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Effects of Laser Energy on n-Ge/p-SnS Hetrojunction Diode Detector in Different Environments

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Abstract: In the present work, heterojunction diode detectors will be prepared using germanium wafers as a substrate material and 200 nm tin sulfide thickness will be evaporated by using thermal evaporation method as thin film on the substrate. Nd:YAG laser (λ=532 nm) with different energy densities (5.66 J/cm^2 and 11.32 J/cm^2) is used to diffuse the SnS inside the surface of the germanium samples with 10 laser shots in different environments (vacuum and distilled water). I-V characteristics in the dark illumination, C-V characteristics, transmission measurements, spectral responsivity and quantum efficiency were investigated at 300K. The C-V measurements have shown that the heterojunction were of abrupt type and the maximum value of build-in potential is equal to 1.78V in water environment .The results showed that the detectors have two peaks at 900 nm and 1250 nm and the maximum spectral responsivity can be obtained at λ=1250 nm in water environment. Also the quantum efficiency has two peaks at 900nm and 1250 nm and it is increase the increase in laser energy density and this increase is to be clear in the water environment more than the vacuum environment.

Introduction

In recent years, thin films of SnS have attracted much for photovoltaic applications due to the high absorption (>104cm^{-1}) and high conductivity [1,2]. SnS is an important optoelectronic material that is found in zinc blend with lattice constant (a=0.5845 nm) [3], orthorhombic with lattice constants (a=0.385 nm, b= 1.142 nm c= 0.438 nm) crystal structures [4,5].The optical properties of SnS vary depending on synthesizing or fabrication method, but most work agrees with direct (1.2-1.5) eV and indirect (1.0-1.2) eV band gap values. These properties enable SnS thin films to be used as an absorption layer in the fabrication of hetrojunction solar cell [4].

Heterojunction devices are playing an increasingly important role in optoelectronics. They are produced by combining semiconductors that have different bandgap energies but closely matching lattice parameters. These devices are epitaxially formed on single-crystal substrates. Laser diodes and photodetectors are the most important optoelectronic heterostructures, although other types of devices, such as transistors, can also be fabricated [6]

There are many available techniques for the fabrication of heterojunctions. Those based of most photoelectric devices such as detectors, solar cells and semiconductor lasers. Such heterojunctions are prepared by growing epitaxially one semiconductor material onto a different semiconductor material. The most common preparation techniques are chemical - vapor deposition (CVD), solution growth, alloying, sputtering and vacuum evaporation [7].

The thin film in this study is deposited by thermal evaporation. This method has many advantages, it is simple, economic and viable technique, which produces thin films of good quality for device applications. In this work, an attempt has been made to prepare SnS films by thermal evaporation in order to investigate their optical and electrical properties.

In the present work SnS thin films have been prepared by using thermal evaporation process on germanium substrate. The optical and electrical properties of the deposited films with different laser energies and environments were studied.

Experimental Work

Preparation Technique

Single crystal germanium wafers (n-type) with dimensions (5x5x0.3) mm were used as a substrates. A wet chemical etching technique is used in this work .The wafers of germanium are immersed in the H_2O/H_2O_2 (9:1) as etching solution in a beaker for several minutes to remove the native oxides on the surface. This solution was used to etch and polish the germanium wafers instantaneously, then the substrates were dried by using an electronic blower. After etching process, thermal evaporation process with Edwards coating unit model E306A was used for deposition of high purity (99.9%) p-SnS thin films with thickness of 200 nm on the Ge wafers. The thickness of the films can be calculated using the following equation[8] :

$$t = \frac{m * 10}{A * d} \quad (1)$$

where (t) is the thickness in nanometers, (m) is the mass of the coating in milligrams, (A) is the area tested in square centimeters, and (d) is the density in gram per cubic centimeter.

The system contains the essential elements typically required to obtain a high vacuum. The evaporation processes have been performed at room temperature. The pressure during the evaporation was approximated to (10^{-5}) torr. The rate of deposition was controlled at about (0.68 nm/sec), and the distance between the source and substrate was kept at (15) cm.

