Band Gap Energy for SiC Thin Films Prepared By TEACO$_2$ Laser Irradiated With Nuclear Radiation

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Abstract

The effect of high energy radiation on the energy gap of compound semiconductor Silicon Carbide (SiC) are viewed. Emphasis is placed on those effects which can be interpreted in terms of energy levels. The goal is to develop semiconductors operating at high temperature with low energy gaps by induced permanent damage in SiC irradiated by gamma source.

TEACO$_2$ laser used for producing SiC thin films. Spectrophotometer lambda -UV, Visible instrument is used to determine energy gap (E_g). Co-60, Cs-137, and Sr-90 are used to irradiate SiC samples for different time of irradiation. Possible interpretation of the changing in E_g values as the time of irradiation change is discussed.

Key words: Nuclear radiation , Band gap energy, SiC thin film.

Introduction

Most who work in the field of nuclear hardening of electronic equipment are aware that many aspects of their efforts rely on related facts obtained over a long period of time. The big picture of nuclear hardening includes some scientific endeavors, yet analyses are being made that apply a kind of art. The total environment, which consists of radiation from various sources (fission, fusion, space radiation's, nuclear weapons), affects matter down to the subatomic level and is quite dependent on the domain of influence. The dominant failure mechanism in almost every design problem is lifetime degradation. It causes a decrease in power output [1].

It is necessary to obtain the functional dependence of basic semiconductor properties on radiation flounce and energy. There are two basic aspects of the interaction of radiation with semiconductor. A large fraction of the energy of an incident energetic particles or photons goes into electronic processes (excitation and ionization), and this produces a temporary or transient disturbance in the semiconductor which disappears shortly after the radiation source is removed. The remainder of the incident energy goes into atomic processes, and produces displacements of atoms within the crystal lattice. The fraction of these displacements which remain after long times 1000 second at room temperature will be called permanent damage.

The interaction of energetic electrons with semiconductor is fairly easy to analyze. If the energetic electron passes sufficiently close to the nucleus (so that coulomb screening is in effective), then a coulomb scattering event will occur. During this event the electron will transfer some of its energy

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to the lattice atom. The maximum amount of energy that can be transferred is given by:

$$T_m = \frac{2\left(\varepsilon_e + 2m_e c^2\right)}{Mc^2}\varepsilon_e$$

Where ε_e, m_e= electron's energy and mass, and c=velocity of light, and M = lattice atom mass. If the energy transferred to the lattice atom is greater than a certain amount, the lattice atom will be displayed to an interstitial position. This energy is between 10 and 25 eV. The displaced atom will leave behind a vacancy in the crystal lattice. The resulting vacancy-interstitial pair is called a Frenkel defect. But the effects of ionizing radiation are other than the creation of permanent displacement type damage, the energetic radiation, create electron-hole pairs by exciting electrons across the forbidden gap. As a result, whenever gamma rays are incident on a semiconductor, there is an increase in the density of electrons and holes (due to pair generation) which will decay back to the original densities if the ionizing source is removed.

In general, it is found that the average energy required to create an electron-hole pair is roughly three times the band gap of the semiconductor. This is because some of the energy is lost through other mechanism (for SiC semiconductor the band gap energy is 3 eV and radiation ionization energy is 9 eV) [2].

In this paper, the effect of ionization radiation on the energy gap for SiC semiconductors are studied. One of the reasons for the initial work on SiC was its possible application for devices operating at high temperature due to its high energy gaps and its chemical inertness [3,4]. The high energy gaps of the SiC semiconductor, make them attractive as solid-state ultra-violet detectors, moreover, the chemical inertness of SiC means that high operating temperatures should be permissible so that the material could be used as a flame detector, in which application its insensitivity to longer wavelength radiation is an advantage. Detectors made from SiC with response peaks around 0.28 μm [5].

Materials and Methods

Fig.(l) shows the process which used for producing silicon carbide thin films by using TEACO$_2$ laser to induced reaction in the gas phase, C_2H_4 have been used as additive to SiH_4 [6]. Reactant gases that vibrationally heated by absorbing energy emitted from TEACO$_2$ laser decomposes through collision assisted multiple photon dissociation causing SiC thin films , their thickness is 5000 A.

The prepared samples were irradiated by different gamma doses from Cs-137 (0.662 MeV) and Co-60 (1.173 and 1.333 MeV) with same activity (0.2 mCi) and beta doses Sr-90 with different activities (0.1 and 1.0 mCi) respectively. The irradiation facility is at the College of Science, Baghdad University. Irradiation was carried out in air at room temperature and at an intermediate value of relative humidity (60 %).

