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Abstract

Full Text

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Academician of the Academy of Sciences of the Ukrainian SSR B. G. LAZAREV,
L. S. LAZAREVA,
S. I. GORIDOV, S. G. SHULMAN

PROPERTIES OF FILM HALL SENSORS MADE OF INDIUM ARSENIDE IN A STRONG CONSTANT MAGNETIC FIELD AT LIQUID-HELIUM TEMPERATURES

The increasingly widespread use of superconducting solenoids with a wide range of fields requires sufficiently accurate, reliable, and simple meters of magnetic-field strength.

As is known, under ordinary conditions one of the methods of measuring a magnetic field is the use of sensors employing the Hall effect. Semiconductor Hall sensors do indeed possess a number of advantages—they are inertialess, small in size, and sufficiently simple in operation. However, the data on their use pertain to a comparatively small range of magnetic fields and to conditions of ordinary temperatures. Only in one paper by Glasnik, Chovanec, and Polak ([1]) are there data on the investigation of a Hall sensor made of InSb single crystals at a temperature of 4.2° K. These sensors were studied up to fields of 50 kOe and, under these conditions, possess satisfactory linearity of the output voltage with the field. The Hall emf at 50 kOe is 4 mV, i.e., their sensitivity is $8 \cdot 10^{-2}$ µV/Oe. At room temperature the sensitivity of these sensors is practically the same. N. E. Alekseevskii and co-workers ([2]) note the linearity of these sensors up to 80 kOe at liquid-helium temperature.

Fig. 1. Dependence of the Hall emf on the magnetic-field strength for sensor No. 383

Recently at the Institute of Semiconductors of the Academy of Sciences of the USSR, film Hall sensors made of indium arsenide have been developed and are being manufactured, with a sensitivity at room temperature of 10–100

Fig. 2. Dependence of the Hall emf on magnetic-field strength for sensor No. 357

Figure 2: Fig. 2. Dependence of the Hall emf on magnetic-field strength for sensor No. 357

μV/Oe, i.e., considerably greater than that of sensors made of indium antimonide. In film sensors made of indium arsenide, in the temperature interval from +200 to −60°, the temperature coefficient of sensitivity is also very small ($3–5 \cdot 10^{-2}$%/degree) ([3]). It was natural to investigate these sensors at liquid-helium temperatures.

In the present communication we present the results of investigations of Hall sensors based on thin films of indium arsenide at 4.2 and 2° K in magnetic fields up to $\sim$ 107 kOe, produced by a superconducting solenoid. A few words about the manufacture of the sensors.

To obtain indium arsenide films, the method of separate evaporation of In and As from two crucibles ([4]) was used, the temperatures of which were set—

were evaporated separately (1000 and 350° respectively). The substrate temperature in this process had to be sufficiently high (~700°) to ensure the formation of the compound InAs and the removal of excess unreacted arsenic atoms. The substrates were round plates of electrocorundum 0.3 mm thick, with diameters of 3 and 1 mm. Four contacts were applied to the polished surface of the plate by firing a silver paste. After deposition of the rectangular semiconductor film, these contacts served as current and Hall electrodes, to which thin wires (d = 0.05-0.1 mm) leading to the measuring circuit were soldered. The film sensor fabricated in this way is firmly bonded to the substrate and has good mechanical strength.

Fig. 2. Dependence of the Hall emf on magnetic-field strength for sensor No. 357

The Hall emf was measured by the potentiometric method. In this case, owing to the sufficiently high sensitivity of the sensors, it proved possible to use a PP potentiometer. In these measurements, accurate knowledge and maintenance of the current through the sensor are important; the latter was measured by a second PP potentiometer from the voltage drop across a standard resistance (1 Ω) connected in series with the Hall sensor. Such conditions ensured measurement with an error of $< 0.1\%$. Naturally, if necessary, the accuracy can be increased by switching to more precise potentiometers.

As is usually done in studies of the Hall effect, the measurements were carried out with current reversal. Measurements were performed on typical sensors of two sizes. On a corundum plate 3 mm in diameter there was a rectangular sensor film with dimensions $1 \times 1.5 \times 5 \times 10^{-3}$ mm (No. 383). A still smaller sensor, with a film area of 0.01 mm^2 ($\sim 0.1 \times 0.1$ mm) and of the same thickness, was placed on a corundum plate 1 mm in diameter (No. 357).

