NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
HALL EFFECT INVESTIGATIONS
QUARTERLY PROGRESS REPORT
1 JANUARY TO 31 MARCH 1963

H. H. WIEDER
A. R. CLAWSON

RESEARCH DEPARTMENT

NAVWEPS REPORT 8156
15 MAY 1963

NAVAL ORDNANCE LABORATORY CORONA
CORONA, CALIFORNIA
ABSTRACT

The properties of Cu-doped p-type films of InSb on pyrex substrates are described in terms of the two-band charge carrier model applied to bulk crystalline InSb. The calculated virtual mobility ratio is shown to be of the order of 32, which is in fair agreement with values expected from the polycrystalline material. Data from present and past experiments on annealing and recrystallization of vacuum-deposited films are in agreement.
FOREWORD

A continuing study of the Hall effect in thin semiconductor films is being conducted at the Naval Ordnance Laboratory, as authorized by the Bureau of Naval Weapons WepTask RREN-04-371/211-1/F008-01-15. This work is aimed toward the development of thin film Hall generators and other devices based upon the Hall effect. Electrical and electronic components and circuits employing this phenomenon are also being investigated.

This third quarterly report covers the period 1 January to 31 March 1963.

C. J. HUMPHREYS
Head, Research Department
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>Inside front cover</td>
</tr>
<tr>
<td>FOREWORD</td>
<td>i</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>GENERAL RELATIONS FOR THE MIXED CONDUCTIVITY REGION OF InSb FILMS</td>
<td>2</td>
</tr>
<tr>
<td>EXPERIMENTAL</td>
<td>6</td>
</tr>
<tr>
<td>RECRYSTALLIZED InSb FILMS ON PYREX</td>
<td>14</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>16</td>
</tr>
</tbody>
</table>
INTRODUCTION

Previous progress reports (Refs. 1 and 2) discussed the properties of indium antimonide films produced by means of the three-temperature control process. It was shown that considerable scatter in the electron mobility $\mu$ and the conductivity $\sigma$ were found in films produced sequentially under conditions of evaporation and processing assumed to be identical.

All the films were n-type throughout a temperature range of 373 to 87°K. The scatter in $\mu$ and $\sigma$ could be due to a variety of causes; two of these were selected for further investigations.

1. The size of the crystallites making up the film has a considerable effect on the virtual electron mobility. Consequently, the development of methods for growing films composed of a few large crystals is desirable. One such method was discussed in the last progress report (Ref. 2). Further studies along this line were carried out during this reporting period and will be continued.

2. The compensation by acceptor impurities, of either impurity-activated or intrinsically generated electrons was considered to be another possible reason for the observed scatter. This is particularly likely if the impurities diffuse rapidly through the film during its formation and if the concentration of such impurities varies during sequential evaporations.

It has been found that copper acts as a p-type impurity in InSb and, even in very small concentration, tends to create a compensation effect such as proposed above. Since Cu is present in the evaporation chamber (Ref. 3) as part of the cooling system and other fixtures, its effects need to be considered in the evaluation of the galvanomagnetic properties of films produced by present techniques.

In this report, the properties of InSb films, deliberately Cu-doped, will be discussed in terms of the two-band model applied to bulk InSb. Data will also be presented on further annealing and alloying studies of InSb films deposited on pyrex substrates.
GENERAL RELATIONS FOR THE MIXED CONDUCTIVITY REGION OF InSb FILMS

In the discussion below, the following assumptions are made:

1. The InSb film is a semiconductor obeying classical statistics, the electrons and holes being contributed by intrinsic generation as well as by impurity activation.

2. The temperature region is that in which all donors and acceptors are and remain ionized.

3. Surfaces of constant energy in momentum space are spherical.

4. Mean free paths of both holes and electrons are independent of energy. This is true if thermal scattering is the only significant scattering mechanism; i.e., if scattering from ionized impurity centers is disregarded.