Results and Discussion

The results of absorption and transmission data of light for any wavelength which are taken by

Spectrophotometer type lambda- UV, VISIBLE for wavelengths (λ) between (200-1100 nm). The measurement of the optical energy gap is done by the following: when the light with an intensity I_o falls on a material with thickness X , it obeys the following equation:

$$I = I_{o} \exp(-\alpha X)$$

Where I is transmitted intensity and α is absorption coefficient, $I/1_o$ represents the transmittance (T) and the absorb (A)

$$A = \log(1/T),$$
$$T = \exp(-2.303A)$$
$$\alpha = 2.303(A/X)$$ [α was calculated at every wavelength (λ)]

The absorbance spectrum of the unirradiated substrate was taken as the reference to determine the absorption of the irradiated films. The absorption in non crystalline materials are normally analyzed in the Tauc Eq. $\lfloor \alpha h\nu = B(h\nu - E_a)\rfloor$, which is used to find the type of the optical transition and optical energy gap, which could be deduced from the best straight line can be drawn between $(\alpha h\nu)$ versus $(h\nu)$. Where B is constant $= 4\pi\sigma_{o} = nCE_{\infty}$, C is the speed of light, σ_o is the extrapolated d.c. conductivity at T = ∞, n is the refractive index and E_∞ is an energy which is a measure of the extent of band tailing, normally obtained from Urbach law [7]. Table (1) presented the results of the energy gap and time of irradiation for SiC samples.

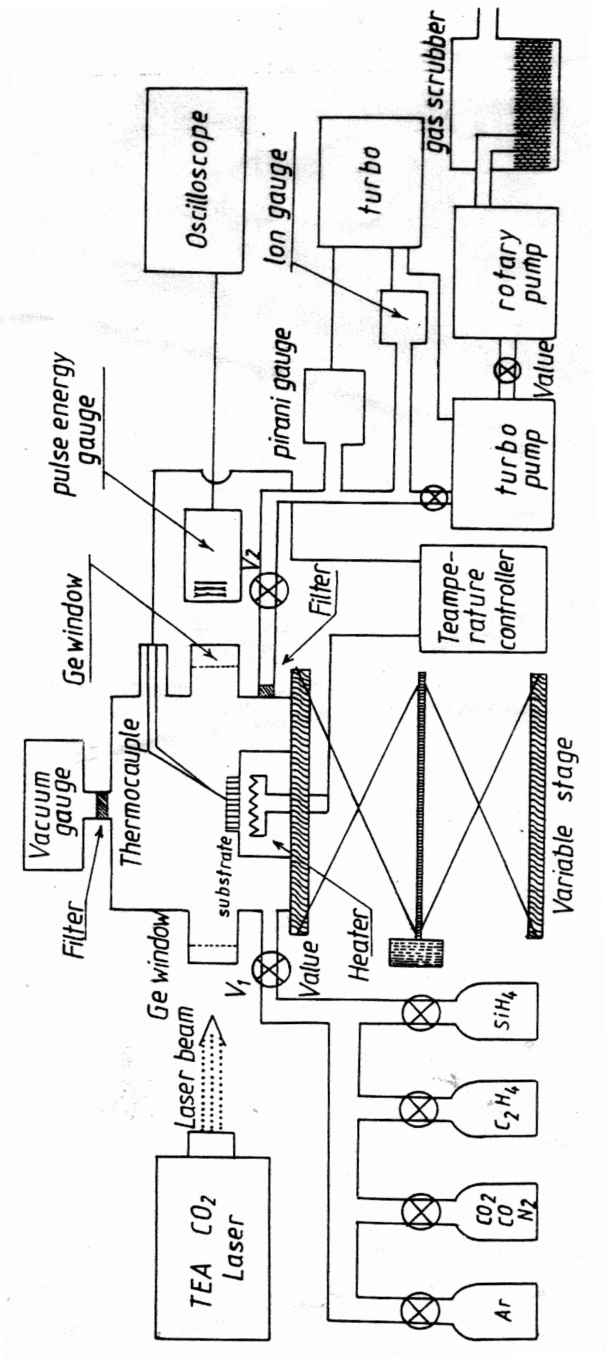

Fig.(1) Block diagram deposition system

Table (1): Values of band gap energy for SiC samples exposed to gamma and beta rays as a function of exposure time

Time (min)	**E_g for sample irradiated by Cs-137**	**Time (min)**	**E_g for sample irradiated by Co-60**	**Time (min)**	**E_g for sample irradiated by Sr-90 (0.1 mCi)**	**Time (min)**	**E_g for sample irradiated by Sr-90 (1 mCi)**
0	1.55	0	1.50	0	1.45	0	1.55
30	1.15	30	1.30	30	1.40	30	1.35
60	0.85	60	1.20	60	1.35	60	1.25
90	0.35	90	1.05	90	0.85	90	1.15
120	0.25	120	0.70	*60	1.05	*60	1.20
*30	0.65	*4320	0.95	*120	1.25	*120	1.35
*90	0.90	---		*180	1.45	*180	1. 55
*3600	0.90						

