Studying the Effect of Magnetic Filed on the Electrical Properties of Germanium Diode

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Abstract:

The germanium P-N junction diode is used as a gauss meter probe. Depending on the magneto resistance of the diode a differential amplifier circuit has been designed and built for this purpose. The differential amplifier can detect and measure changes in electrical properties of the diode. Due to the fact that these changes are not linear to magnetic field, the circuit is further modified to produce out put reading that have linear relationships to magnetic field values.

دراسة تأثير المجال المغناطيسي على الخواص الكهربائية لثنائي الجرمانيوم

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ملخص البحث :

تم استخدام ثنائي (P-N) جرمانيوم كمجس لقياس المجالات المغناطيسي. بالاعتماد على خاصية المقاومة المغناطيسية تم تصميم وبناء مضخم تفاضلي لهذا الغرض. يستطيع هذا المضخم التفاضلي قياس التغيرات في الخواص الكهربائية للثنائي. ونظراً لكون هذه التغيرات لا تتصف استجابتها الخطية لتاثير المجالات المغناطيسية فقد تم تتطوير الدائرة بحيث تعطي قياسات تتناسب خطياً مع قيم المجال المغناطيسي.

Introduction :

The effect of various external conditions on the electrical behavior of commercial P-N junction diodes has been a subject of great interest since the early days of the semiconductor junction era. The influence of temperature on the I-V characteristics has led to the use of diodes as thermometers for various temperature ranges [1,2]. The effect of magnetic field on the I-V characteristics of In-Sb diode has been studied by Calawa et al [3].

Magnetic fields measurements are usually carried out using Hall effect probe [4]. The main advantage of these probes is the linear relationship between magnetic fields and Hall voltage. On the other hand these probes are suitable to mechanical and electrical damage. In this work, we try to seek an alternative device for magnetic field measurements. In an attempt to do so, the magneto resistive properties of a p-n germanium diode are utilized. Magneto resistance is defined as an increase of the electrical resistance in magnetic field. It is a consequence of the Lorentz force which curve the carrier trajectories. This reduce the mean free path in the direction of electric field and thus also the electrical conductivity [5].

The effect of magnetic field on semiconductor:

The interaction of magnetic field with a orbiting electron lead to splitting of energy levels formally occupied by electrons (when the magnetic field is equal to zero) This changes the usually parabolic density of states into discrete sublevels [6]. The valance band and conduction band shift downward and upward respectively. Thus, and in the presence of high magnetic fields, the transport characteristics are modified and new phenomena appear.

One of these phenomena which appear at high magnetic fields, have led to methods suitable for the determination of the effective mass of carriers [7]. carriers effective mass is one of the most important device parameters, which is strongly related to the carrier mobility, In absence of magnetic field, the energy of a particle (E) in a semiconductor, depends on its wave vector (k) in the following manner [8].

$$E = \frac{\hbar K^2}{2m^*} \qquad (1)$$

In the presence of a magnetic field (B), the carriers describe helical paths between two successive collisions. For small collision frequencies carriers suffer from rotations about the magnetic field before they collide again and proceed on a different path. The helical motion of electrons in such cases are quantized and the energy equation can be modified to[6].

$$E = (n + \frac{1}{2})\hbar\omega_c + \frac{\hbar^2 K_B^2}{2m^*} \qquad (2)$$

Where $n \geq 0$ is an integer and it is the quantum number of the level, $\boldsymbol{K_B}$ is the component of $\boldsymbol{K}$ parallel to **B** and ω_c is the cyclotron frequency of the carrier in the magnetic field which is given by:

$$\omega_c = \frac{eB}{m^*} \text{ ……………………………………………………………………………………(3)}$$

The energy band, in the ($\boldsymbol{K_B}$, E) plane looks as in fig(1) [6].