The relations for the Hall coefficient $R_h$ and the conductivity $\sigma$ (Ref. 1) are then

$$R_h = \left( -\frac{1}{e} \right) \frac{nb^2 - p}{nb + p} \sigma = ne\mu_n + pe\mu_p$$

where

- $n$ = the electron concentration per cm$^3$
- $p$ = the hole concentration per cm$^3$
- $b = \mu_n/\mu_p$, the ratio of the electron to hole mobilities
- $e$ = charge on the electron

In this equation it is considered that the drift mobility $\mu_d$ and the Hall mobility $\mu_H$ are equal.

Let the concentration per cm$^3$ of donors be $N_D$ and that of acceptors be $N_A$. Then

$$p - N_A = n - N_D$$

Solving equation (2) for $p$ and substituting this value in equation (1) yields

$$R_h = \left( -\frac{1}{e} \right) \frac{n(b^2 - 1) - N_A + N_D}{[nb + 1 + N_A - N_D]^2}$$
The maximum value of $R_h$ may be determined from $\frac{dR_h}{dn} = 0$; hence, from equation (3)

$$\frac{dR_h}{dn} = \frac{b^2 - 1}{[b^2 - 1]^2} \cdot \frac{n(b^2 - 1) - N_A + N_D}{2(b + 1)} = 0 \quad (4)$$

which becomes

$$(b^2 - 1)[n(b + 1) + N_A - N_D] = 2(b + 1)[n(b^2 - 1) - N_A + N_D] \quad (5)$$

Dividing by $(b^2 - 1)$ yields

$$n(b + 1) + N_A - N_D = 2(b + 1) \left( n - \frac{N_A - N_D}{b^2 - 1} \right) \quad (6)$$

Solving for $n$ gives

$$N_A - N_D + 2(b + 1) \left( \frac{N_A - N_D}{b^2 - 1} \right) = 2n(b + 1) - n(b + 1) \quad (7)$$

Hence

$$(N_A - N_D)(b^2 - 1) + 2(b + 1)(N_A - N_D) = n(b + 1)(b^2 - 1) \quad (8)$$

By collecting terms

$$[b + 1](b - 1)(N_A - N_D) + 2(N_A - N_D) = n(b + 1)(b^2 - 1) \quad (9)$$

Hence

$$(N_A - N_D)(b + 1) = n(b^2 - 1) \quad (10)$$

Therefore, at the temperature at which $R_h$ is a maximum,

$$n_m = \frac{b + 1}{b^2 - 1} (N_A - N_D) = \frac{N_A - N_D}{b - 1} \quad (11)$$
The value of \( n \) from equation (11) is substituted in equation (3) to yield the value of \( R_{hm} \).

\[
R_{hm} = \left( \frac{1}{e} \right) \left( \frac{N_A - N_D}{b - 1} \right) \left( \frac{b^2 - 1}{(b + 1) + (N_A - N_D)} \right)^2
\]

By rearranging terms and performing the required algebraic manipulations, this becomes

\[
R_{hm} = \left( \frac{1}{e} \right) \left( \frac{(N_A - N_D)(b - 1)b}{2b(N_A - N_D)^2} \right)
\]

Thus

\[
R_{hm} = \left( \frac{1}{4be} \right) \left( \frac{b - 1}{N_A - N_D} \right)^2
\]

Now consider the situation in the extrinsic (impurity-activated) temperature region. Let the electron concentration \( n \) be zero; then from equation (2) \( p = N_A - N_D \), and from equation (3)

\[
R_{hx} = \left( \frac{1}{e} \right) \left( \frac{1}{N_A - N_D} \right)
\]

The ratio of \( R_{hm}/R_{hx} \) is therefore, by means of equations (14) and (15),

\[
\frac{R_{hm}}{R_{hx}} = \frac{(b - 1)^2}{4b}
\]

A minimum in \( R_h \) may be determined from equation (1)—i.e., \( nb^2 = p \), and from equation (3)—i.e., \( n(b^2 - 1) = N_A - N_D \). Both of these correspond to \( R_h = 0 \). Note that if \( (R_h)_{ex} \) is determined experimentally the quantity \( (N_A - N_D) \) may be calculated. Since, in general,

\[
np = n_1^2
\]

introducing equation (2) into equation (17) yields
\[ n(n + N_A - N_D) = n_i^2 \]  

