The effect of substrate temperatures on the characterization of CdSe:Cu detector

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Abstract

The CdSe:Cu photoconductive detector was fabricated using vacuum technique on glass substrate at different temperatures. The effect of the substrate temperatures of the prepared films upon, the structural , I-V characteristics, photoconductive properties, spectral response, quantum efficiency, NEP, gain and detectivity properties of the detector was studied. The structure of the prepared films was studied using XRD. It was found that the crystal structure is improvement with increasing doping and substrate temperatures. It was found that better photoconductive characteristics can be reached when CdSe:Cu films substrate temperature increased from room temperature up to T_s 250°C.

The structure of these films are amorphous at pure CdSe with small peaks at (002) direction, and the structure with Cu impurity are polycrystalline with high intensity at the direction (002) and small peaks at the direction (102) which indicate a hexagonal and cubic structure with lattice constant (a=4.27, c=7.02)A. The crystal structure are improving from polycrystalline to single phase(002) direction and hexagonal structure with lattice constant(c=7.02)A by increasing of substrate temperatures. It was found that the gain coefficient was increased with an increase of the substrate temperatures and better result obtained at 250°C. The CdSe:Cu detector showing gain coefficient up to $6.7x10^3$ for white illumination 1000Lux.

The maximum value of spectral response (R_λ) were at (0.71, 0.71, 0.69, 0.68., 0.675)μm for films prepared at substrate temperatures(28, 100, 150, 200, 250) °C respectively. This mean that the spectral response is increased with the increase of λ .The highest value of R_λ was for films prepared at T_s =250°C decreases with the decreasing of T_s. The quantum efficiency (η) increases with the increasing T_s and the NEP decreases with increasing T_s. The maximum value of D^*occurs at λ=(0.71, 0.71, 0.69, 0.68., 0.675)μm was equal to ($1.023X10^{12}$, $1.157\ X10^{12}$,$1.27\ X10^{12}$,$1.39\ X10^{12}$,$1.46\ X10^{12}$)Cm.$Hz^{1/2}W^{-1}$ for T_s (28, 100, 150, 200, 250) °C respectively.

1-Introduction:

II-VI compounds are important materials for such applications photoconducting, photovoltaic cells, and other optical devices. These materials can be obtained in thin film form by evaporation, sputtering, pyrolysis and chemical deposition techniques[1]. CdSe is primarily of interest for photoconductive applications[2], as thin film transistor, a detector of faster response than CdS[4-6]. The photoconductive properties of these depend mainly on the preparation condition such as impurity concentration and the substrate temperature of the film [1]. The optical absorption coefficient exceeds $5x10^4cm^{-1}$ for all wavelength below 700nm and the direct forbidden gap energy is approximately1.7eV. Properly prepared films of (1-2) μm

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visible wavelength region. With a room temperatures (28°C), the absorption edge at approximately 730nm[7]. Extensive studies have been carried out on the photoconducting properties of copper doped CdSe films with varying of impurity concentration[8] and the present paper deals with these properties for CdSe:Cu prepared at different substrate temperatures.

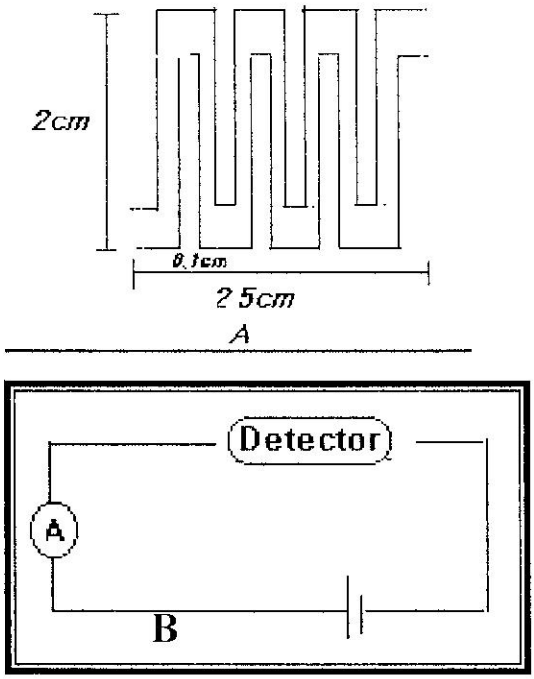

Fig.(1)A-Represent the geometrical arrangement of the mask of th photoconductive, B-Schematic for photoconductive Circuit.)

