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Simple Experimental Method for Estimating B and Gap in Silicon

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□ ABSTRACT □

In this work, energy band gap is estimated by passing small forward current through silicon junction diode. The junction voltage variation is studied versus temperature at constant current, and the T-V curve is drawn. From temperature – voltage curve, energy gap is determined. The temperature dependence of E_g has been studied, too.

Keywords: band gap energy, silicon, temperature, current and voltage.

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طريقة تجريبية بسيطة لتقدير عرض فجوة الطاقة في السيليكون

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□ ملخّص □

في هذا العمل، يتم تمرير تيار كهربائي صغير في حالة الاستقطاب المباشر لمتصل ثنائي مصنوع من السيلكون أحادي البلورة. ثم تدرس تغيرات الجهد بين طرفي المتصل بدلالة درجة الحرارة مع المحافظة على ثبات قيمة التيار. يمكننا في النهاية تحديد قيمة عرض الفجوة E_g من الخط البياني لدرجة الحرارة بدلالة الجهد. ندرس في هذه الورقة أيضاً تبعية E_g لدرجة الحرارة في السيليكون.

الكلمات المفتاحية: عرض فجوة الطاقة، سيلكون، درجة الحرارة، والجهد والتيار.

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Introduction:

Semiconductors,especially silicon single crystals, are the main materials for modern device fabrication. Computre, we use now to write this paper, calculaters, mobiles, ..almost all the technology we use in our live contains integrated circuits IC which made of a semiconductor. So,what makes semiconductor so special? An essential electrical characteristic of semiconductores is that they do not allow electrons move so easily between valence band and conduction band, i.e. they forbid them of having energy between these two bands. Hence, The energy gap between the two bands is called forbidden band, also knowen as band gap energy. Now, let us consider silicon single crystal that has a small energy gap in the order of 1 eV. At T=0 K, all electrons are in the valence band, and there is no electron in the conduction band. Thus, silicon is poor conductor at law temperatures. At room temperature and under normal atmospheric value of E_g is estemated to be about 1.12 eV [2,6]. The thermal energy kT at room temperature is a good fraction of E_g , and an appreciable numbers of electrones are thermally excited from the valence band to the conduction band (Fig.1).

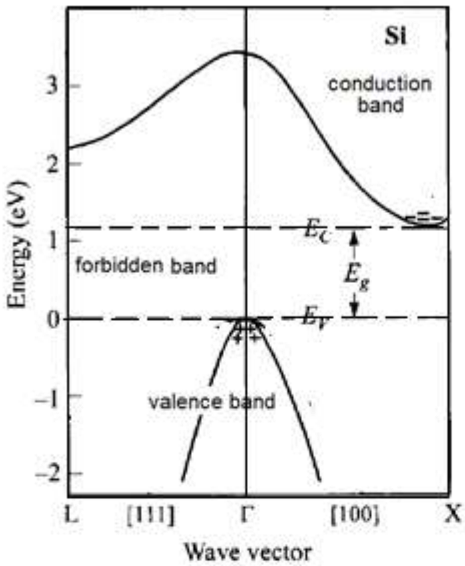


Fig.(1). Band gap of silicon single crystal.

Since there are many empty states in the conduction band, a small applied potential can easily move electrons resulting in a moderate current. Such a silicon is called intrinsic semiconductor. Intrinsic silicon is useless for electronic applications, because of its low conduction at room temperature. Adding impurity atoms from the third or fifth groupe elements can increase the silicon conduction. Addition of impurity from the fifth group elements (such As) result in n-type silicon ,and an addition of impurity from third group elements (such Al) results in p-type silicon. Combining both n-type and p-type in one device form a p-n junction. A p-n junction diode serves an imoprtant role both in modern electonic applications and in understanding other semiconductor devices. Intrinsing semiconductors are not available easily for measuring E_g . Doped semiconductors are available for E_g measurements. However, the presence of impurity atoms will slightly modify the energy gap of the parent element. Therfore, to reduce the contribution of impurity atoms they subdued by passing very low forward current through the junction. Several different methods, using p-n junction diode, have been discussed to ascertain the validity of band gap value mentioned above.[7-10]. It has been found experimentally that, within a certain temperature range, the relationship between temperature and voltage is almost linear given a constant current passing through the diode. It will be showen that this linearity is a direct consequence of the constancy of the current flowing through the diode, and the experimental results can be used to detrmine the band gap energy of silicon.