Consequently, \( n^2 + n(N_A - N_D) = n_i^2 \); thus

\[ n = -\frac{(N_A - N_D)}{2} \pm \frac{1}{2} \left[ \left( N_A - N_D \right)^2 + 4n_i^2 \right]^{\frac{1}{2}} \]  

(19)

Therefore, if \( n_i \) is known at any temperature, \( n \) may be calculated, provided that \( (N_A - N_D) \) has first been determined in the extrinsic region. Equation (11) may now be rewritten

\[ n_m = \frac{N_A - N_D}{b - 1} = -\frac{N_A - N_D}{2} \pm \frac{1}{2} \left[ \left( N_A - N_D \right)^2 + 4n_i^2 \right]^{\frac{1}{2}} \]  

(20)

Solving for this yields

\[ (N_A - N_D) \left( \frac{1}{b - 1} + \frac{1}{2} \right) = \frac{1}{2} \left[ \left( N_A - N_D \right)^2 + 4n_i^2 \right]^{\frac{1}{2}} \]  

(21)

which, upon further algebraic manipulation, becomes

\[ (N_A - N_D) \left( \frac{b + 1}{b - 1} \right) = \left[ \left( N_A - N_D \right)^2 + 4n_i^2 \right]^{\frac{1}{2}} \]  

(22)

\[ (N_A - N_D)^2 \left( \frac{b + 1}{b - 1} \right)^2 = (N_A - N_D)^2 + 4n_i^2 \]  

(23)

By collecting terms, this becomes

\[ \left( N_A - N_D \right)^2 \left[ \frac{(b + 1)^2}{(b - 1)^2} - 1 \right] = 4n_i^2 = \left( N_A - N_D \right)^2 \left[ \frac{(b + 1)^2 - (b - 1)^2}{(b - 1)^2} \right] \]  

(24)

Consequently,

\[ 4n_i^2 = \left( N_A - N_D \right)^2 \left[ \frac{b^2 + 2b + 1 - b^2 + 2b - 1}{(b - 1)^2} \right] \]  

(25)

Therefore, at the temperature for which \( R_h \) is a maximum,
Equation (26) may, however, be derived in a much simpler fashion. In equation (18), note that

\[ n_{im} = N_A - N_D \left( \frac{b^2}{b - 1} \right) \]  

Equation (26) may, however, be derived in a much simpler fashion. In equation (18), note that

\[ n_{im}^2 = n_m^2 + n_m \left( N_A - N_D \right) \]  

Replacing \( n_m \) in equation (27) by its value in equation (18)

\[ n_{im}^2 = \left( \frac{N_A - N_D}{b - 1} \right)^2 + \left( \frac{N_A - N_D}{b - 1} \right)^2 = \left( \frac{N_A - N_D}{b - 1} \right)^2 \frac{b}{(b - 1)^2} \]  

which immediately yields equation (27).

**EXPERIMENTAL**

Figure 1 shows the Hall voltage \( V_H \) as a function of drive current \( I_H \) in a constant magnetic field of \( H = 5 \times 10^3 \) oersteds at \( 23^\circ \)C ambient, for a Cu-doped InSb film on glass (Sample 88A). The Hall voltage is linear in \( I_H \) for values smaller than \( 10 \) mA. For higher drive currents \( V_H \) rises in a nonlinear manner because of induced Joule heating in the sample. The Hall coefficient therefore rises with temperature, contrary to the behavior of the undoped InSb films, which exhibit a decrease in \( R_H \) with temperature (Ref. 1).

