Design and construction of a device for measuring the density of carriers of thin semiconductor films by using thermoelectric power

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Abstract: A simple system for measuring some electrical properties of thin semiconductor films is presented by using the technique of thermoelectric power. In order to achieve a precise temperature control two Peltier junction were used to generate a gradient of temperature in the semiconductor films. Measurements were realized in Erbium doped CdS thin films in order to asses the density of carriers and the type of carrier..

Key-words: Thin films, semiconductors, thermoelectric power, Peltier junction.

1. Introduction

The density, type and the mobility of carriers are some of the most important features in the study of the electrical properties in semiconductors thin films, they determine their specific application in electronic devices. In the frame of electronic transportation the thermoelectricity or thermoelectric power is the most sensitive method for studying differences of the Fermi level [1] in doped materials with resistivities between 10^{-3}-10^{3} Ω/cm^2. Besides, thermoelectric power is one of the independent methods for evaluating the sign, the density and the mobility of the majority carriers in a doped semiconductor material. The main problem when thermoelectric power measurements are carried out is the presence of noise, since the generated voltage is the order of microvolts. In this work an electronic system has been designed with the purpose to reduce the effects of noise and to solve the problem of measuring high resistivity samples in which the technique of Hall effect is no longer a possibility.

2. Thermoelectric power

When a temperature gradient is generated through a semiconductor material, a differential voltage (ΔV) is developed by the sample, this phenomenon is known as the Seebeck effect and the thermoelectric power coefficient α is defined as [2]:

$$\alpha(\overline{T}) = -\frac{d(\Delta V)}{d(\Delta T)} \qquad (1)$$

where $\overline{T}$ is the average temperature.

If a spherical model of bands is used and scattering of carrier is mainly due to phonons, the thermoelectric power coefficient α can be represented, after some steps, by the following function:

$$|\alpha| = 86\left[x - \frac{2F_1(x)}{F_0(x)}\right]\frac{\mu V}{°K} \qquad (2)$$

where:

F_1 y F_0 are the Fermi integral of order 1 and 0 respectively [3].

The concentration of majority carriers, n (or p) at room temperature can be described by

$$\mathrm{n(x)} \cong 2.82\times10^{19}\left(\frac{\mathbf{m}^*}{\mathbf{m}_0}\right)^{3/2}\mathbf{F}_{1/2}(\mathbf{x})\mathbf{cm}^{-3} \qquad (3)$$

where:

m^* = Effective mass (~0.1 m_0 for electrons in the conduction band, ~0.4 m_0 for holes in the valence band in case for instance)

m_0 = Electron rest mass.

$F_{1/2}$ is the Fermi function of order ½ [4]. Because (2) and (3) are functions of x, the density of majority carriers can be determined as a function of the thermopower directly, if the Fermi integrals tabulated by J. Tauc are used [5]. In Eqs. (2) and (3) x equals(E_f-E_c)/KT for electrons and (E_v-E_f)/KT for holes. Here E_f means fermilevel

$F_{1/2}(x)$, $F_0(x)$ and $F_1(x)$ are evaluated for each *x* used here as a parameter, in order to determine *n* as a function of α. The plot of *n* vs α is shown in figure 1 for CdSe.

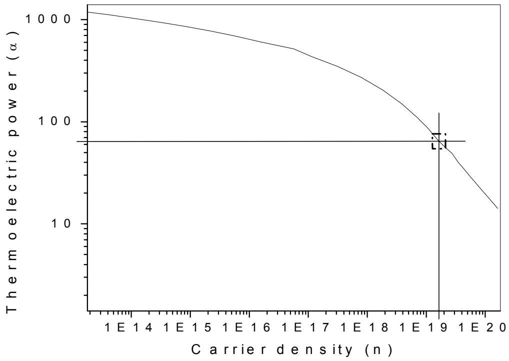

Figure 1. Graph of n vs α .

The intersection of the curve with the value of the thermoelectric measured gives the density of carriers *n* of CdSe.