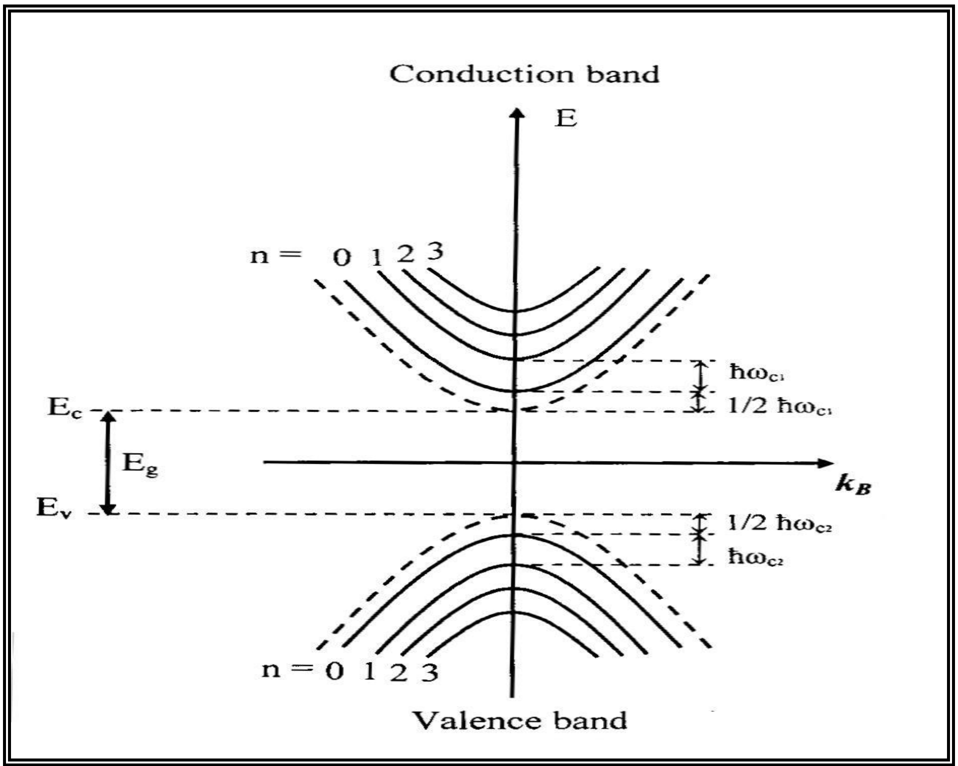

Fig (1) Energy–momentum diagram in presence of a magnetic field [6].

The aim of the present work is to study the effect of the magnetic field for construct a gauss meter. We report results of a study of the effect of magnetic field on the voltage current properties of a commercial germanium diode type AA118. Results show that the electrical properties of the diode are highly sensitive to the magnetic field intensity. This effect is utilized to build a gauss meter.

Experimental Setup :

Due to the fact that the magnetic field effects on germanium diode electrical properties are of the order on few tenths of a micro ampere, amplification becomes a necessity. Another problem here is the temperature effects. These can under certain circumstances become comparable or even exceed magnetic effects. The above two problems are solved simultaneously through the use of the circuit in figure (2). This circuit in principle represents a differential amplifier. Both BC237 transistors are biased in identical manners. The DC power supply V_{cc} is connected to the circuit through the potentiometer. If the two diodes are under the same external conditions (temperature and magnetic field), one can easily adjust the potentiometer to get a zero setting reading on the measuring device (the high impedance voltmeter).