Figure 2 shows \( R_H \) as a function of the reciprocal absolute temperature for the sample measured in the linear region defined by \( V_H \) as a function of \( I_H \). The curve is typical of p-type InSb, showing a maximum in \( R_H \) and an inversion in sign below the temperature at which \( R_H = 0 \). Data for \( R_H \) was obtained in the linear region of a curve like that of Figure 1. Subsequent tests for the thermoelectric potential between a hot and cold junction in contact with the sample while the latter was immersed in liquid nitrogen showed that, in the extrinsic region, the charge carriers are holes.

Figure 3 shows the dependence of the sample conductivity \( \sigma \) upon the absolute temperature. The conductivity was determined from two-terminal measurements of resistance made across the drive electrodes and the geometry of the sample. The thickness was determined from
FIGURE 1. Hall Voltage Dependence Upon Drive Current of a Cu-Doped InSb Film at 23°C in a Magnetic Field of $5 \times 10^3$ Oersteds
FIGURE 2. Dependence of the Hall Coefficient Upon the Absolute Reciprocal Temperature for a Cu-Doped InSb Film in a Magnetic Field of $5 \times 10^3$ Oersteds.
FIGURE 3. Dependence of the Electrical Conductivity Upon the Reciprocal Absolute Temperature at Zero Magnetic Field for a Cu-Doped InSb Film
infrared reflection interference measurements (Ref. 3) and is at best an average value. The dispersion across the sample is not known. Therefore, the conductivity values shown in Figure 3 should be regarded as nominal although, over the temperature region shown, the values are self-consistent to within the experimental error estimated at less than 2 percent. By taking the drift mobility $\mu_d$ to be identical with the Hall mobility $\mu_H$, the concentration of impurities may be determined from the temperature-independent extrinsic Hall coefficient $R_h$ in Figure 2.

Since $(R_h)_m = -120 \text{ cm}^3/\text{coul}$ and $(R_h)_x = 16 \text{ cm}^3/\text{coul}$, then from equation (16)

$$\frac{(R_h)_m}{(R_h)_x} = -7.5 = \frac{(b - 1)^2}{4b}$$

and therefore

$$30b = (1 - b)^2 \quad (29)$$

The mobility ratio $b$ is therefore

$$b = 16 \pm \frac{1}{2} \left(32^2 - 4\right)^{1/2} = 16 \pm \frac{1}{2}(1020)^{1/2} = 16 \pm 15.97 \quad (30)$$

By rejecting the negative root it is found that

$$b = 32 \quad (31)$$

The impurity concentration may now be calculated from equation (15) as

$$\left(\frac{N_A - N_D}{N_A - N_D}\right)^{-1} = \frac{e(R_h)_x}{1.6}(10^{-19}) 16 = (2.56)(10^{18})$$

$$\left(\frac{N_A - N_D}{N_A - N_D}\right) = (3.91)(10^{17}) \text{ holes/cm}^3 \quad (32)$$

By using equation (11), the electron concentration at the temperature for which $R_h$ is a maximum is

$$n_m = \frac{(3.91)(10^{17})}{31} = (1.26)(10^{16}) \text{ electrons/cm}^3 \quad (33)$$

By means of equation (2), hole concentration at the same temperature is
\[ p_m = (3.91)(10^{17}) + (0.126)(10^{17}) = (4.04)(10^{17}) \text{ holes/cm}^3 \quad (34) \]

By using equation (26), the intrinsic electron concentration at the same temperature is

\[ (n_i)_{max} = (3.91)(10^{17}) \frac{5.65}{31} = (7.12)(10^{16}) \text{ electrons/cm}^3 \quad (35) \]

It is seen, therefore, that the hole concentration is nearly one order of magnitude larger than the intrinsic electron concentration at \( R_h = R_{hm} \) and thus causes a considerable compensation effect. The general expression for the conductivity is \( \sigma = e\mu_p [n(b + 1) + N_A - N_D] \) and since \( \sigma_m = 23.5 \text{ (ohm-cm)}^{-1} \) from Figure 3, it follows that

\[ \mu_{pm} = \frac{\sigma_m}{e[n_m(b + 1) + N_A - N_D]} \quad (36) \]