After thermal evaporation process, Nd:YAG laser (λ=532 nm) with different energy densities (5.66 J/cm^2 and 11.32 J/cm^2) is used to diffused the SnS inside the surface of the germanium samples with (10) laser shots in different environments (vacccum and distilled water). Table (1) shows the Nd:YAG laser specification and parameters. Ohmic contacts were applied by evaporating the aluminium which has a high purity (99%) as an electrods.

Table (1) : Nd:YAG laser specification and parameters.

Wavelength	1064nm&532nm
Spot Diameter	1~7mm
Width of Pulse	<10ns
Pulse Energy	400-1500mJ
Repetition Rate	1-6Hz adjustable

Experimental Measurements

The optical transmission spectra of the deposited SnS thin films were measured by UV-3600 UV-VIS-NIR spectrophotometer with (1cm) cuvette (quartz cell normally of 1 cm x 1 cm size cross section), the optical properties where calculated as a function of the wavelength in the range (600-1800) nm .

The electrical properties of the diode detectors such as current-voltage characteristics and built in potential was measured using two point probe method as shown in Figure (1). The spectral responsivity of the photodetector was obtained using monochromator with tungsten lamp, the measurements carried out under normal illumination from SnS side as shown in Figure (2).

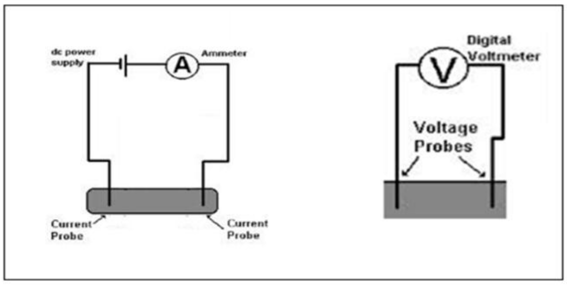


Fig.(1) : Two Point Probe Method

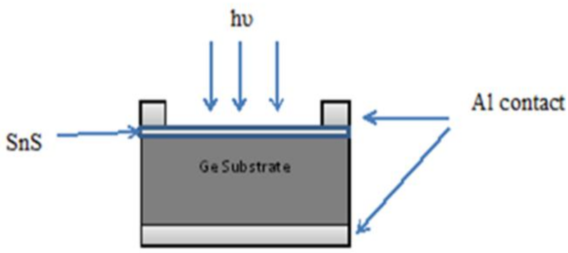


Fig. (2) : The Configuration of n-Ge/p-SnS Hetrojunction Diode Detector

Results and Discussion

Figure (3) shows the surface micrograph of SnS films on germanium wafers which are irradiated by second harmonic Nd: YAG laser with different energy densities (5.66 J/cm^2 and 11.32 J/cm^2) in vacuum and distilled water environments.