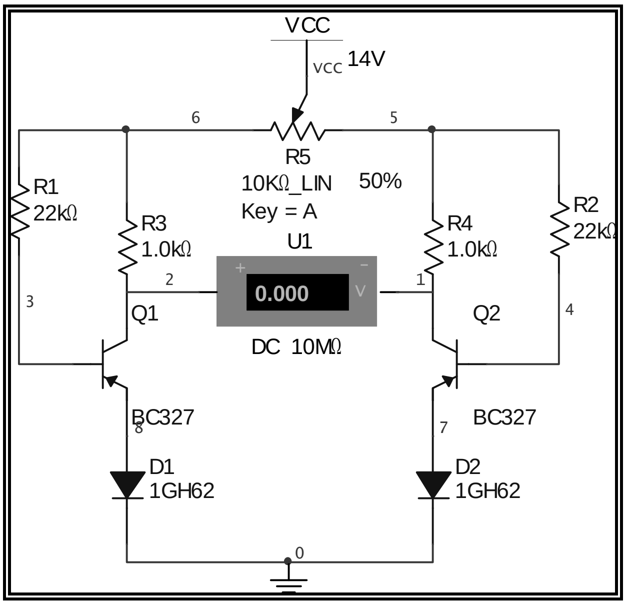

Figure (2) basic electronic circuit

When one of the diodes is subjected to a magnetic field, the voltmeter will start giving a reading which is different from zero. Any other external effects such as temperature etc will have no effect on this reading. This is because both diodes are under the influence of these other effects. However, the effect of magnetic field is now isolated because only one diode is used to probe the magnetic field. Thus this design helps to isolate magnetic field effects from all other effects.

Results and Discussions:

The magnetic field of a model J cenco electromagnet is used in this work. sets of data of the actual magnetic field as measured by a Lybold Hall effect gauss meter and the voltmeter reading in our circuit with one of the diodes being inserted in the field are measured, see table (1). Measurements are carried out using several values of the gap width. Results are plotted in figure (3).

Table (1):Voltmeter reading corresponding to value of magnetic filed

B(mT)	550	630	750	870	900	930	950	980	1000
V(mV)	247	390	592	668	692	705	715	721	731

Although a simple quadratic fit can describe the data points reasonably well, extrapolation of this fit to lower magnetic field values seem to give unrealistic results. These lower magnetic field values could not be measured experimentally due effects related to the sensitivity of the voltmeter available.

Exponential fit is attempted. It seems to give physically acceptable results with over 95% confidence level. The 2 milli-volt zero magnetic field reading is in good agreement with ∓ 1 milli-volts fluctuations we observed during measurements. The exponential nature of the variation is also encouraging in the sense that it makes the germanium diode a more suitable measurement device of even higher magnetic fields.

Although the above circuit operates in a satisfactory way, the problem of the nonlinearity of measurements against magnetic field is of some concern. A linear circuit will be far better than an exponential one. To achieve the required linearity, the out put of the circuit may be applied to a logarithmic dc amplifier. However, all our attempts to get such amplifier on the local market are not met with any success. Thus, it was decided to build such amplifier.