The hole mobility for \( R_h = R_{hm} \) is therefore given by

\[ \mu_{pm} = \frac{23.5}{(1.6)(10^{-19})(1.26)(10^{16})(33 + 39.1)(10^{16})} \quad (37) \]

Thus, the hole mobility is

\[ \mu_{pm} = 182 \text{ cm}^2 \text{ (volt-sec)}^{-1} \quad (38) \]

and the electron mobility \( \mu_n \) is

\[ \mu_n = 32 \mu_p = 5.824 \times 10^3 \text{ cm}^2 \text{ (volt-sec)}^{-1} \quad (39) \]

These mobilities are considerably lower than the values to be expected from bulk InSb. However, even in n-type films of InSb the electron mobilities are smaller by a factor of three than in the crystalline material. The origin of the scattering mechanism responsible for this effect is not yet known.

The electron and hole concentrations may be calculated quite easily at the temperature where \( R_h = 0 \) since \( n_0 b^2 = p_0 \). Equation (2) still applies and it follows that

\[ n_0 + N_A - N_D = m_0 b^2 \quad (40) \]
If the mobility ratio is assumed to be essentially temperature-independent over the temperature range between \( R_{hm} \) and \( R_h = 0 \), then

\[
\begin{align*}
n_0 &= (3.82) \times 10^{14} \text{ electrons/cm}^3 \\
p_0 &= (3.91) \times 10^{17} \text{ holes/cm}^3
\end{align*}
\]  

(41)

The conductivity at this temperature may be expressed in terms of equation (1) as

\[
\sigma = e n_0 \mu_n n_0 (1 + b) \tag{42}
\]

Using the value \( \sigma_0 = 9 \text{(ohm-cm)}^{-1} \) determined from Figure 3 and the \( n_0 \) calculated above, the electron mobility decreased from its value at \( R_h = R_{hm} \) to \( \mu_n n_0 = 4460 \text{ cm}^2/(\text{volt-sec}) \) at \( R_h = 0 \). The hole mobility is then

\[
\mu_p n_0 = \frac{\sigma_0/e}{n_0 (b + 1) + N_A - N_D} \tag{43}
\]

Hence, \( \mu_p n_0 = 139 \text{ cm}^2/(\text{volt-sec}) \). Since it has been assumed that \( b \) is a constant, both \( \mu_n \) and \( \mu_p \) have decreased from their value at \( R_{hm} \) to \( R_h = 0 \) by approximately 24 percent.

The concentration of intrinsically generated electrons at the temperature for which \( R_h = 0 \) may be derived by means of equation (18) is

\[
n_{i0}^2 = n_i^2 + n_i (N_A - N_D) \tag{44}
\]

With equation (40) substituted into (44)

\[
n_{i0} = (N_A - N_D) \left( \frac{b}{b^2 - 1} \right) \tag{45}
\]

The intrinsic electron concentration at this temperature is therefore \( n_{i0} = (1.22) \times 10^{16} \text{ electrons/cm}^3 \), which may be contrasted with the earlier calculated value of \( n_{im} = (7.12) \times 10^{16} \text{ electrons/cm}^3 \) at \( R_h = R_{hm} \).

The concentration of intrinsically generated electrons in InSb may be expressed to a fair approximation (Ref. 4) as
\[ n_1 \approx (5.7)(10^{14} T^{3/2}) \exp(-0.125/kT) \]  

(46)

Thus, using equation (45) with \( A = (5.7)(10^{14} T^{3/2}) \),

\[ \frac{b(N_A - N_D)}{A(b^2 - 1)} = \exp(-0.125/kT) = \frac{N_A - N_D}{Ab} \]

(47)

Consequently, since \( k = (8.63)(10^{-5} \text{ ev * K}^{-1}) \),

\[ \frac{(1.448)(10^3)}{T_0} = \log Ab - \log (N_A - N_D) \]

(48)

Thus, the temperature \( T_0 \) at which \( R_h = 0 \) is given as a function of the impurity concentration is

\[ T_0 = \frac{(1.448)(10^3)}{\log Ab - \log (N_A - N_D)} \]

