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Magnetic Field Plotter for Superconducting Films

Detailed analysis of the trapped-flux memory cell[1] and other superconducting film devices will depend on a complete description of the magnetic field configurations under given operating conditions. This note describes a sensitive, high-resolution apparatus which uses a conical vapor-deposited probe for plotting the magnetic field distributions of superconducting films. The use of high-resolution bismuth-*wire* probes has been reported by Meshkovsky and Shalnikov.[2]

In the work reported here, a probe utilizing the Hall effect acts as the field-sensitive element. Although Hall coefficient measurements are usually performed with single crystals, this probe is formed by vacuum-metalizing bismuth through a suitable mask onto a glass substrate, as illustrated in Fig. 1. Bismuth has previously been used in vapor-deposited probes because of its large Hall coefficient and its relative ease of evaporation. The probe described here is deposited on a conically-shaped glass substrate in order to reduce the disturbing magnetic field effects caused by the current through the probe leads.

The potential measured at the Hall probe[3] is

$$V = \frac{RIH}{t},$$

where R = Hall coefficient;

I = probe current;

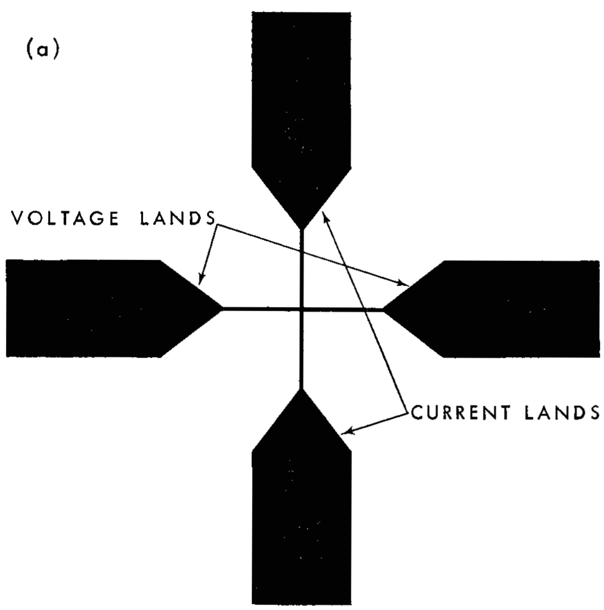
t = probe thickness in the direction of the magnetic field;

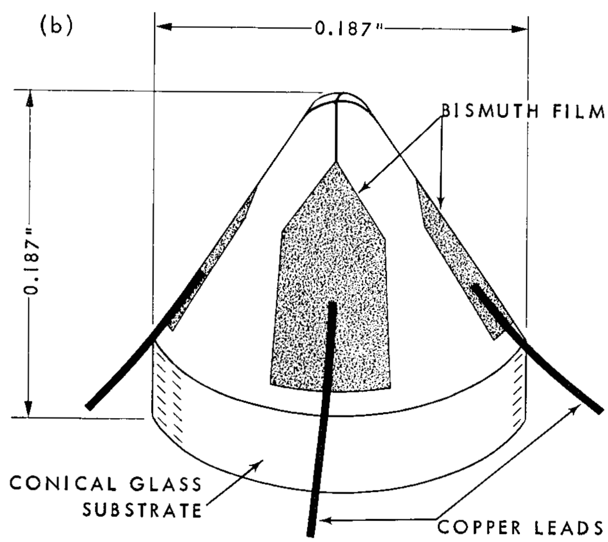
H = magnetic field perpendicular to the plane of the probe.

Quantities V, I, and H are mutually perpendicular. The probe current is expected to have a uniform distribution within the area connecting the two current-land areas (Fig. 1a), with some very slight fringing into the areas leading to the voltage lands. It follows that the resolution of the probe may be considered as the dimensions of that portion of the probe common to both the current and voltage circuits. The resolution obtained at present is

Figure 1 **Configuration of evaporated bismuth film on Hall probe.**

a) Mask pattern.
b) Film on conical glass substrate.