3. MEASUREMENT TECHNIQUES AND NOISE SUPRESSION

Upon measuring extremely small voltages one has mainly to deal with two problems, one of them is the measurement process, the instrument of measure affects the system which is being measured, in other words, the instrument frequently takes part of the variable for carrying out the measurement. This effect is illustrated in Figure 2:

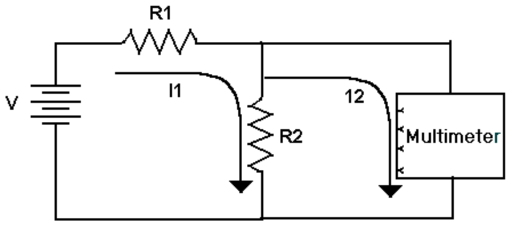

Figure 2. Load Effect in a measurement.

A conventional multimeter has an input impedance of 10MΩ, which means that this instrument needs a current of 1Volt/10MΩ=10^{-7}Amperes for each volt of reading. If one divide this current by the value of the electron charge the number of carriers per second necessary for accomplish 1 volt of measuring is obtained.

This value is far away from zero, hence a possible solution is to use a meter with greater impedance, however this solution is not the cheapest solution, a better solution is to use an instrumentation amplifier like the AD620, which has an input impedance of 10GΩ. With this amplifier it is only necessary to reach $1\text{Volt}/10\text{G}\Omega=10^{-10}$ Amperes, in this way the sample is affected 10^3 times less than in the previous case.

Another problem to deal is the noise. The presence of noise degrades the quality of a signal and imposes the ultimate limit of the magnitude of signals that can be successfully detected, measured and interpreted. The quality of signal in presence of noise is specified by means of signal to noise ratio (SNR), defined as the ratio of the power of the signal to the power of the noise E_n^2, the root-mean-square (rms) value E_n of a noise voltage is defined as:

$$E_n = \sqrt{\frac{1}{\tau}\int_0^{\tau} e_n^2(t)dt} \qquad (4)$$

Where τ is a suitable averaging time interval, $e_n(t)$ represents the instantaneous value of the noise. Similar to case of conventional ac signals the value of E_n^2 represents the average power dissipated by the corresponding noise signal in a 1 Ω resistor. In the case of noise and other type of signals there is a very important relationship between the bandwidth (BW) of the detection and the average power measured given by

$$E_n^2 = \frac{1}{2\pi}\int_0^{BW} S_n(\omega)d\omega \qquad (5)$$

where $S_n(\omega)$ is the spectral noise power density.

The minimum detectable signal is defined as the mean signal that yields SNR=1, Figure 3 shows the spectral noise density of the AD620 provided by the manufacturer

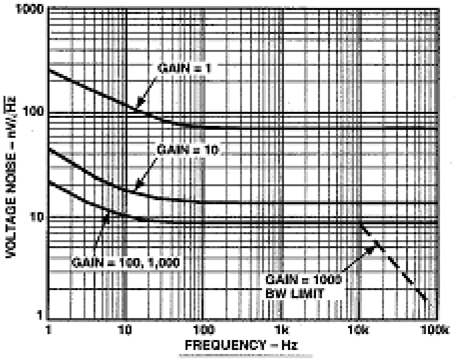

Figure 3. Spectral noise density in nano volts (nV) over square root of the frequency in Hertz (Hz) of the AD620 instrumentation amplifier.

The figure 3 shows the square root of the spectral noise density $S_n(\omega)$, the $\sqrt{S_n(\omega)}$ spectrum noise has a constant value of $9\frac{nV}{\sqrt{Hz}}$ if the gain of the amplifier is 100 or more, this gain is tuned by using an external resistor connected between the terminals 1 and 8 of the AD620, in our case the value is 499 Ω, which gives a gain of 100.

The square value E_n^2 gives the power density, by using the equation (5) one obtains the total noise power due to the amplifier as:

$$E_n^2 = \left(9\frac{nV}{\sqrt{Hz}}\right)^2 BW \qquad (6)$$

where:

nV=is the voltage noise (nano-Volts)

Hz=Hertz

BW= Band With of detection

In order to reduce the noise power E_n^2, is necessary to reduce the bandwidth (BW) of the detection, this is achieved by using a passive first order low pass filter as shown in figure 4.

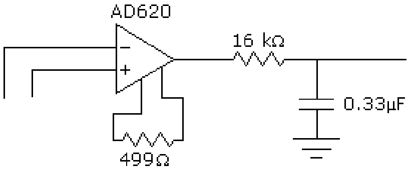

Figure 4. Circuit of carriers measurement.