2-Experimental:

Cadmium selenide (CdSe)(99.999)%doped with copper by chemical diffusion by mixed with solution of CuCl(5wt%) and dried at 100°C for one hour and were taken as a source materials. The film of CdSe:Cu deposited onto glass substrate at various temperatures (T_s =28-250°C) from molybdenum boat using Balzers coating unit reaching a vacuum of ~10^{-6}Torr with rate of deposition(1/90) μm/sec.The distance between the boat and substrate is 15cm. The films thickness(1μm) was determined using JOEL-JSM-644 scanning electron microscope. The crystal structure of the prepared films has been determined by (XRD)studies. The electrodes were Aluminum vacuum deposited and Fig.(1A) represents the geometrical arrangement of the mask of the photoconductive films, this arrangement has been taken to get better properties due to the large area of the effective material, the distance between the electrode is small of about (0.1)cm. The I-V characteristics for dark and under illumination was measured using HP digital multimeter, Tungsten filament lamp in the range (0.2-3) μm, and supplied with D.C power supply (see Fig.(1B)) and the intensity of the illumination were (10,100,1000)Lux without filter in visible range(0.4-0.9) μm. The sample of the CdSe:Cu films were placed in the dark container and connected to the circuit as shown in Fig.(1B), which provided to d.c bias voltage from (0-120)V, after that the dark current has been responded. The photocurrent has been taken after exposed the samples to the light with varying the bias voltage between(0-120)V.

Fig.(1)A-Represent the geometrical arrangement of the mask of th photoconductive, B-Schematic for photoconductive Circuit.)

3-Results and Discussion:

3-1 XRD Studies:

we can see from X-ray diffraction measurements as shown in Fig.(2) that the structure of these films are amorphous for pure CdSe film with small peaks at (002) direction, and when we are doping this sample with Cu impurity the structure are polycrystalline with high intensity at the direction (002) and small peaks at the direction (102) which indicate a hexagonal and cubic structure according to the ASTM cards data with

lattice constant (a=4.27, c=7.02)A. The crystal structure are improving from polycrystalline to single phase(002) direction and hexagonal structure with lattice constant(c=7.02)A by increasing of substrate temperatures, this results are agreement with the researchers[6,9,10]. The average grain size of this sample are varied between (80-81.4nm) and this is agreement with Shreekanthan[11].

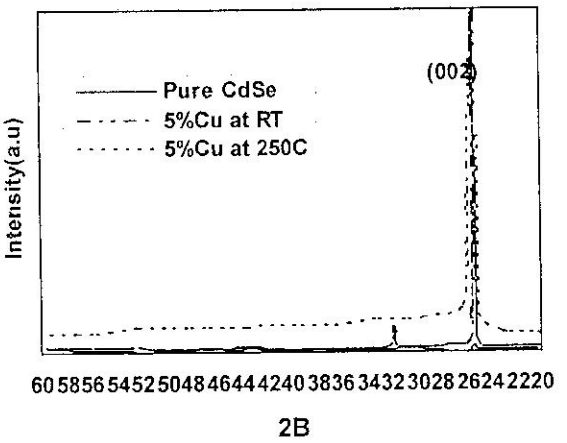

Fig.(2)X-ray diffraction pattern for pure CdSe and doped with 5wt%Cu at RT and 250°C.

3-1 -I-V Characteristics:

The I-V characteristics for the range (0-120)V are shown in Fig.(3), It is seen that the dark current (I_d) of the films increase with increases of the substrate temperatures for 5wt% of Cu which prepared at T_s (28, 100, 150, 200, 250) °C. As expected the behavior is linear and this increasing of the dark current as a function of the bias voltage is believed due to the increase in the grain size with increasing growth temperature followed by transition to agglomerated island like structure[9]. It is well known that the grain boundaries have a dominate effect in limiting the mean free path(l) and the lifetime (τ)due to scattering with grain boundaries geometrically and due to intergrain potential and due to extent of the impurity which act the sensitization centers[9].The value of dark current for pure CdSe is about 10^{-6}Amp at bias voltage 30V which prepared at the same technique and condition[9], whereas the value of dark current for CdSe:Cu at 30V is about 10^{-9}Amp, this mean that the dark current decreases with increases of impurity concentration due to improvement in crystal structure and recrystallization by adding the impurity[11].