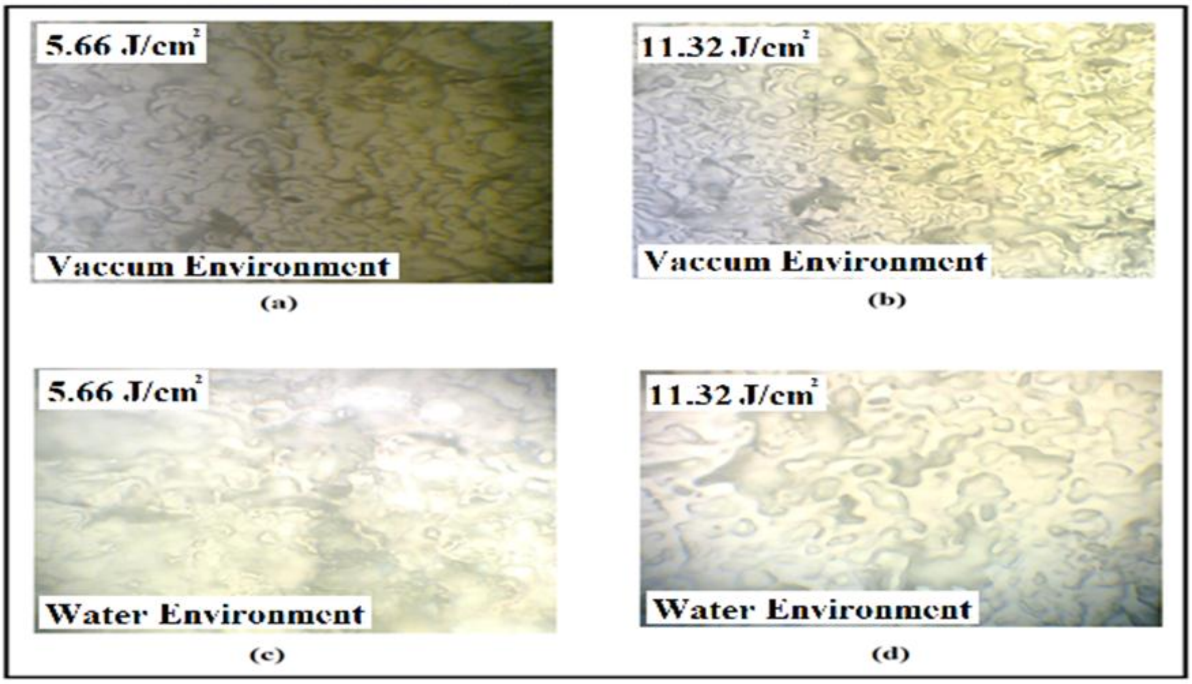


Fig.(3): Surface Micrograph of SnS Films on Germanium Wafers

The films surface consists of spherical shape of grains with discontinuous nature this is due to the droplet splashes onto the germanium wafer with lesser decomposition which leads to porous and less adhesive of film which is observed visually. The grain size can be calculated by using Scherrer equation:[10]

$$g_s = \frac{\kappa \lambda}{B \cos \theta} \qquad (2)$$

where B is the broadening solely due to small crystallite size , κ is a constant

whose value depends on particle shape and usually taken as 1; θ the Bragg ‘s angle, λ is a wavelength of incident X-ray beam

Table (2) shows the grain size with different energy densities and environments. In vaccum environment the grain size is small and increased with increasing of laser energy density while in water environment the formation of larger grains can be observed with increasing of laser energy. The formation of bigger grains is due to the coherence of smaller grains. These results are compared favourably with [11].

Table (2): The Grain Size in Different Environments and Laser Energy Densities

Energy density (J/cm^2)	Grain Size in Vaccum (Å)	Grain Size in Water (Å)
0 (initial)	154	168
5.66	172	187
11.32	197	253

The optical properties of n-Ge/p-SnS samples prepared by thermal evaporation process and irradiated with Nd:YAG laser were studied by measuring the transmission (T) between (λ=2)μm and (λ=24)μm in order to determine the optical characterization of the fabricated samples. Figure (4) shows that the transmittance for all samples under investigation decreases with increasing the wavelength however with increasing laser energy densities the transmittance decreases for a fixed wavelength. In vacuum environment it was found that the average transmittance of the samples is larger than the average transmittance in water environment .This smooth increase is due to high crystalline nature of the prepared samples.

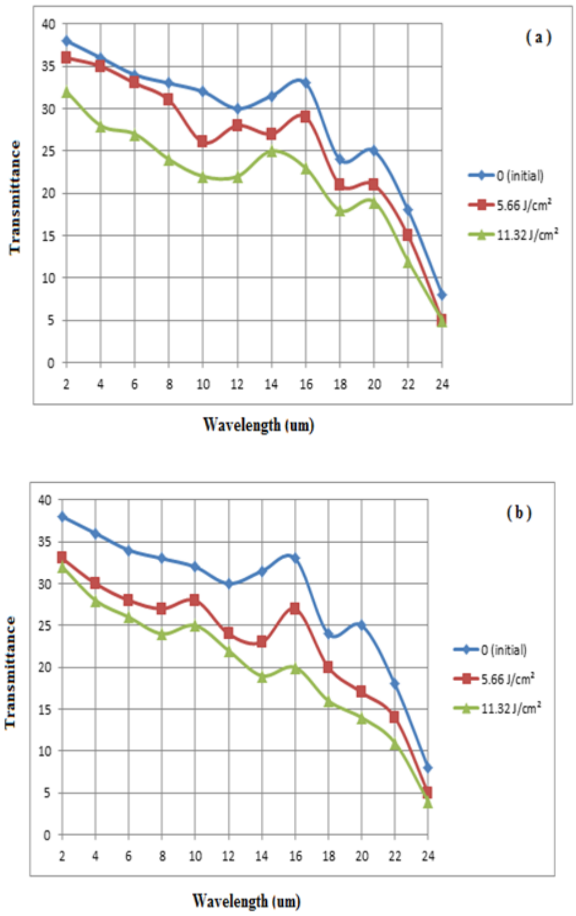


Fig.(4): The Transmittance for All Samples under Investigation; (a)Vacuum Environment , (b) Water Environment

The absorption coefficient α of SnS film was determined from the absorbance measurements, and calculated using the following relation ;

$$\alpha = 2.303A/t \qquad (3)$$

where (t) is the thickness of the film.