To determine the dependence of the Hall emf on the field, the sensor was placed at the center of a superconducting solenoid, for which the dependence of field on current had previously been studied (the solenoid constant was determined) by a ballistic method with an error of less than 1%.

At helium temperatures, the instrumental nonequipotentiality of the sensors in zero field is small: at a current of 50 mA this value did not exceed 0.02 mV (i.e., the accuracy of the PP); as will be seen below, this corresponds to an error in field measurement of < 2 Oe for sensor No. 383.

The curves in Figs. 1 and 2 show the dependences of the Hall emf on magnetic-field strength for the sensors described. Fig. 1 refers to the larger sensor (No. 383) up to 107 kOe, Fig. 2 to the smaller one (No. 357) up to 65 kOe. The main measurements were carried out at 4.2°K; a number of measurements were performed at 2°K—within the accuracy of the measurements (~0.1%) there is no difference in the course of the curves in this temperature interval; the current in the sensors was 50 mA.

From these curves it is evident that, for sensors of both sizes, the dependences of their emf on field deviate somewhat from linearity. More precisely, after a slightly curvilinear initial segment in weak fields (up to 20 kOe), the emf is strictly linear with field within the accuracy of the measurements.

The slopes of the sections in weak fields are 14 and 2.485 μV/Oe for the large and small sensors, respectively; in strong fields these slopes are 10.81 and 1.87 μV/Oe. The ratios of the slope values in weak and strong fields for both types of sensors are, within the accuracy of their determination, identical and indicate the reproducibility of their manufacture. The average sensitivity of the large sensor up to fields of 107 kOe is 11.28 μV/Oe, and that of the small sensor up to 65 kOe is 2.00 μV/Oe.

The dependences of the output voltage of the sensors on the field were taken at currents passed through them of 2, 5, 10, 20, 25, and 50 mA and are strictly linear with current; in the curves of Figs. 1 and 2 the points obtained at different currents, reduced to a current of 50 mA, are plotted—they all lie well on the common curves.

The data obtained at 4.2 and 2°K show that the sensitivity of thin-film indium arsenide sensors is close to its rated value at room temperature. More precisely, this circumstance was clarified by measurement on one and the same large-size sensor at room temperature and at 4.2°K. At room temperature, measurements were carried out in fields up to 10 kOe (in a conventional electromagnet), using nuclear magnetic resonance to determine the field values (with an accuracy of $\sim 10^{-4}$%); the Hall emf was measured with an accuracy of 0.05%. At 4.2°K this dependence was taken in a superconducting solenoid.

Fig. 3. Dependence of the Hall emf on the magnetic-field strength H for sensor No. 383 at temperatures of 300 and 4.2°K.

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Figure 3: Fig. 3. Dependence of the Hall emf on magnetic-field strength H for sensor No. 383 at temperatures of 300 and 4.2°K

Figure 3 shows the curves of the sensor readings as a function of field at 300 and 4.2°K. The curve taken at room temperature lies only slightly higher than that taken at 4.2°K. The average temperature coefficient of sensitivity (from 4.2 to 300°K) for this sensor is found to be $1.5 \cdot 10^{-2}$%/degree and is considerably smaller than the average according to the rated data for the range $-60 \div 200^{\circ}$C (0.03–0.05%/degree).

The sensors are stable after prolonged use in liquid helium (i.e., after repeated coolings and warmings); their calibration, within the measurement accuracy, remains unchanged over the entire field interval studied (0–107 kOe).

Apparently, owing to their polycrystallinity, the sensors are free of the oscillations of the emf with field observed in single crystals of indium antimonide ([1]). Thanks to the ceramic substrate, the sensors have good mechanical strength. Their small dimensions (down to 0.01 mm^2) make them very convenient for accurate determination of the field topology in the very smallest field volumes.

Physical-Technical Institute
Academy of Sciences of the USSR

Institute of Semiconductors
Academy of Sciences of the USSR

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Note: Figure translations are in progress. See original paper for figures.