The importance and the aim of this work:

As we mentioned above, determenation of energy band gap in semiconductorse is of a great importance because the enormous variation in electrical conductivity of solids may be explained qualitatively in terms of their energy bands. The aim of this paper is to investigate the value of bandgap in silicon, which is widely used in integrated circuit fabrications nowadays. We aim, also, to compare between different methods coherent to this work.

Methods and Experiment:

I.Theoretical Studay

The basic theory of current-voltage characteristics of a p-n junction was established by Shockley [1,4,5], The equation describing this relationship for ideal diode can be written as following**:**

$$\boldsymbol{I = I_0 [e^{\left(eV/kT\right)} - 1]} \qquad \textbf{(1)}$$

Where I is the current passing through the diode, I_0 reverse saturation current, V is the voltage across the diode, T is the absolute temperature, k is Boltzmann constant, and e is the electron charge. Equation (1) is discussed extensively in the literature [1,2,11,12,13], but in this work we do some simplifications. Realy, we need an expression for I_0 , which depends on temperature but not on V. In a p-n junction made of silicon and at T=300 K the fruction $e/_{kT}$ is estimated to be about 40. Thus, in case of forward bias and for V> 0.1 volts, the factor $e^{(eV/kT)}$ becomes too much bigger than the number 1, and equation (1) can be written as following:

$$\boldsymbol{I \cong I_0 e^{\left(eV/kT\right)}} \qquad \textbf{(2)}$$

However, it has been showen that I_0 is proportional to Boltzmann factor $e^{\left(-E_g/kT\right)}$ and to $T^{(3+\gamma/2)}$, where γ is constant[1,9]. So, we may can write:

$$I_0 = A\, T^{(3+\gamma/2)} . e^{\left(-E_g/kT\right)} \qquad (3)$$

The temperature dependance of the term $T^{(3+\gamma/2)}$ is not valuable compared with the exponential term, and we can treat $B = A.T^{(3+\gamma/2)}$ as almost constant. It is expected that in the reverse direction, where $|I| \cong I_0$ the current will increase approximately as $e^{\left(-E_g/kT\right)}$; and in the forward direction, where equation (2) is valid, the current will increase approximately as $e^{[-\frac{(E_g-eV)}{kT}]}$,[1]. Therefore, we can rewrite equation(3) as following:

$$\boldsymbol{I_0 = B.e^{\left(-E_g/_{kT}\right)}} \qquad (4)$$

From equations (2) and (4) we can obtain the following formola for the current, [3]:

$$I = B\ e^{(eV/kT - E_0/kT)} \qquad (5)$$

Experimentally, the current can be maintained constant, and thus we can write :

$$C = eV/kT - E_0/kT) \qquad (6)$$

$$T = \left(\frac{e}{kC}\right)V - \frac{E_g}{kC} \qquad (7)$$

This equation (7) is very important for calculating E_g , it reflects the linear relation between voltage and temperature. If we write $a = {}^{e}/_{kC}$ and $b = {}^{-E_g}/_{kC}$ then we can obtain the two following equations:

$$T = a\,V + b \qquad (8)$$

$$E_g = -\frac{b}{a}e \qquad (9)$$

It is clear now that E_g can be easily calculated if we know the values of a and b, which can be determined experimentally, providing that E_g do not depend strongly on temperature.

II. Experiment

Figure (2) illustrates the schematic diagram of the circuit used for temperature-Voltage data measurments. The circuit consists of tow parts; first part includes FIT transistor which provides the constant current[14], and the second part includes a p-n junction which used to measure the T-V calibration curve of the junction. The whole circuit is powered by a constant voltage power supply at 9 volts. The 100-kΩ variable resistor used to adjust the circuit current at 10 μA . The voltage drop across the p-n juncton is measured by adigital voltmeter.

A mercury thrmometer is used to measure the temperature of the p-n junction. The p-n junction is put in contact with the resevior of the thermometer, and both are wrapped together in a thin protected foil. In order to have the suitable temperature, we use electrical heater, but for a temperatures around $0\,^0C$ we use an ice-salt mixture. Finally, the experiment was chosen for its importance and for its simplicity, even though it loose high precision.