(49)

An increase in the concentration of acceptor centers leads to an upward shift in \( T_0 \). An increase in the Cu concentration should, therefore, lead to a displacement of \( T_0 \) toward higher temperatures; this was verified experimentally. Since \( b >> 1 \) in InSb, the ratio \( \frac{n_{im}}{n_{i0}} \) may be expressed as

\[ \frac{n_{im}}{n_{i0}} = \frac{(b + 1)}{b^2} \approx b^{1/2} \]

(50)

With \( b^{1/2} = 5.65 \), \( n_{im} = (7.12)(10^{16}) \) electrons/cm\(^2\). It follows that \( n_{i0} \) should be \( (1.26)(10^{16}) \) electrons/cm\(^3\). This, of course, is in fair agreement with the value of \( n_{i0} = (1.22)(10^{16}) \) electrons/cm\(^3\) calculated by means of equation (45).

The experimental data presented here illustrate the significant effect of Cu in doping InSb films. Since, for the present, we are concerned primarily with obtaining uncompensated electronic conduction in these films, efforts will be made to keep acceptor impurities out of the evaporation system in the hope of obtaining better reproducibility of deposition.

The properties and application of other p-type doped films are reserved for further extensive investigations.
RECRYSTALLIZED InSb FILMS ON PYREX

The procedure for recrystallizing InSb films described in the last progress report (Ref. 2) was used on additional films in order to confirm the advantages of this post-evaporation processing. A summary of the experimental data is shown in Table 1. The resistance of the films has decreased by a factor of 10 to 30; the mobility has increased by a factor of 5 to 10.

The improvement in the films as a result of the recrystallization may be seen in:

1. A decrease in the effective resistance of individual Hall generators and consequently a smaller voltage drop across them for a given Hall current. Since the maximum Hall current is limited by the thermal dissipation of the film and substrate, higher currents may be applied to the samples after recrystallization processing without exceeding the nominal value imposed by the onset of Joule heating.

2. For a fixed magnetic field sensitivity expressed as \( \frac{v_h}{B} \), the recrystallized films exhibit a smaller input power dissipation and consequently a smaller thermal drift of the misalignment potential.

Assuming that the magnetic field sensitivity \( \frac{v_h}{B} \) is a parameter held constant before and after recrystallization, the ratio of \( P_b \), the input power before annealing, to \( P_a \), the power required after annealing in order to obtain this sensitivity, is

\[
\frac{P_b}{P_a} = \left( \frac{\frac{v_h}{iB}}{r_b} \right)^2 \frac{r_b}{r_a}
\]

In a similar fashion the input potential to the Hall plate before and after annealing and recrystallization is given by

\[
\frac{v_b}{v_a} = \left( \frac{\frac{v_h}{iB}}{r_b} \right) \frac{r_0}{r_b}
\]

In view of the results illustrated in the following table and the earlier data (Ref. 2), the advantages of the recrystallization process are considered to be firmly established. It is apparent that the process
TABLE 1. DATA ON InSb FILMS ON PYREX, BEFORE AND AFTER BEING INDIUM-COATED AND RECRYSTALLIZED