Figure (5) shows the curves of absorption coefficient (α) vs hυ of the samples.Increasing in the value of the coefficient was observed with increasing of laser energy densities in water environment greater than the increasing in its value in vacuum environment this increasing is due to the high crystalline nature of the prepared thin films. These results are compared favourably with [1, 2, 11].

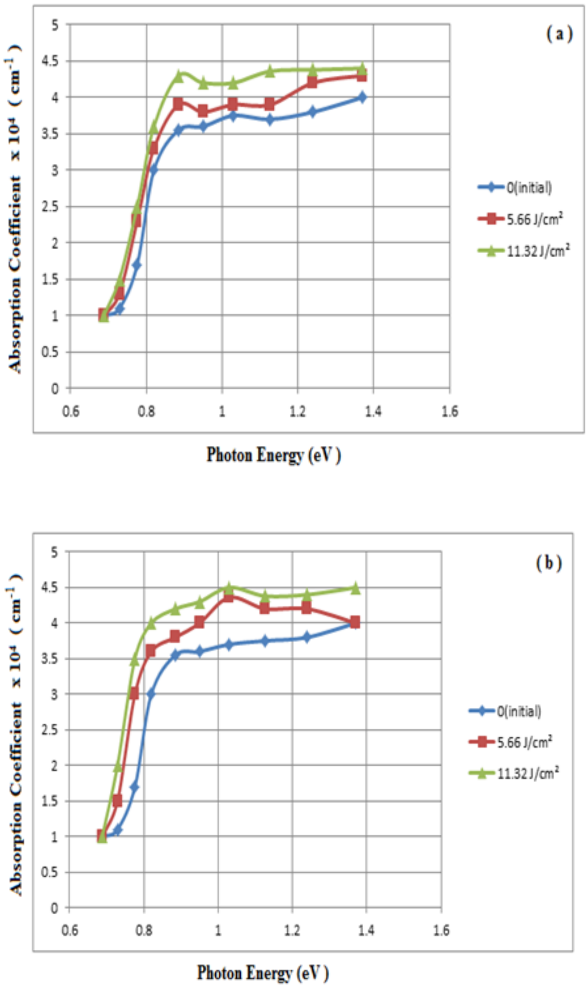


Fig.(5): The curves of absorption coefficient (α) vs (hυ) of the samples; (a)Vacuum Environment , (b) Water Environment

The I-V characteristics of n-Ge/p-SnS heterojunction under dark condition for vaccum environment and water environment can be shown in Figure (6) and Figure (7) respectively. In the forward bias region, the current increase with increasing the voltage, but in the reverse bias region , the current was found to increase slowly with increasing the voltage and havs a soft breakdown behavior. These Figure s shows that the I-V characteristics of n-Ge/p-SnS heterojunction it has been improved when increasing the laser energy density especially in water environment. One of the most important features of the I-V characteristics of n-Ge/p-SnS heterojunction diodes irradiated in water environment was very high rectification, especially very high forward current at relative low leakage current at energy density 11.32 J/cm^2.

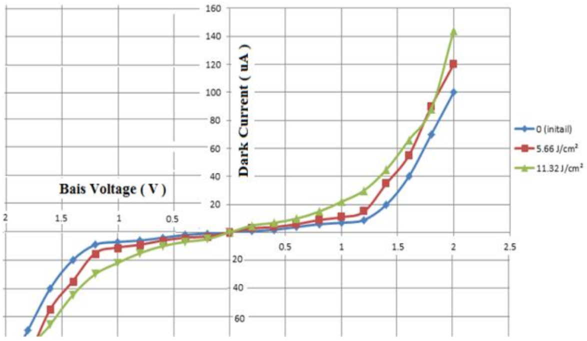


Fig.(6): The I-V characteristics of n-Ge/p-SnS Heterojunction under Dark Condition for Vaccum Environment