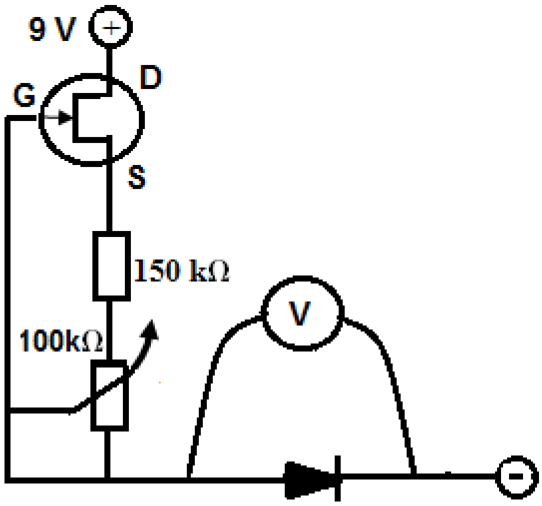


Figure (2). schematic diagram of the circuit used for temperature-Voltage data measurments.

Results and discussion

The obtained results are given in table (1), and the corresponding T-V curve is showen in figure (3). The horizontal axis shows the variations in voltage ranging between 0.18 V and 0.46V, whereas vertical axes illustrates temperature in the range of 275 K to 375 K. The data exhibits a good linear relationship between absolute temperature and the voltage drop across p-n junction in the temperature range mentioned above. The straight line fits the experimental data, and the corresponding equation is inserted insid the figure.

Table(1). measured data

V	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46
T	375	368	361	355	348	342	335	328	321	313	306	298	290	283	275