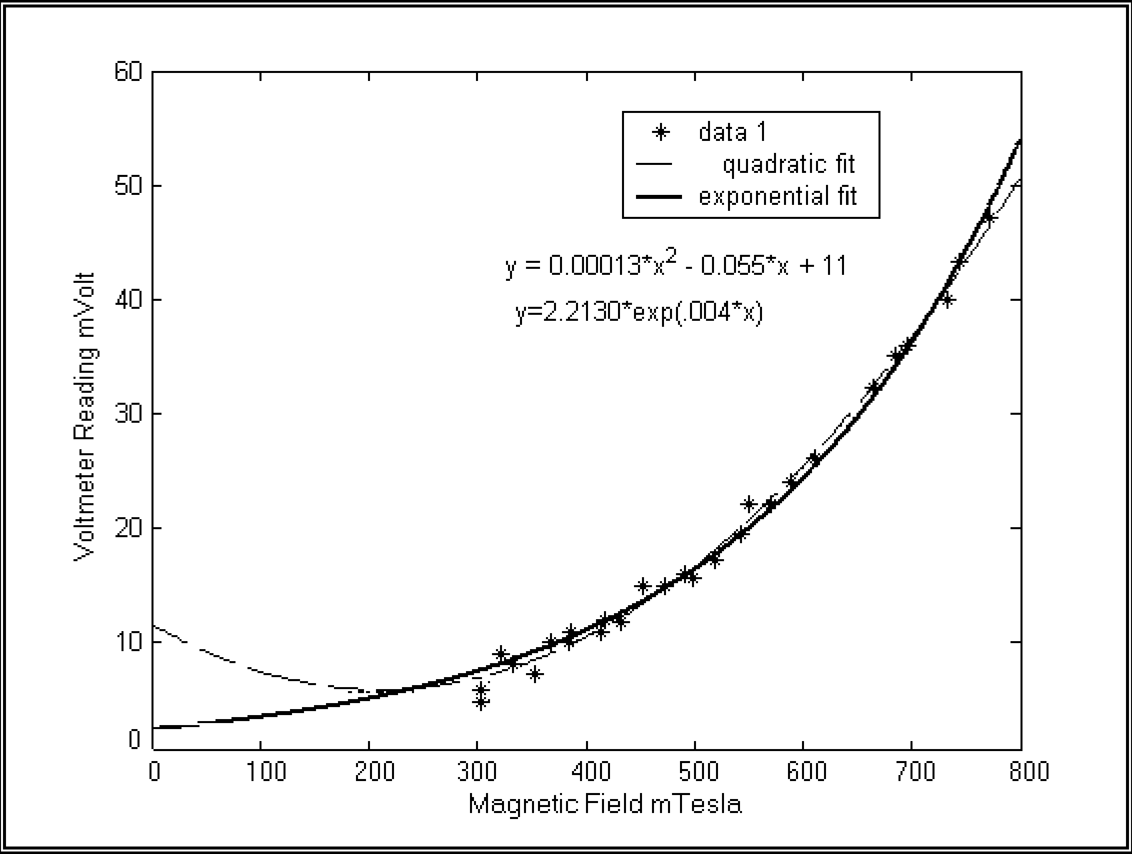

Figure (3) Variation of circuit voltmeter reading with magnetic field

The circuit diagram of this amplifier is shown in figure (4). This design is entirely the product of the author's work based of basic principles and trial and error attempts. The basic principle used here is that the I-V characteristics of a diode is mostly exponential it self. It has the general form

$$I = I_0[\ \exp(V-\varphi)/kT - 1\ ] \tag{4}$$

I is the current, V the bias voltage, I_0 the minority carrier backward current, φ the barrier potential, T the absolute temperature, and k is the Boltzman constant.

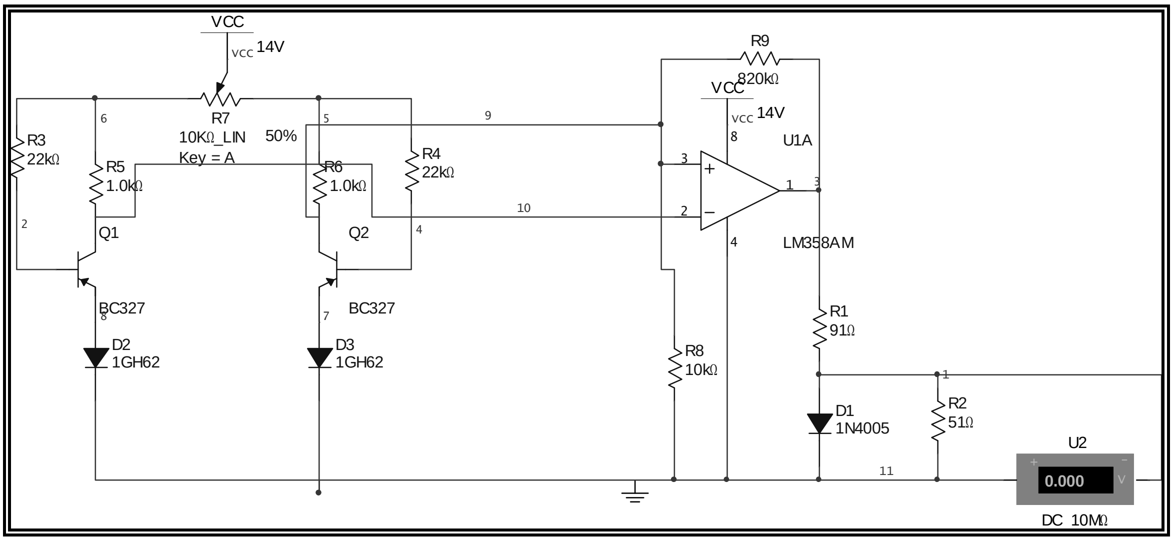

Figure (4) Complete circuit diagram with the linearization circuit

When a current I passes through a diode, the voltage V is almost proportional to the logarithm of the current. Thus the diode can in principle be considered as a logarithmic analog conversion device. The parametric nature of this conversion depends on the way other circuit elements are connected to the diode.

