CHAPTER 1

INTRODUCTION
SECTION 1.1

BRIEF REVIEW OF PREVIOUS EXPERIMENTAL WORK ON THE
EFFECT OF TEMPERATURE AND MAGNETIC FIELD ON THE
PHYSICS OF SEMICONDUCTOR DEVICES AND
THE SCOPE OF THE PRESENT STUDY

Of all the solids that man has put into technical use, the class called semiconductors is one of the most interesting. One of the characteristic features of the science of semiconductors is that the results of fundamental investigations in this field very rapidly find technological applications. Practical applications of semiconductors exerted and continue to exert a deep revolutionizing influence on many branches of science and technology.

Of all the semiconducting materials, the covalent elemental semiconductors, namely germanium and silicon are by far the best known, most thoroughly understood, and most widely used for the fabrication of practical devices. The reason for this is that the technological problems in purification, crystallisation and device fabrication are simple. Hence, most of the semiconductor diodes and transistors for general use, are usually made up of germanium and silicon. The use of these semiconductor devices in electronic industry and in our daily life is consistently increasing. The increasing importance of these devices has led many researchers to understand their properties more thoroughly.
Table 1.1

Some of the Physical Properties of Germanium and Silicon

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Germanium</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>IV</td>
<td>IV</td>
</tr>
<tr>
<td>Crystal structure</td>
<td>diamond</td>
<td>diamond</td>
</tr>
<tr>
<td><strong>Lattice spacing $\AA$</strong></td>
<td>5.65754</td>
<td>5.43072</td>
</tr>
<tr>
<td>Band gap at $300^\circ K$ (eV)</td>
<td>0.66</td>
<td>1.12</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>16.0</td>
<td>11.5</td>
</tr>
<tr>
<td>***Electron mobility at $300^\circ K$ cm$^2$/Vs</td>
<td>3900</td>
<td>1500</td>
</tr>
<tr>
<td>***Hole mobility at $300^\circ K$ cm$^2$/Vs</td>
<td>1900</td>
<td>600</td>
</tr>
</tbody>
</table>

*R.A. Smith, 'Semiconductors' (Cambridge University Press, 1968)*


### Table 1.2

**Ionization Energies** for Donor and Acceptor Centres in Germanium and Silicon (eV)

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Donor (D) or Acceptor (A)</th>
<th>Germanium</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>D</td>
<td>0.0120</td>
<td>0.045</td>
</tr>
<tr>
<td>As</td>
<td>D</td>
<td>0.0127</td>
<td>0.050</td>
</tr>
<tr>
<td>Sb</td>
<td>D</td>
<td>0.0100</td>
<td>0.039</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>0.0104</td>
<td>0.045</td>
</tr>
<tr>
<td>Al</td>
<td>A</td>
<td>0.0102</td>
<td>0.060</td>
</tr>
<tr>
<td>Ga</td>
<td>A</td>
<td>0.0108</td>
<td>0.070</td>
</tr>
<tr>
<td>In</td>
<td>A</td>
<td>0.0112</td>
<td>0.160</td>
</tr>
</tbody>
</table>

*J. P. Winkles, 'Solid State and Semiconductor Physics'*

<table>
<thead>
<tr>
<th></th>
<th>Germanium</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons $m_e$</td>
<td>1.64 $m_0$</td>
<td>0.98 $m_0$</td>
</tr>
<tr>
<td>$m_e^\perp$</td>
<td>0.0819 $m_0$</td>
<td>0.19 $m_0$</td>
</tr>
<tr>
<td>$m_e^\parallel / m_e^\perp$</td>
<td>20.0</td>
<td>5.20</td>
</tr>
<tr>
<td>Holes $m_h$</td>
<td>0.044 $m_0$</td>
<td>0.160 $m_0$</td>
</tr>
<tr>
<td>$m_h^\parallel$</td>
<td>0.280 $m_0$</td>
<td>0.490 $m_0$</td>
</tr>
<tr>
<td>$m_h^\perp$</td>
<td>0.077 $m_0$</td>
<td>0.245 $m_0$</td>
</tr>
</tbody>
</table>

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Some of the general physical properties of germanium and silicon are given in the tables, 1.1, 1.2, and 1.3.

There are bulk effect semiconductor devices. They do not contain any p-n junction. The transport behaviour of charge carriers in these devices depends, apart from the concentration of donor or acceptor impurities, on external influences such as temperature, pressure, electric and magnetic fields. The influence of magnetic field and temperature on the behaviour of these devices is appreciable and these phenomena led to the invention of the principle of Hall effect, magneto-resistances and thermistors, all of which have many practical applications.

In contrast to the bulk devices, the p-n junction devices vis., diodes and transistors have inherent potential barriers inside their structure, which control the conduction mechanism. The height of the potential barrier depends upon the density of charge carriers in the bulk material on either side of the potential barrier. The conduction mechanism in p-n junctions depends on the applied bias, apart from the external influences such as temperature, pressure, magnetic field etc.,

Charge carrier densities, mobilities, diffusion constants, conductivities and their lifetimes are some
of the important parameters of semiconductors. The dependence of resistivity and Hall coefficient in semiconductors have been known from the work\(^1\) at Purdue University by Lark-Horowitz et al and at the university of Pennsylvania by Seitz and his collaborators. Debye and Conwell\(^2\) studied the effect of temperature on resistivity and Hall coefficient of a set of n-type arsenic doped germanium samples. The dependence of electrical conductivity, carrier concentration and electron mobility on temperature for a series of n-type germanium samples covering a wide range of donor impurity, has been reported by Conwell\(^3\). Fritzsche and Lark-Horowitz\(^4\) studied the behaviour of resistivity and Hall coefficient in indium-doped, gallium-doped p-type germanium samples at low temperatures. Morin\(^5\) reported the nature of variation of the ratio of Hall mobility to conductivity mobility with temperature, both for electrons and holes in germanium. Morin and Hatta\(^6\) repeated the same experiments on silicon crystals.