The circuit has been projected to have a cutoff frequency of 30Hz, for further narrowing of the bandwidth, the average of the measurements by using a oscilloscope can be done.

3.1 Development of the thermoelectric power meter.

For measurements it is necessary to create, in first place a gradient of temperature in the sample. This was achieved by using thermo-coolers, which work as solid state heat pump. The pump is based on the Peltier effect.

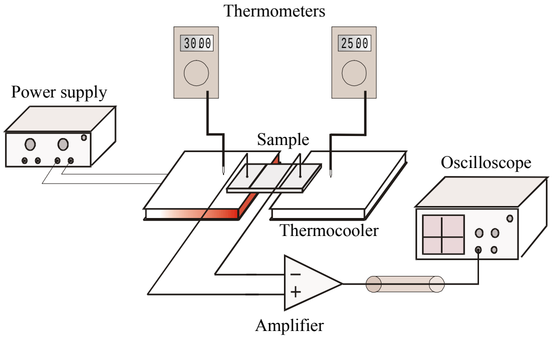

Figure 5. Electronic system used to determine the density of carriers.

This device generates 0.5°C of difference of temperature between its two larger faces for each 100mV applied. The resolution on temperature gives very good measurement results, besides this kind of devices allows us to maintain a precise temperature control. The semiconductor sample is placed between two thermo-coolers as shown in figure 5. One of them is controlled by a constant voltage, the other one is controlled by a variable voltage with this arrangement we produce a controlled gradient of temperature in the sample and with the instrumentation amplifier the thermo-voltage generated by the sample can be measured accurately. In order to avoid external interferences the whole system is placed in a metallic box.

4. Results of thermoelectric power

Our instrument was used on CdS samples films doped with different concentrations of Erbium, which were grown on glases by the technique of chemical bath. Erbium included into the CdS during the growth process. The increase of the dopant was obtained by means of an increase in the relative volume (Vr) of the salt contaning Er. Nine different values of Vr were employed.

The sign of the thermo voltage generated by the sample of CdS:Er indicates an *n* type material. Since the measurement of the thermoelectric power, corresponding to the different films of CdS:Er determined by the equation (1) and of the equation (3), the density of carriers could be evaluated. The results for different concentrations of dopant are shown in the following figure:

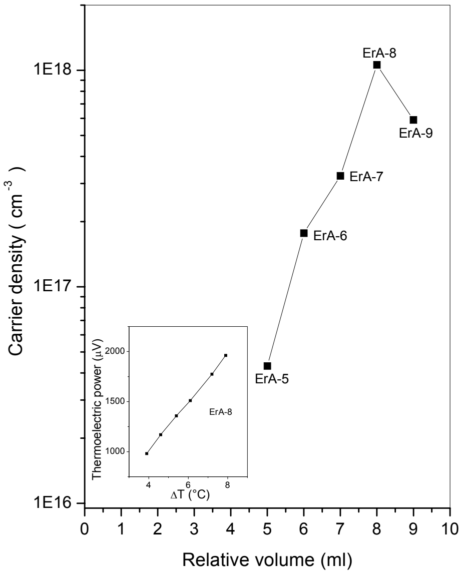

Figure 6. The density of carriers plotted against the relative volume. The inset illustrates the experimental points followed by the thermoelectric power as a function of the gradient ΔT of temperature applied.

In the figure 6 we can observe that the density of carriers enhances when the concentration of Er increaces also, this behavior was expected in this work by us as the conductivity augments when the Er concentration rises. Such process reaches a saturation at the sample Er-8 and then decays because trapping levels and dispersion by the impurities introduced is increased. Therefore the measurements done with the device constructed in this work are reliable. The inset of the same figure shows the method for evaluating α, for the sample Er-A8, defined in equation 1. Actually, an approximation to a linear behavior was used to have a unique slope value.

4.- CONCLUSIONS

The usefulness of the device fabricated was demonstrated in the measurements of the sign and density of carriers in Er-doped samples of Cds films.
On base of these results it can be said that we have developed an enough reliable electronic system for measuring the density of carriers in a doped semiconductor.

It was also demonstrated that by using cheap components it is possible to build a voltage meter with a input impedance extremely high which can be used in a thermo-power measurements device for high resistivity samples among other applications.

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