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Hall Effect and Mobility of n-type and p-type Germanium at Different Magnetic Fields and at Different Concentrations

MADAN JEE*, VEENA KUMARI†, RAMNATH SINGH‡, VIJAY PRASAD and AMITA SINGH
Department of Physics
J.L. College, Hajipur, Vaishali, India

An experimental investigation of Hall effect and mobility of germanium crystals at different magnetic fields are reported. n-Type and p-type of germanium with different kinds of impurity and different concentrations were used. A large decrease in the magnitude of the Hall constant with increasing magnetic fields have been observed in both p-type and n-type germanium crystals. A satisfactory agreement between theory and experimental results was found.

INTRODUCTION

Since the discovery of the Hall effect in metals, semiconductors and insulators, it has been a subject of intensive research both in theoretical and experimental fields. Hung and Gliessman[1–3] studied the resistivity and Hall effect of germanium at low temperatures. Samples of germanium, n-type and p-type, were used for study. Measurements were done from room temperature down to the liquid helium temperature. The results were seen to be independent of magnetic field variation between 1000 and 5000 gauss, in both increasing and decreasing temperature ranges. The resistivity and Hall coefficients did not increase indefinitely as the temperature was reduced, as predicted by usual theory. Actually the Hall coefficient for each sample was found to go through a maximum at low temperature, while the resistivity approached a saturation value.

Hung[2] postulated that the conduction in an impurity band is the dominating process at different temperatures. At low temperatures the number of carriers in the impurity band is equal to the number of carriers in the conduction band observed at higher temperatures, in the exhaustion range and that the mobility in the impurity band is extremely small compared to the ordinary mobility in the conduction band.

The conduction properties of an impurity band have been discussed by several authors[4].

Bullis and Krag[5] made the measurement of Hall coefficient as a function of magnetic field at 77 K on single crystals of n-type germanium for several

†Department of Chemistry, Samta College, Janadaha.
‡P.R. College, Sonepur.

orientations. They suggested that the explaination of their experimental results lay in a theory based on an energy independent mean free time.

In this paper the main purpose of the work reported was to study the mobility of electrons and holes in different semiconductors as derived from Hall effect and resistivity data. Experiments have been performed with a number of n-type and p-type germanium crystals. For study single crystals as well as polycrystalline pressed samples were used. All the single crystals were doped with various impurities at the time of preparation.

EXPERIMENTAL

Preparation of germanium single crystals with predetermined resistivity

When purified, a germanium ingot has a polycrystalline structure, it is yet unsuitable for the manufacture of the semi-conductor devices.

To meet the requirements of semiconductor electronics a germanium ingot should have a monocrystalline structure.

Most suitable method is crystal growth from melt known as the Czochralsky method. In this technique purified polycrystalline germanium is loaded into a graphite or quartz crucible. A pure single crystal seed is then mounted into the graphite or quartz holder. Prior to crystallization, the single crystal seed is dipped into the germanium and kept there for some time until its surface layer fuses. The furnace is hermetically sealed and evacuated to a vacuum of 10^{-4} to 5×10^{-5} mm of Hg. The semi-conductor material is melted by the graphite heater after which the rotatory mechanism of the crucible is set into motion to maintain a uniform temperature gradient of the molten metal. Another mechanism is then brought into action to rotate and lift the upper rod together with seed. As the seed is raised and the heat removed through it the melt starts to crystallize round the seed. A single crystal is thus formed which is gradually pulled from the melt. Simultaneously additional refining to the single crystal is achieved in the molten metal. This process allows large well-oriented germanium ingots to be prepared.

Procedure

A three electrode system was used for the Hall effect and mobility measurements. In this way the difficulties with electrode asymmetries were eliminated. The primary current through the sample was controlled by potentiometric arrangement and it was measured by a sensitive D.C. milliameter P.GW/MA.I. The sample holder consists of a teflon plate, cut in square shape. Five springs, made of brass, were pressing the sample on the holder and it was tested that electrical contact was good. The five springs were being pressed by five adjustable screws, fitted on a frame made of bakelite. The whole thing was closed in a brass box of size 14.5 × 14.5 cm. Connecting terminals were taken outside and fitted at the topcover of the brass encloser. The box was made airtight such that the medium inside the box could be filled completely by nitrogen gas. Heating coils were suspended from the top of the box such that the central part of filament was at the centre of the crystal. A brass rod, drilled at centre, was inserted into the chamber via top of the encloser such that the lower end of the rod remained close to the crystal but not in electrical contact with the sample. Some mercury was poured into the drilled rod and a sensitive thermometer was put in it. The thermometer measured the temperature of the crystal. Hall voltage V_H and props voltage V_p were recorded.

