current through sample No. 1 at a level high enough to cause thermal pinching and associated melting of the lattice within the pinch column, a momentary indication of a closed circuit was noted at the positive current contact. The second pulse of current delivered a net energy to the pinch channel approximately 80% that required to melt all the crystal within the column, 10% more energy than the previous pulse delivered. This produced an extrusion of sufficient height to close permanently the detection circuit 10 μsec after the power was turned off. A very small extrusion was noted by microscopic examination at the negative contact; otherwise no change in the appearance of the sample could be observed.

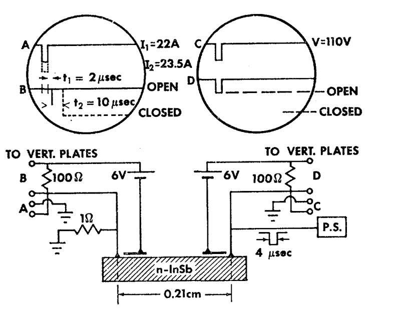

Fig. 1. Schematic of circuit diagram used to detect extrusions and line drawings of the oscilloscope traces observed during two successive current pulses. Traces *C* and *D* are the same for both pulses; the dashed lines in traces *A* and *B* refer to the second pulse at 23.5 A.

Since repeated experiments had indicated that the extrusions were by far more pronounced at the positive contact, only it was supplied with a detector for the experiment depicted in Fig. 2. A single pulse of 4-μsec duration, producing a total current of 20 A and 57% of the energy necessary to melt the entire column of lattice, caused the detection circuit to close 42 μsec after pinching ceased. It remained closed for only 18 μsec. Microscopic examination revealed a "squirted" cone with a dent at the top where it evidently had contacted the platinum plate. Apparently as the cone cooled it moved from the detecting plate.

The diameters of the cones at their bases are the same as those of the pinch column, typically 6×10^{-3} cm. (See I, Table I for measurements of eight pinch

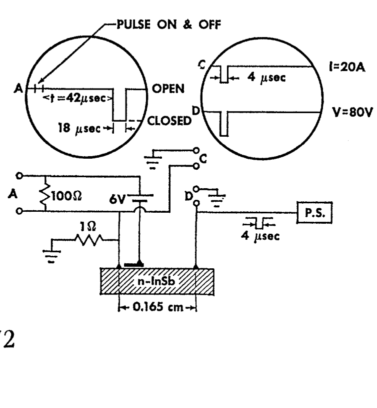

Fig. 2. Schematic of the circuit diagram used for the detection of an extrusion in sample No. 2 and line drawings of the oscilloscope traces showing the results of the measurement.

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column radii.) Microscopic investigation of the soldered contacts show them to be unchanged by thermal pinching; the extrusions clearly come from the InSb crystals, not the solder.

DISCUSSION

The appearance of extrusions from the crystals at their surfaces immediately adjacent to the current-carrying contacts at a definite time after the cessation of thermal pinching suggests the following mechanism. As the pinch column melts the lattice within its well-defined path (see I for details) the melt accumulates vacancies. When the power is turned off, solidification begins at the outer shell of the pinch column and the solid phase moves radially toward the axis. Since the solidification takes place rapidly, within a few tens of μsec, some vacancies are trapped in the solid phase. The expansion caused by freezing at the outer shell then forces some of the remaining molten crystal out the ends of the pinch channel.

The preferential appearance of the "squirted" cones at the positive current contact is probably the result of higher temperatures in its region than at the negative contact, but why such a consistent temperature gradient should exist is not understood.

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Viscosity of Liquid He II

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The viscosity of liquid He^4 has been measured between 1.10°K and the lambda point. A new type of viscometer was used, based on the damping of the transverse vibrations of a fine wire stretched between two rigid supports. The simplicity of the hydrodynamic problem and the low nuisance damping of the wire make this technique particularly appropriate for the measurement of small viscosities. The smoothed data are presented and found to be in good agreement with the latest rotating cylinder viscometer results. In different experimental runs the vibration frequency was varied by a factor of seven and the wire diameter by a factor of three. There was no evidence of systematic trend due to mean free-path effects or geometrical corrections.

I. INTRODUCTION

The viscosity of liquid-helium II has been measured by many different investigators, using various experimental techniques. In recent years, the methods have included mass flow in fine capillaries,[1–3] heat transport in capillaries,[4] oscillating disks,[5–10] torsional vibrations of cylinders,[11–13] attenuation of sound,[14] and constant angular velocity viscometers.[15,16] The results vary widely, especially in the temperature range below 1.6°K, and there are few examples of close correspondence between the sets of data obtained with different techniques. Each method has its peculiar difficulties and inaccuracies. One major problem in any hydrodynamic measurement is the correction for nonideality of the measuring device; end and edge corrections often prove to be large and difficult to estimate. Oscillating disk experiments also require careful measurement of the natural decay time of the system. This paper reports on measurements obtained with a new type of viscometer,[17] which is based upon the attenuation of transverse vibrations of a taut wire. This technique eliminates many of the difficulties mentioned above and gives viscosity measurements of high precision and reliability. These results agree very well with recent measurements obtained by a rotating cylinder viscometer.[15,16]

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