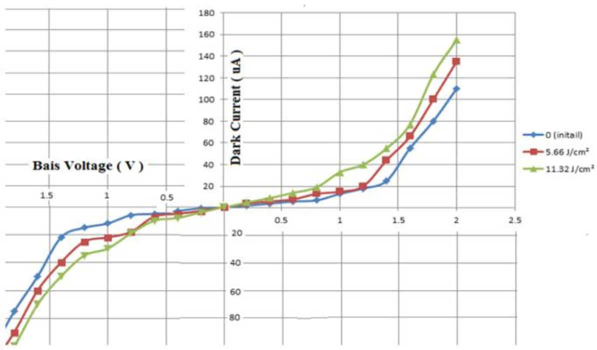
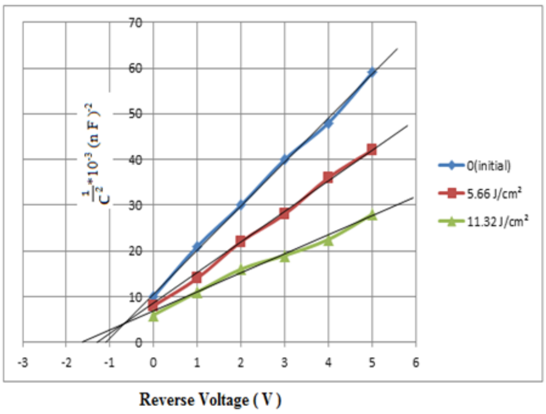


Fig.(7): The I-V characteristics of n-Ge/p-SnS Heterojunction under Dark Condition for Water Environment

Figure (8) shows the variation of the reciprocal of square capacitance versus reverse bias voltage . It is obvious that the junctionis abrupt type due to linear variation of capacitance versus reverse voltage . The value of the built- in-potential (V_{bi}) in vaccum environment it can obtained by extrapolating the curve at point ($1/C^2=0$) and has a values (1.1V , 1.25V , 1.55V) for (initial , 5.66 J/cm^2 , 11.32 J/cm^2) respectively , while in water environment it has a values of (1.2V , 1.4V , 1.78 V) for (initial , 5.66 J/cm^2 , 11.32 J/cm^2) respectively.



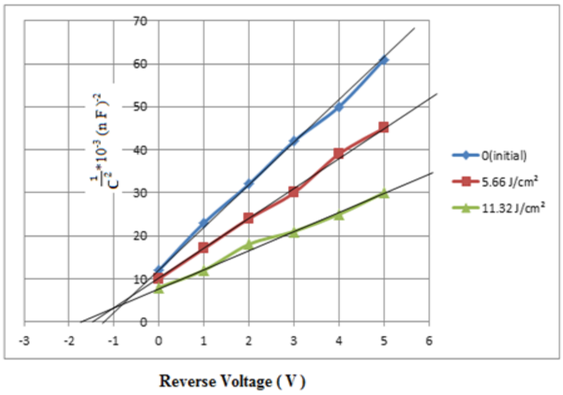


Fig.(8): The Variation of the Reciprocal of Square Capacitance Versus Reverse Bias Voltage

Table (3) shows the average values of built-in potential in the present study and other studies. This increasing in the value of built – in-potential especially in water environment is due to the increasing of the width of the depletion region (increasing the area of absorption) and this is because some part of SnS atoms penetrated into the germanium wafer as a result of the effects of the laser-induced stress and shock waves which provide the conditions for rapid mass transfer of SnS because of transformation of the point defect structure and barodiffusion.

Table (3) : Average Values of Built-in Potential in the Present Study and Other Studies

Built- in potential (V) (average)	References
1.38	Present Study
1.1	[12]
1.54	[13]
1.43	[14]

The responsivity is an important parameter that is usually specified by the manufacturer knowledge of the responsivity allows the user to determine how mach detector signal will be available for a specific application and can be calculated by the equation:[8,9]

$$R(\lambda)=\frac{I_{Ph}}{P_{in}(\lambda)}. \quad (4)$$

Where, I_{ph}: *is* the photocurrent.

$P_{in}(\lambda)$: is the input power.