In this experimental arrangement van der Pauw technique was employed.

RESULTS AND DISCUSSIONS

Hall coefficent R_H, electrical resistivity ρ and mobility μ of germanium crystals were measured and findings are as follows.

TABLE–1
n-TYPE Ge AT 25°C

H in KG	ρ in ohm-cm	R_H in cm^3/coulomb	$\mu = -\frac{8}{3\pi}\frac{R_H}{\rho}$ in cm^2/(volt sec)	Extrinsic carrier density $n = \frac{7.4 \times 10^{18}}{R_H}$ per cc
1	10.65	3.6000×10^4	2869.2719	2.0555×10^{14}
2	10.70	3.3360×10^4	2646.4341	2.2182×10^{14}
3	10.72	3.0992×10^4	2453.9948	2.3877×10^{14}
4	10.78	2.8992×10^4	2282.8545	2.5524×10^{14}
5	10.80	2.7648×10^4	2172.9953	2.6765×10^{14}
6	10.83	2.6560×10^4	2081.7014	2.7860×10^{14}
7	10.89	2.5600×10^4	1995.4043	2.8906×10^{14}
8	10.90	2.4640×10^4	1918.8146	3.0032×10^{14}
9	10.96	2.4000×10^4	1858.7437	3.0832×10^{14}

TABLE–2
p-TYPE Ge AT 25°C

H in KG	ρ in ohm-cm	R_H in cm^3/coulomb	μ in cm^2 (volt sec)	n per cc
1	26.800	5.4333×10^4	1720.8791	1.3619×10^{14}
2	26.904	5.7466×10^4	1813.0840	1.2877×10^{14}
3	26.995	5.8099×10^4	1826.8867	1.2736×10^{14}
4	27.060	5.5066×10^4	1727.3479	1.3430×10^{14}
5	27.177	5.1666×10^4	1613.7183	1.4322×10^{14}
6	27.268	4.8633×10^4	1513.9083	1.5210×10^{14}
7	27.346	4.5999×10^4	1427.8508	1.6086×10^{14}
8	27.450	4.3666×10^4	1350.2883	1.6946×10^{14}
9	27.554	4.1833×10^4	1288.7142	1.7689×10^{14}

TABLE–3
p-TYPE Ge AT 40°C

H in KG	ρ in ohm-cm	R_H in cm^3/coulomb	μ in cm^2 (volt sec)	n per cc
1	17.349	1.4766×10^4	722.4816	5.0113×10^{14}
2	17.635	1.2166×10^4	585.6187	6.0821×10^{14}
3	17.921	1.0566×10^4	500.4890	7.0031×10^{14}
4	18.220	0.9933×10^4	462.7702	7.4496×10^{14}
5	18.480	0.9666×10^4	444.0108	7.6552×10^{14}
6	18.753	0.9433×10^4	426.9856	7.8445×10^{14}
7	19.013	0.9033×10^4	403.2888	8.1919×10^{14}
8	19.299	0.8833×10^4	388.5157	8.3773×10^{14}
9	19.546	0.8666×10^4	376.3682	8.5385×10^{14}

A large decrease in the magnitude of the Hall constant R_H with increasing magnetic field has been observed in both p and n-type germanium. This decrease has also been observed previously in p-type germanium at low magnetic fields. This has been explained on the assumption that there are two types of holes of two different masses in p-type germanium. No such decrease in Hall coefficient R_H has there been reported in n-type germanium. This is also not to be expected as there can be only one type of conduction band electrons.

However in the present work it has been found that a large decrease in R_H occurs in the Sb-doped germanium with increasing magnetic field.

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