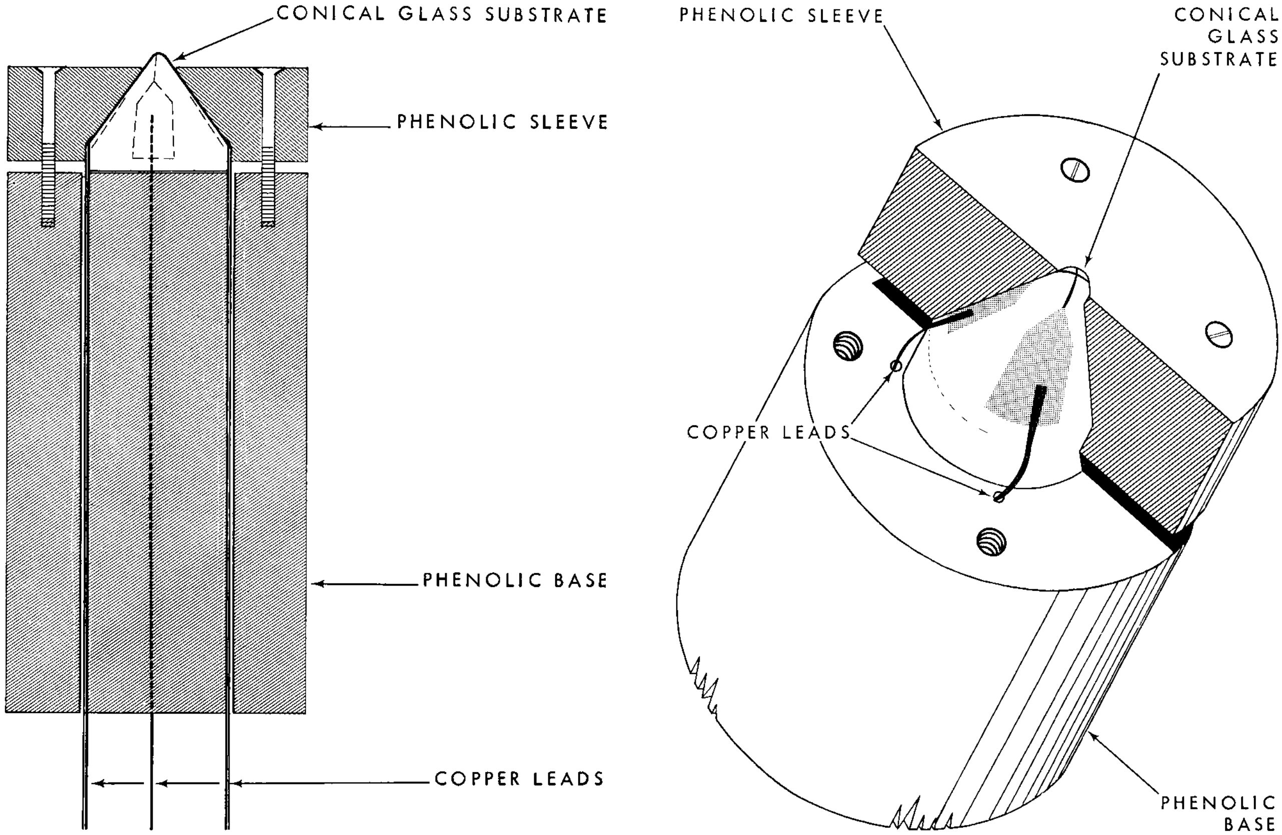


Figure 2 **Two views of the probe assembly.**
The phenolic sleeve maintains pressure contact between copper wire and bismuth film.

approximately 0.001 inch by 0.001 inch. It should be possible to improve this by a factor of two by employing changes in the mask which would reduce the field-sensitive area.

Because the Hall voltage is inversely proportional to the thickness of the probe material, a very thin bismuth film is desirable. However, attempts to reduce the thickness below 10,000 A have not resulted in increased sensitivity, possibly because of a significant change in the Hall coefficient of bismuth. For this reason the bismuth probes have been evaporated to a thickness of approximately 10,000 A. Hall coefficients for the probes have ranged from approximately 1×10^{-8} to 4×10^{-8} volt-cm/amp-oersted at a temperature of 4.2°K. These values are in the same order of magnitude as for bulk (polycrystalline) bismuth.

A wet cell is used to supply a direct current to the bismuth probe, resulting in a dc Hall voltage. (The magnetic field distributions being measured are, of course, static.) The resultant Hall voltage is amplified by a Liston-Becker Model 14 Breaker Amplifier and indicated on a Greibach Model 500 Millivoltmeter. For a probe current of 1 ma, a sensitivity of 0.3 microvolts per oersted is obtained. The lowest detectable field is limited by the noise in the system, which is equivalent to a field of approximately 0.05 oersted.