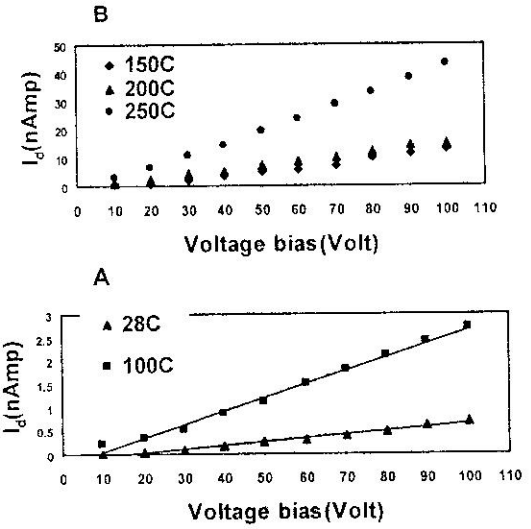

Fig.(3)The dark current with bias voltage for CdSe:Cu (5wt% Cu)films which deposited at T_s (28, 100, 150, 200, 250) °C.

The photocurrent increase in Fig.(4) with increasing of bias voltage and illumination intensity. The low intensity of illumination causes trapping by the Cu centers inside the band gap of CdSe and this attributed to that illumination was not sufficient to excitation all the carriers from valence band to conduction band or to the doping levels and this lead to capture the carriers at these levels. At higher intensities (1000Lux), more increase in the photocurrent was observed due to saturation of trapping centers which reduces their activities as a free carriers traps[18]. The photo current also increases with increasing of substrate temperatures as shown in Fig.(4) due to improvement in the crystallanity of

the films that mean increase of the mobility of free charge carriers reaching the conduction band at shorter transient time where the captured and recombination centers become ineffective. Also, we can observe from Fig.(4A,B) that the relations between the current and voltage are linear at substrate temperatures(28, 100) °C, while this relation is semi linear at higher substrate temperatures (150, 200, 250) °C as shown in Fig.(4C,D), and it reaches to saturation limit at higher voltage, this mean that all carriers is arrive to the conduction band without any trappings, impurity and recombination centers at higher voltage and shorter transient time, therefore it reaches to saturation limit Fig.(4).

3-3Photoconducting Properties:

From Fig.(5A,B) it is found that the dark and photoconductivity increase with increasing the substrate temperature for CdSe:Cu thin films. This behavior seems to be due to the better crystallanity of the films and this result in agreement with other workers[3,10,12]. It is observed that the value of photoconductivity and that was normal process because in most photoconductive detectors the incident radiation produces a change in conductivity by raising from valence band to the conduction band or by free electrons of the semiconductor or holes from impurity centers[13]and this impurity in our case is copper[8].