<table>
<thead>
<tr>
<th>Sample</th>
<th>$v_{H/iBr}$</th>
<th>$v_{H/iB}$</th>
<th>Input Voltage</th>
<th>Input Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0 \times 10^{-6}$</td>
<td>$r_0$</td>
<td>$(v_b/v_a)$</td>
<td>$(P_b/P_a)$</td>
</tr>
<tr>
<td>Before</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>103A</td>
<td>4.1</td>
<td>35.4</td>
<td>3010</td>
<td>115</td>
</tr>
<tr>
<td>103B</td>
<td>4.1</td>
<td>32.0</td>
<td>3010</td>
<td>276</td>
</tr>
<tr>
<td>103C</td>
<td>4.1</td>
<td>32.8</td>
<td>3010</td>
<td>108</td>
</tr>
<tr>
<td>104A</td>
<td>4.6</td>
<td>11.9</td>
<td>835</td>
<td>730</td>
</tr>
<tr>
<td>(partially boiled off)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>104B</td>
<td>4.6</td>
<td>22.0</td>
<td>835</td>
<td>81</td>
</tr>
<tr>
<td>105A</td>
<td>4.4</td>
<td>23.7</td>
<td>1650</td>
<td>81</td>
</tr>
<tr>
<td>105B</td>
<td>4.4</td>
<td>24.9</td>
<td>1650</td>
<td>58</td>
</tr>
<tr>
<td>105C</td>
<td>4.4</td>
<td>21.7</td>
<td>1650</td>
<td>60</td>
</tr>
<tr>
<td>106A</td>
<td>2.7</td>
<td>30.9</td>
<td>1630</td>
<td>33</td>
</tr>
</tbody>
</table>

should apply to other semiconductors as well. Additional procedures for improving the crystallinity of the deposit will be investigated during the next reporting period.
REFERENCES


1. Semiconducting films—Electromagnetic properties
2. Hall effect
3. Clawson, A.

The properties of Cu-doped p-type films of InSb on pyrex substrates are described in terms of the two-band charge carrier model applied to bulk crystalline InSb. The calculated virtual mobility ratio is shown to be of the order of 32, which is in fair agreement with values expected from the polycrystalline material. Data from present and past experiments on annealing and recrystallization of vacuum-deposited films are in agreement.

This is the third report in the series. Preceding reports were NAVWEPS Report 7242 (1 July–30 September 1962) and NAVWEPS Report 8148 (1 October–31 December 1962).

---

1. Semiconducting films—Electromagnetic properties
2. Hall effect
3. Wieder, H.
4. Clawson, A.

The properties of Cu-doped p-type films of InSb on pyrex substrates are described in terms of the two-band charge carrier model applied to bulk crystalline InSb. The calculated virtual mobility ratio is shown to be of the order of 32, which is in fair agreement with values expected from the polycrystalline material. Data from present and past experiments on annealing and recrystallization of vacuum-deposited films are in agreement.

This is the third report in the series. Preceding reports were NAVWEPS Report 7242 (1 July–30 September 1962) and NAVWEPS Report 8148 (1 October–31 December 1962).
### INITIAL DISTRIBUTION

<table>
<thead>
<tr>
<th>Copies</th>
<th>Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Chief, Bureau of Naval Weapons**

Navy Department  
Washington 25, D. C.  
Attn: Code RA

**Director**  
National Bureau of Standards  
Washington 25, D. C.  
Attn: Div. 14.1 (S. Rubin)

**Officer in Charge**  
Naval Weapons Services Office  
U. S. Naval Station  
(Washington Navy Yard Annex)  
Washington 25, D. C.  
Attn: Code 120

**Defense Documentation Center**  
Arlington Hall Station  
Arlington 12, Virginia

**Commander**  
Naval Ordnance Laboratory  
White Oak  
Silver Spring, Maryland  

**Director**  
Naval Research Laboratory  
Washington 25, D. C.  
Attn: Code 5210 (A. Brodzinsky)

**Commanding Officer**  
Naval Avionics Facility  
Indianapolis, Indiana  
Attn: Code 902 (D. Triller)

**Commanding Officer**  
Naval Air Development Center  
Johnsville, Pennsylvania  
Attn: Code E. L. 52 (H. Martin)

**Applied Physics Laboratory**  
Johns Hopkins University  
Howard County, Maryland  
Attn: Code GME (W. Liben)

**Motorola, Inc.**  
Military Electronics Division  
Chicago Center  
1450 N. Cicero Avenue  
Chicago 51, Illinois  
Attn: Dr. Ernest A. Keller

**NOLC:**

C. J. Humphreys, Code 40  
R. L. Conger, Code 42  
A. R. Clawson, Code 423  
H. H. Wieder, Code 423  
R. F. Potter, Code 43  
Technical Library, Code 234

NOLC 7-63-100