A conically shaped piece of glass, approximately 0.187 inch in diameter at the base, is used as the substrate for the bismuth evaporation. The sensitive part of the probe is evaporated on the tip of the glass cone with four land areas falling on the side of the cone. A phenolic receptacle holds the probe and permits pressure contacts to be made to the land areas. The conical design permits free movement of the probe, minimizing possible damage to the film under measurement. The complete probe assembly, shown in Fig. 2, is rigidly connected to the end of a thin-walled cupro-nickel tube. Adjacent to this is a second tube, which supports the film under measurement. The two tubes are sufficiently long to permit the film and probe to be suspended in a liquid-helium Dewar flask. Relative motion between the two shafts is provided by a micrometer table to which both tubes are attached, as shown in Fig. 3. The probe may be moved a distance of one inch in the X and Y directions and up to one-half inch in the Z direction. The micrometer barrels controlling the relative movements may be read to 0.0001 inch.

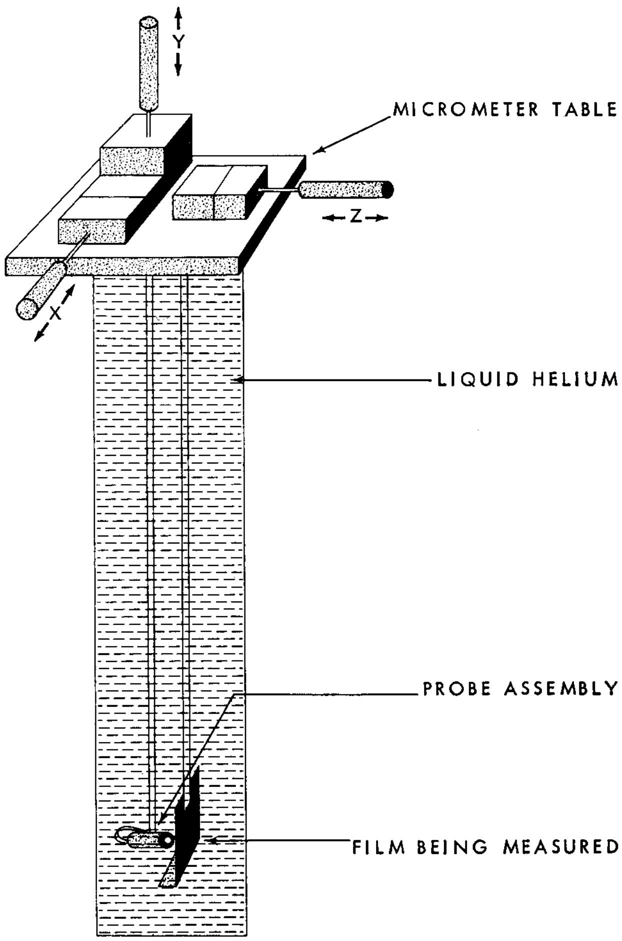


Figure 3 **Magnetic field plotter for measurements at liquid-helium temperature.**

The probe and superconducting film however, are connected to the micrometer table by two thin-walled tubes. This arrangement may subject the probe and film to a certain amount of vibration. It is possible, then, that the resolution of the probe travel may be poorer than 0.0001 inch. The complete assembly exclusive of the micrometer table is designed to operate within a Dewar flask having an inside diameter of two inches.

This probe assembly is currently being used to plot the magnetic field distributions around superconducting lead films. A paper describing these field distributions will be published at a later date.

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References

1. J. W. Crowe, *IBM Journal,* **1,** 295-303 (October 1957).
2. A. Meshkovsky and A. Shalnikov, *J. Exp. and Theor. Phys. USSR,* **17,** 851-861 (1947).
3. The potential measured at the voltage leads of the Hall probe might be expected to include the Ettinghausen effect, the Nernst effect, the Righi-Leduc effect as well as the Hall effect. The first three effects are expected to be less than the accuracy of the Hall voltage measurement because (1) the field-sensitive portion of the probe and the voltage contacts are both made of bismuth, and (2) the probe assembly is operated in a liquid-helium bath. The *IR* drop present because of misalignment of the voltage contacts is cancelled out by a battery-supplied voltage.
   See paper by: O. Lindberg, *Proc. IRE* **40,** 1414-1419 (November 1952).

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