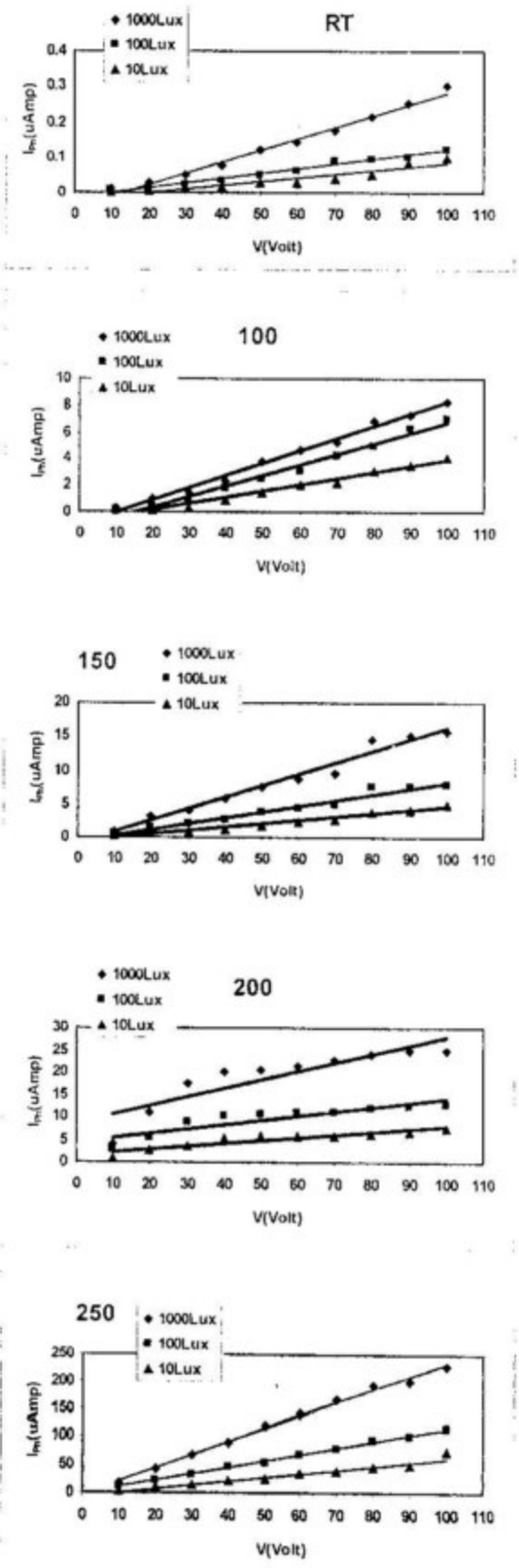

Fig.(4)The variation of photocurrent with bias voltage for CdSe:Cu (5wt% Cu) films which deposited at T_s (28, 100, 150, 200, 250) °C.

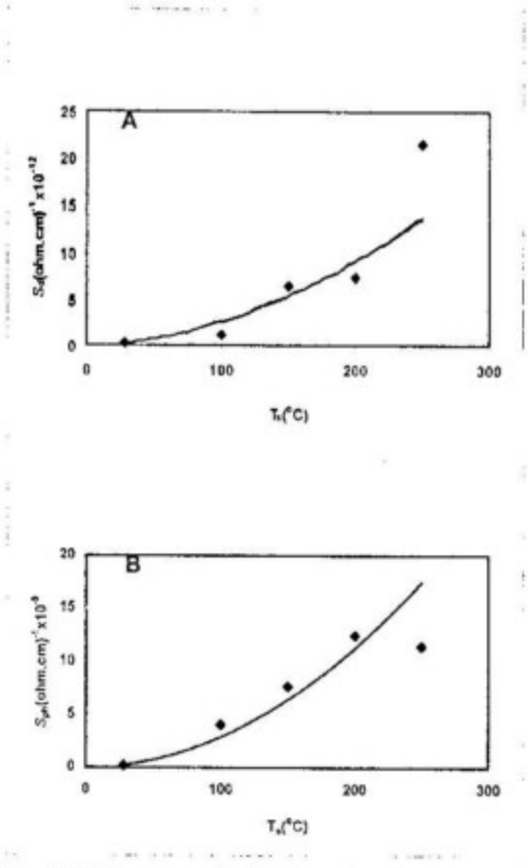

Fig.(5)The variation of dark and photoconductivity respectiviely for CdSe:Cu (5wt% Cu)films which deposited at T_s (28, 100, 150, 200, 250) °C.

3-Gain Coefficient:

The gain (G) of the detector is the photo to dark ratio[9]:

$$G=I_{ph}/I_d \text{----------(1)}$$

Where I_{ph} and I_d are photo and dark current respectively, this ratio is found to increase with increase of T_s at 20Vand at illumination 1000Lux as shown in Fig.(6).This attributed to the impurity in this films and to the substrate temperatures which cause improvement and recrystallization in the lattice structure[1,14].The maximum G value which obtained in the present work was $6.7X10^3$ with illumination of 1000Lux and bias voltage 20V which is higher than the corresponding G value for pure CdSe by 25times which was prepared in the same condition[9]. Further such value of gain obtained is much higher than that published by others researchers. However Glew[15] haf obtained G=60 for CdSe prepared by sputtering method, while Kainthi[16] got a value of $2\ X10^3$ for CdSe single crystal. The higher value of the gain in our work is attributed to the cross- section of holes and electrons. The Cu atoms posses a trapping cross section for holes which indicates that Cu centers acts as a photoconductivity I sensitizer[17] and due to improvement in the structure by heating substrate and doping method as we see in Fig.(2).

