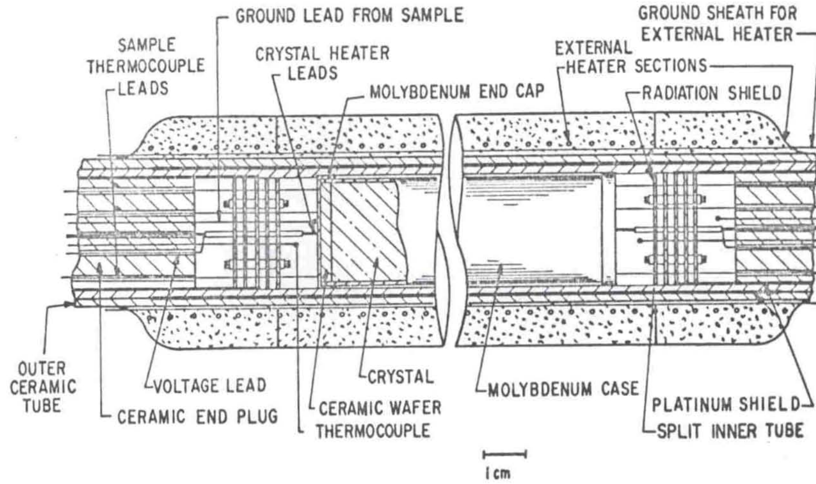

FIG. 1. The high-temperature radial heat flow apparatus showing the crystal sample, heater, thermocouples, and shields.

CRYSTAL SPECIFICATIONS AND PREPARATIONS

A. Low-Temperature Silicon Crystal

The silicon single crystal used for the low-temperature measurements was grown by the pedestal method from a bar of high-purity silicon by W. C. Dash of this laboratory. The growth direction was [111]. It was made with care in order to be oxygen and dislocation free.[2–4] Any vacancy clusters were less than one micron in diameter as determined by etchpit and copper decoration techniques. The pedestal method prevents the silicon from coming in contact with quartz, usually the chief source of oxygen. The crystal was 2 cm long with a geometrical average diameter of 0.44 cm. The diameter varied slightly along the length of the sample. The cross section could be best described as an equilateral triangle with rounded corners, typical of [111] oriented crystals. The room-temperature resistivity was approximately 2000 Ω-cm, and the sample was p type.

B. Crystals Used at High Temperatures

The silicon and germanium samples were both single crystals, cylindrically shaped, approximately 13 cm long by 2.6 cm in diameter. They had on the order of 10^5 dislocations[5] per cm^2. The Ge crystal was grown by the Čzochralski method with a [100] axis from a charge of zone-refined germanium. The room-temperature resistivity of the charge material was greater than 40 Ω-cm which indicates that it was basically intrinsic. The dominant impurity in the charge was specified as antimony. The single crystal of silicon was produced by the floating zone process. The atmosphere was argon and the axis of the cylinder was [111]. The diameter of the "as-received" crystals varied slightly along the axis. Their crystal faces were clearly visible.

A rather elaborate machining operation was used on the crystals in order to insure that the axial heater was exactly in the center of the sample and that the thermocouples were at exactly known positions along the radii. These physical conditions imposed on the heater and thermocouples were solved by cutting the sample into two exactly equal half-cylinders. For this purpose, the original single crystal was centerless, ground to a uniform diameter and carefully cut lengthwise into two approximately equal halves. The flat side of each half-cylinder was given an optically flat polish so that the halves would fit tightly together. Thermocouple grooves were then cut in one of the halves. The nominal radial distances of the center line of the three thermocouple grooves from the axis were: 2.5 and 10 mm on one side of the heater groove, and 6.5 mm on the other side. A heater groove was cut along the axis of each half so that the heater would be in the center of the assembled cylinder. After the grooves were cut, the two halves were temporarily cemented together, but were offset slightly along the longitudinal axis. They were centerless ground a second time so that the interfacial plane and heater wire passed through the center of the cylinder.

After the machining, the sample was assembled and encapsulated in a molybdenum case with a high-purity Al_2O_3 ceramic wafer placed at each end. See Fig. 1. Molybdenum was used because it does not form any low melting alloys with either Si or Ge. Neither the Mo nor the Al_2O_3 contributes electrically active impurities to the Si or Ge in significant amounts during the lengthy, high-temperature runs.

The intrinsic electronic K could be suppressed if, inadvertently, the material became highly doped to a level of about 10^{18} carriers/cc. As a check on the impurity concentration, the electrical conductivity and Hall coefficient of the germanium and silicon samples were measured before and after the high-temperature measurements. Before use the room-temperature resistivity of the germanium crystal was 46.6 Ω-cm, and the

[2] W. C. Dash, J. Appl. Phys. 29, 736 (1958).
[3] W. C. Dash, J. Appl. Phys. 30, 459 (1959).
[4] W. C. Dash, J. Appl. Phys. 31, 736 (1960).
[5] W. C. Dash (private communication).