Early measurements of magneto-resistance were made on polycrystalline samples of germanium and silicon. Pearson and Suhl\(^7\) were probably the first to make measurements on single crystals of germanium. Pearson and Herring\(^8\) reported significant results from their measurements on single crystals of silicon. This effect was
found to depend not only on the relative orientations of current and magnetic field but also on the crystal orientation. The orientations used by Della Pergola and Sette\textsuperscript{9} in germanium showed a negligible effect at room temperature. The studies of Wang\textsuperscript{10} indicate that in n-type germanium, the longitudinal magneto-resistance effect is more pronounced than the transverse effect. But according to Smith\textsuperscript{11}, the longitudinal magneto-resistance is much smaller than the transverse component in p-type germanium and silicon.

Sandiford\textsuperscript{12} and Bernard\textsuperscript{13} were probably the first, to study the effect of temperature on the characteristics of p-n junctions of silicon and germanium. Explanation for the temperature dependence of the device characteristics have been given by Strutt\textsuperscript{14}. Capacitance measurements on reverse biased p-n junctions near avalanche breakdown region have been done by Sudha Mahadevan and Suryan\textsuperscript{15}. The variation of transistor volt-ampere characteristics as a function of temperature has been discussed briefly by Searle et al\textsuperscript{16}. The temperature dependence of transconductance $g_m$ and drain resistance $r_d$ of junction field effect transistors has been discussed briefly by Willman and Halkias\textsuperscript{17}. The importance of zero temperature coefficient
point has been stressed by Jamwal and Peer. Shift of peak voltage with increasing temperature in tunnel diodes was studied by Nanavathi. Though the temperature dependence of UJT characteristics has already been studied, no clear explanation is given for the dependence of peak voltage and valley voltage.

The effect of magnetic field on the characteristics of diode portions of germanium transistors 2N34 and 2N35 was studied by Srivastava and Misra. They found a decrease in diode current on the application of magnetic field. Karakushan and Staeev have observed a large decrease in the current of a long diode at high injection currents. Parshal and Mehta carried out their experiments on a large variety of germanium and silicon diodes at room temperature and liquid air temperature. They reported that germanium diodes show a large decrease in forward current on the application of magnetic field while the effect of magnetic field on silicon diodes is negligible. Khan constructed a transistorized gausmeter, using germanium diode as a magnetic probe. Parshad et al observed that the magnetic field has no effect on the lifetime of minority carriers in germanium and silicon diodes. But Misra and Srivastava observed that the lifetime of minority carriers in alloy junction
transistors decreases under the influence of magnetic field. Ramaswami et al.\textsuperscript{27} also observed a change in the minority carrier lifetime in emitter-base diodes of germanium transistors under the influence of a magnetic field of field strength 20 kOe. Visra\textsuperscript{28} has observed a decrement in the current gain of 2N654 germanium transistor, on the application of magnetic field. Parshad and Nehta\textsuperscript{29} studied the effect of magnetic field on the current amplification factor of germanium and silicon transistors and they observed that the magnetic field has negligible effect on the current gain of silicon transistors. Singh and Prasad\textsuperscript{30} reported that the power law transfer characteristic of JFETs remain unchanged even in the presence of a magnetic field of strength 12kOe. Jain and Agarwal\textsuperscript{31} studied the effect of magnetic field on the drain current and transconductance of JFETs. They suggested that the decrease in drain current can be utilised in constructing a low cost gauss meter. Yamada\textsuperscript{32} studied the effect of magnetic field on the characteristics of germanium long p-i-n structures. He observed a decrease in the forward current on the application of positive magnetic field and an increase in the current on the application of negative magnetic field. This property was utilised in designing a circuit to provide simple means for detecting magnetic fields. The behaviour of tunnel current in Sasaki diodes in a magnetic
field has been investigated by various workers\textsuperscript{35-38}.

Though a good beginning is made in the study of the properties of semiconductor devices vis., diodes and transistors, by various workers mentioned, the increasing importance of these devices in industry, technology and in our daily life stressed the author to take up a systematic study on the physical behaviour of a few of these devices. The main object of interest in the present study is to understand the transport behaviour of charge carriers in p-n junction devices, as a function of temperature and in static magnetic field, and to see how far the characteristics and parameters of these devices are affected by these external influences and also to see the resultant effect of temperature and magnetic-field, on the bulk regions after they are sandwiched to form p-n junctions. An attempt is also made to make use of the susceptibility of the characteristics of these devices to the external influences, for practical applications.

Studies on the effect of temperature and magnetic field on the forward and reverse characteristics of p-n junction diodes and on the breakdown voltage of zener-diodes have been taken up and the results are presented in chapter 2. The results of the studies carried out on the effect of temperature and magnetic field on the
collector characteristics and current gain of junction transistors, drain and transfer characteristics of field effect transistors and peak and valley voltages of uni-junction transistors are presented in chapter 3.
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