In order to achieve the required linearization, the out put voltage obtained from the circuit in figure (2) is first linearly further amplified by linear integrated circuit operational amplifier LM358 [9,10].The modified circuit is shown in figure (4). The 820 K Ohm and 10 K Ohm resistors set the gain of the amplifier to about 82. The out put from this amplifier is applied to circuit formed by the 1N4007 diode, the series 90 Ohm resistor and the parallel resistor. This later parallel resistor plays an essential role in the linearization process. The value of 90 Ohms is chosen for the series resistor. This choice is a result of a compromise between having the maximum out put current while not overloading the amplifier at the same time. Many values of the parallel resistor are used. The circuit linearity is studied each time. It is found that there is a unique value of this resistor that makes the circuit operation linear. This value is 10 Ohms.

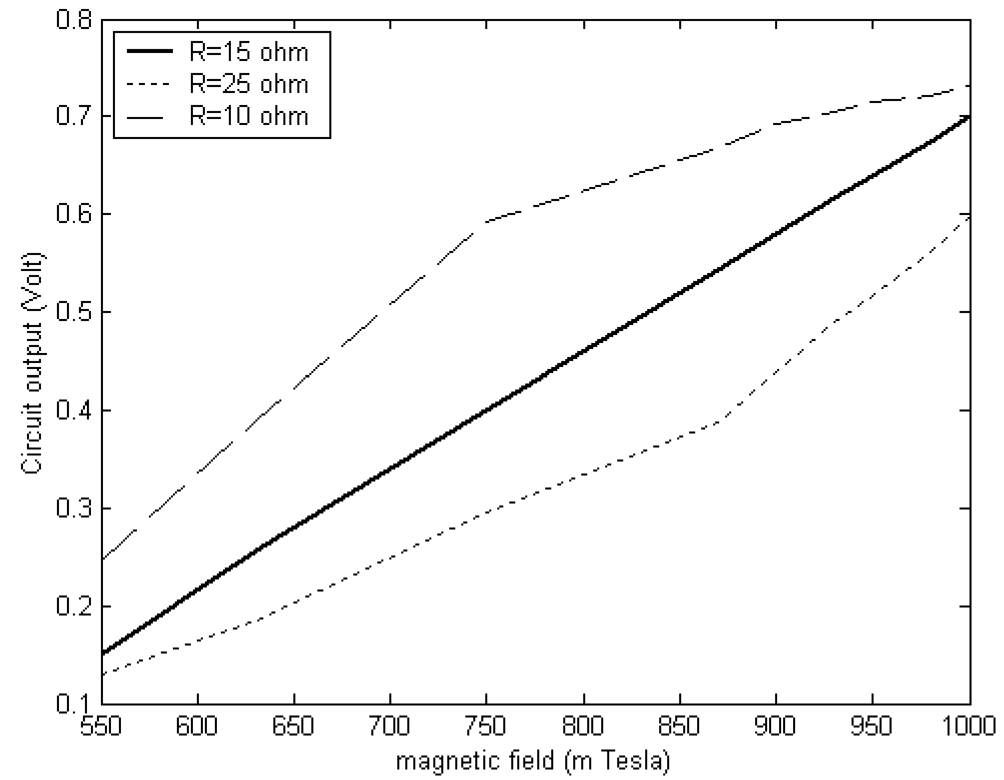

Figure (5) Demonstration of the linearization action

In order to demonstrate the action of this resistor, figure (5) shows that the circuit out put versus magnetic field when this value of the resistor is used. On the same figure, results of using a higher and a lower value are also presented. It is clear that when this value is high, the output still maintains part of the original exponential nature. For resistor values below the critical value, the circuit out put falls below the linear line. Using this critical value of the resistor brings the circuit to the linear operation mode.

Conclusions:

The fact that a germanium commercial diode can be used as a gauss meter probe is demonstrated experimentally. Temperature effects consideration can be overcome using the differential amplifier circuit with two diodes. One diode represents the probe diode. The second diode is a reference diode. Due to the fact that the out put of the circuit is not linear to magnetic field, a linearization circuit is designed, built and added to the original circuit. The circuit in its final form represents an available magnetic field measuring device which can be used for measuring magnetic fields or calibrating electromagnets.

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