***represents to the values that the sources are removed**

The variation of E_g versus time for irradiated samples is presented in Figs, (2) and (3). SiC samples revealed optical direct transitions between bands which leads to energy band gap nearly 1.50 eV but different if these samples irradiated by gamma rays and beta particles. This difference is = 0.5 eV for each time .Its clear from these Figs., that the values of E_g decrease with either increasing dose rate (time of irradiation) and decreasing the energy of incident photons Fig. (2). The effect of energy photons on the E_g for the irradiated samples, it shows a reduced in E_g as the photons energy decrease, this is means that the increase in photons energy result in decreases in the probability of the interaction of photons with matter. It is known, that, below 1 MeV, photoelectric effect predominates.The late effects of the SiC samples irradiated by gamma photons (stored for a period of 4320 hours under atmospheric conditions at room temperature) were also detected. The effect of the ionizing radiation on the SiC samples is the creation of permanent displacement - type damage if the ionizing source is removed. The defects produced by atom displacement introduce energy levels into the forbidden gap of semiconductors. These energy levels can serve as recombination centers for electrons and holes. The capture of the minority carrier (i.e. holes in n- type material) is generally the rate limiting step in the recombination process, since the number of majority carriers is much larger than the number of minority carriers.

In principle, the lifetime reflects the position in the forbidden gap of the energy level of the capture site, so that measurement of the radiation dependence of the lifetime should lead to identification of the defect energy levels produced by atom displacement.

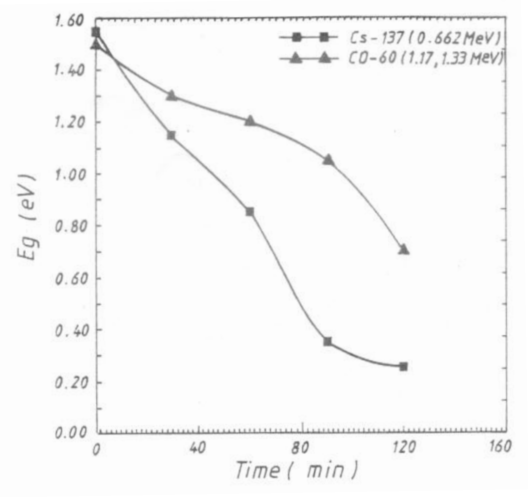

Fig. (2) The dependence of energy gap on the time of irradiation samples for different photons energy.

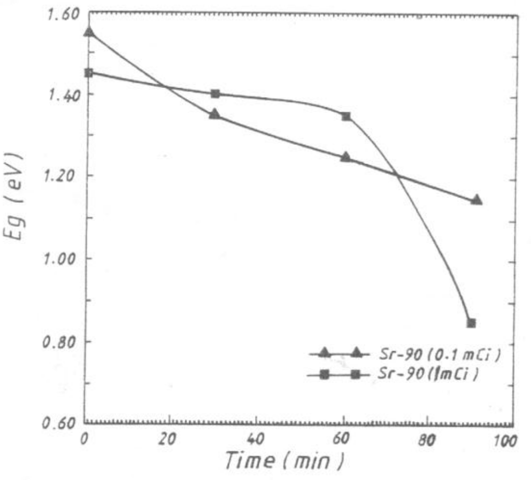

Fig. (3) The dependence of energy gap on the time of irradiation samples for different photons activities.

The beta particles create electron-hole pairs by exciting electrons across the forbidden gap. As a result, whenever beta particles are incident on a semiconductor, there is an increase in the density of electrons and holes (due to pair generation) which will decay back to the original densities if the ionizing source is removed Table (1). The average energy required to create an electron - hole pair is roughly three times the band gap of the semiconductor. This is because of the energy is lost through the mechanisms. Fig. (3) shows a decrease in the energy gap values for samples irradiated by high activity beta particles (1 mCi) than samples irradiated by low activity beta source (0.1 mCi), this behavior is attributed to increase in the probability of interaction (increase in the number of particles) with matter.

Conclusions

It may be concluded from the present investigation that low gamma doses can induce damaging effects to the SiC thin film and properties of their absorption. A new value of $E_g = 0.9$ eV is obtained when the gamma source is removed. This new value is dependent on irradiation time, however but the E_g value of SiC irradiated by beta particles return to initial value when the beta source is removed.

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تأثير الأشعة النووية على فجوة الطاقة للأغشية SiC الرقيقة المحضرة بواسطة ليزر $TEACO_2$

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الخلاصة:

تم دراسة تأثير أشعة كاما وبيتا ذات الطاقات العالية على فجوة الطاقة للأغشية كاربيد السليكون (SiC) الرقيقة.
يهدف هذا البحث إلى الحصول على شبه موصل ذو فجوة طاقة بحدود (0.9eV) يعمل في درجات حرارة عالية، وذلك من خلال إحداث تغيرات دائمية في أغشية SiC الرقيقة من خلال تشعيعه باشعة كاما. استخدم ليزر $TEACO_2$ في تحضير أغشية SiC الرقيقة. ومطياف الأشعة الفوق البنفسجية والمرئية في تحديد فجوة الطاقة (E_g). والمصادر المشعة Co-60 وCs-137 وSr-90 في تشعيع أغشية SiC . حيث تم تعريض هذه الأغشية لجرعات مختلفة من اشعة كاما وبيتا. وقد تم مناقشة تأثير التشعيع من ناحية الجرعة وزمن التشعيع على قيمة فجوة الطاقة (E_g).