Figure (9) shows the spectral responsivity of the fabricated diode detectors. It is noticed that the responsivity curves show good band-pass behavior and two peaks can be observed. First peak at region 900 nm this peak is due to absorption of light in SnS through band-to band absorption while second region at 1250 nm which due to the Ge band gap.

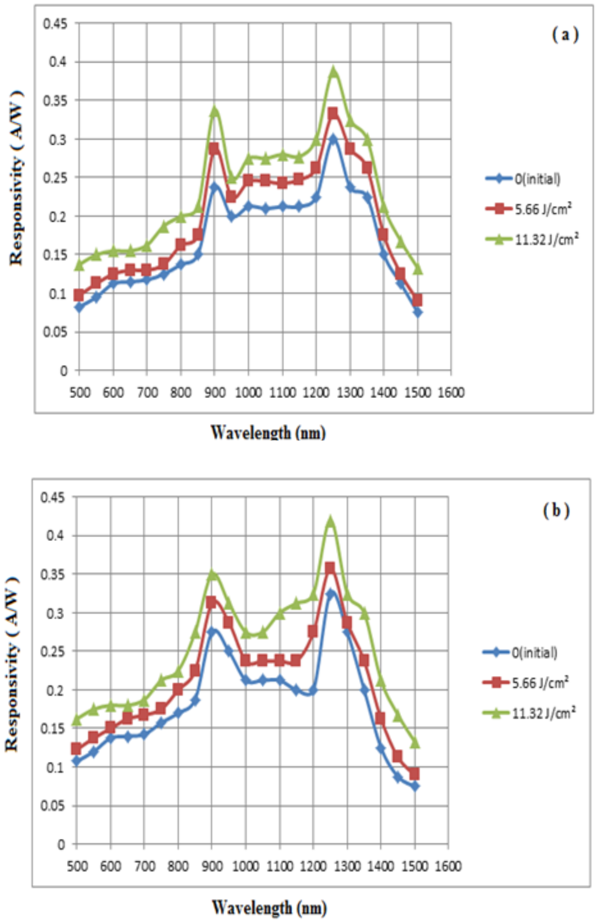


Fig.(9): Spectral Responsivity of the Fabricated Diode Detectors; (a)Vacuum Environment , (b) Water Environment

Table (4): The Responsivity in Different Environments and Laser Energy Densities for Wavelengths (900 nm and 1250 nm).

Energy density (J/cm^2)	Responsivity in Vaccum (A/W)		Responsivity in Water (A/W)	
	λ at 900nm	λ at 1250nm	λ at 00nm	λ at 250nm
0 (initial)	0.24	0.3	0.27	0.33
5.66	0.29	0.34	0.32	0.36
11.32	0.34	0.39	0.36	0.43

Its clear from this table that the responsivity increases with increases of laser energy density and this increase is to be clear in the water environment more than the vacuum environment.

The quantum efficiency is basically another way of expressing the effectiveness of the incident optical energy for producing an output of electrical current, the quantum efficiency *Q* (in percent) may be related to the responsively by the equation:[8][9]

$$Q=100*R(\lambda)*(1.2395/\lambda).. \quad (5)$$

R (λ): is the responsively (in amperes per watt) of the detector at wavelength *λ* (μm) .

Figure (10) shows the quantum efficiency as function of wavelength in different environments for laser energy densities.