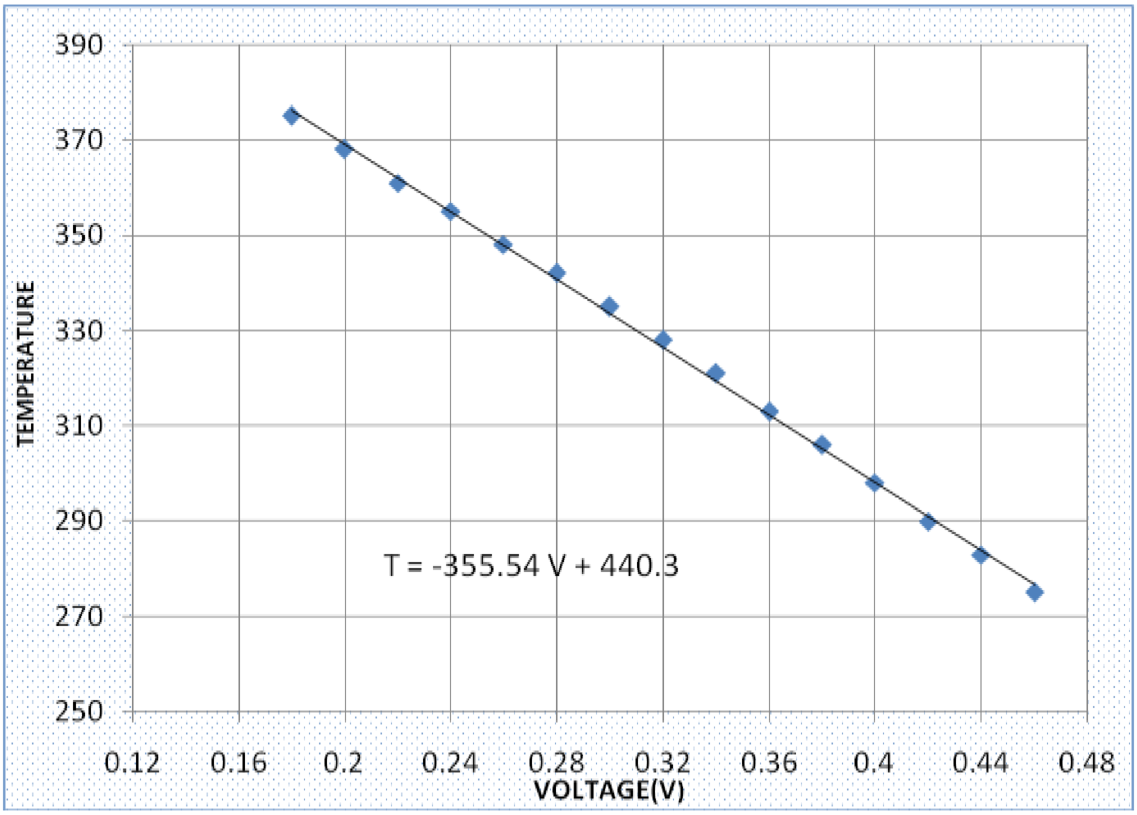


Figure (3). Temperature versuse voltage graph for p-n junction made of silicon. Solid line is the least-squares fit to the data.

From the equation inserted in the diagram (T = -355.54 V + 440.3) we can see that a= -355.54 K/V and b= 440.3 K, so if we substitute these valuse in equatin(9) then we obtain:

$$E_g = -\frac{b}{a}e = \frac{440.3\ K}{355.54\ K/V}e = 1.238\ eV \cong 1.24\ eV\,.$$

Hence, in the temperature range 0f 275 K to 375 K , the value of E_g is approximately 1.24 eV.

Table(2) shows a comparison of some calculated valus of E_g taken from different referances. It is obvios that our E_g value is not quite in agreement with the accepted E_g values for intrinsic silicon 1.12 eV at room temperature (300 K). However, the silicon that we used is doped (unintrinsic) thus its E_g should not match the E_g of its intrinsic one. Morever, in this work we succeeded to illustrate the linear relationship between the temperature and voltage of in p-n junction given a constant current.

Table(2). Comparison of some calculated valus of E_g taken from different referances.

Temperature rang (K)	273-275	273-330 Ref.4	288-383 Ref.15	280-400 Ref.16	240-400 Ref.6	300 Ref.13
E_g (eV)	1.24	1.17	1.23	1.10	1.29	1.12

Let us discuss the validity of our assumption which belong to equation (1). For the highest temperature we used T= 375 K corresponding to V=0.18 the term $eV/kT = 5.56$, and $e^{\left(eV/_{kT}\right)} = e^{(5.56)} = \gg 1$. Therefore, we can neglect the number 1 in the equation (1), and rewrite equation (1) as equation (2) . So, no deviation from the linear T-V characteristic is expected.

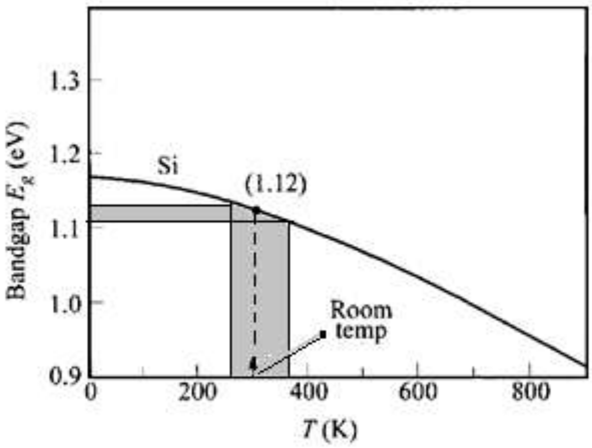
On the other hand, we mentioned, in the theory part of this work, that E_g must not depend strongly on temperature. Realy, this assumption is not exactly true. As a matter of fact E_g depends weakly on the temperature. The variation of band gap with temperature can be expressed approximately by the following univevrsal function [3]:

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T+\beta} \qquad (10)$$

Where α and β are constants.Fiqure (4) illustrates the dependance of E_g on the temperature[3] The region in the diagram of our concern is the black one, illustrates the weak dependance of E_g on temperature.

Conclusion

The band gap energy E_g of silicon and its temperature dependance in the temperature range of 275 K to 375 K has been ivestigated. The results are compared with the results obtained in the literature. Although our result may has lacked high precision, it does provide a coherent and simple approach to understand the behavior of silicon as a semiconductor.



Fiure (4).The dependance of E_g on the temperature. The black zone, used in this work, illustrates the weak dependance of E_g on temperature.

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