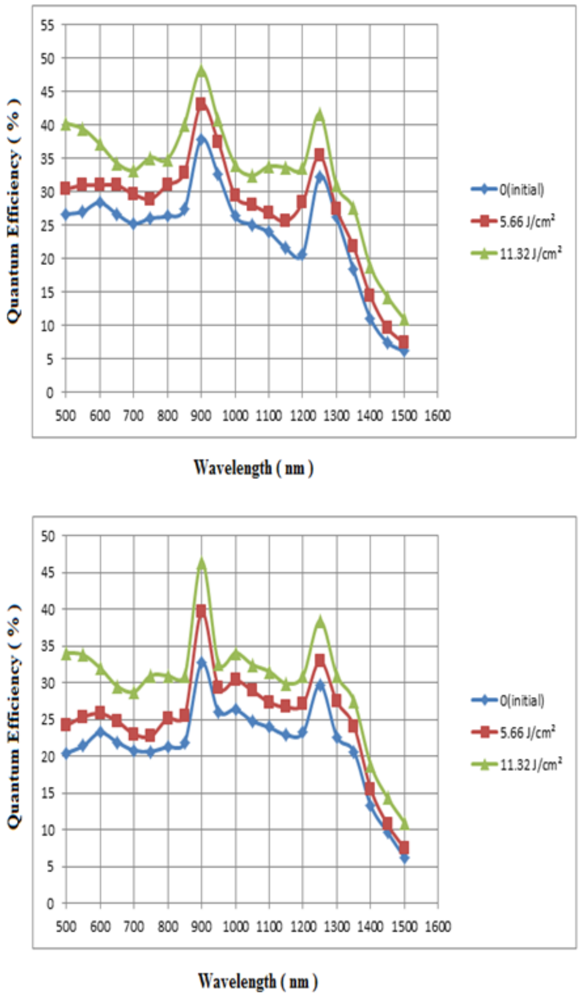


Fig.(10):Quantum Efficiency as a Function of Wavelength; (a)Vacuum Environment , (b) Water Environment

It's clear from Figure that the quantum efficiency has two peaks at 900nm and 1250 nm and it increases with increase of laser energy density. This increase is to be clear in the water environment more than the vacuum environment as shown in table (5).

Table (5): The Quantun Efficiency in Different Environments and Laser Energy Densities for Wavelengths (900 nm and 1250 nm).

Energy density (J/cm^2)	Quantun Efficiency in Vaccum (%)		Quantun Efficiency in Water (%)	
	λ at 900nm	λ at 1250nm	λ at 900nm	λ at 1250nm
0 (initial)	0.24	0.3	0.27	0.33
5.66	0.29	0.34	0.32	0.36
11.32	0.34	0.39	0.36	0.43

Conclusions

The n-Ge/p-SnS hetrojunction diode detector can be prepared by using thermal evaporation process and irradiated with Nd:YAG laser. The films surface consists of spherical shape of grains with intermittent nature this is due to the droplet splashes onto the substrate. In vaccum environment the grain size is small and increased with increasing of laser energy density while in water environment the formation of bigger grains can be observed with increasing of laser energy. n-Ge/p-SnS heterojunction is abrupt type. Two peaks can be observed , first peak at region 900 nm this peak due to absorb of light in SnS through band-to band absorption while second region at 1250 nm which due to the Ge band gap. Quantum efficiency has two peaks at 900nm and 1250 nm and it is increases with increases of laser energy density and this increasing is to be clear in the water environment more than the vacuum environment.

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تاثير طاقة الليزر على شريحة كاشف دايود n-Ge/p-SnS في ظروف مختلفة

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الخلاصة : في هذا البحث تم تحضير كاشف المفرق الهجين نوع n-Ge/p-SnS باستخدام شرائح الجرمانيوم كقاعدة مرسب عليها كبريتيد القصدير بسمك 200 nm .تم استخدام نيديميوم ياك ليزر ذي الطول الموجي 532 nm مع كثافة طاقات مختلفة (٥.٦٦ جول /سم٢ و ١١.٣٢ جول/سم٢) لنشر جزيئات كبريتيد القصدير داخل رقائق الجرمانيوم في بيئات مختلفة (الفراغ والماء). جرى قياس كل من خصائص تيار- جهد في حالة الظلام , خصائص سعة – جهد, الاستجابة النوعية والكفاءة الكمية في درجة حرارة الغرفة. اظهرت قياسات سعة – جهد ان المفرق المصنع هو من النوع الحاد ويمتلك اعلى قيمة جهد بناء داخلي قيمتها ١.٧٨ فولت في البيئة المائية كما اظهرت القياسات ان الكاشف يمتلك قمتين وهي ٩٠٠ نانومتر و١٢٥٠ نانومتر وان اعلى قيمة للاستجابية الطيفية يمكن ان تلاحظ عند الطول الموجي ١٢٥٠ نانومتر في البيئة المائية .تم حساب الكفاءة الكمية للكاشف وقد وجدت ان الكفاءة الكمية للكاشف تزداد مع زيادة كثافة طاقات الليزر في البيئة المائية اكثر من بيئة الفراغ.