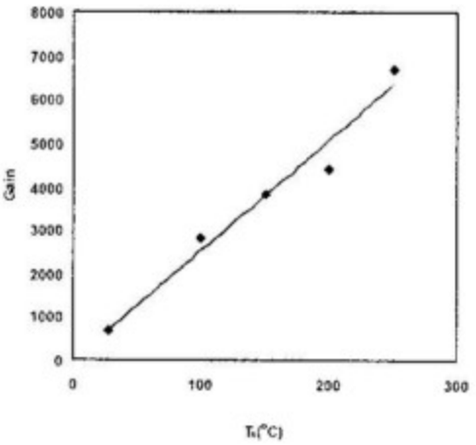

Fig.(6)The gain value as a function of substrate temperatures for CdSe:Cu films

3-5 Spectral Measurements:

The spectral response (R_λ) is represented by the equation[19]:

$$R_\lambda=I_{ph}/P_{in} \text{ (Amp/Watt)----------(2)}$$

Where P_{in} is the power incident. From this measurement the R_λ for CdSe:Cu(5wt%) at different T_s (28, 100, 150, 200, 250) °C has been studied as a function of wavelength in the range(0.4-0.925) μm as shown in Fig.(7). The maximum value of spectral response (R_λ) were at (0.71, 0.71, 0.69, 0.68., 0.675)μm for films prepared at substrate temperatures(28, 100, 150, 200, 250) °C respectively. i.e when the substrate temperatures increase, the peaks of R_λ shift to lower wavelength indicating that they are intimately connected with the microstructure of the films.

From this figure and up to $\lambda = \lambda_{peak}$, R_λ is increased with the increase of λ .The highest value of R_λ was for films prepared at T_s =250˚C decreases with the decreasing of T_s as shown in Fig.(10) and Table(1).

This is attributed to the decreases in the absorption coefficient with increases of T_s and that decreases the effect of Cu impurity, recombination centers, and defects. These value of R_λ are agreement with other researchers[8,9,17]. The values of the relative responsivity are shown in Fig.(7B).

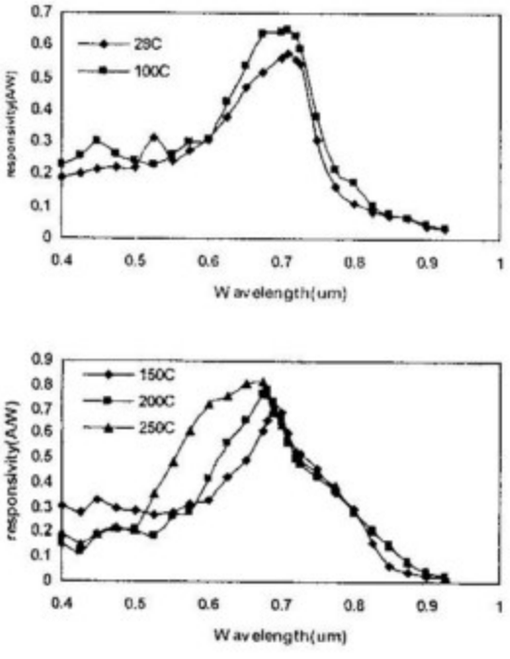

Fig.(7A)Represent the variation of responsivity as a function of wavelength for CdSe:Cu at different T_s.

$$\eta = 1.24 R_\lambda / \lambda \text{---- ----------(3)}$$

and Fig.(8) shows the variation of η as a function of wavelength for CdSe:Cu(5wt%) at different T_s (28, 100, 150, 200, 250) ˚C. It can be seen from this figure and Table(1) that η increases with the increasing T_s (Fig.(10))and this is due to increasing absorption coefficient and decreasing the defect inside the energy gap.

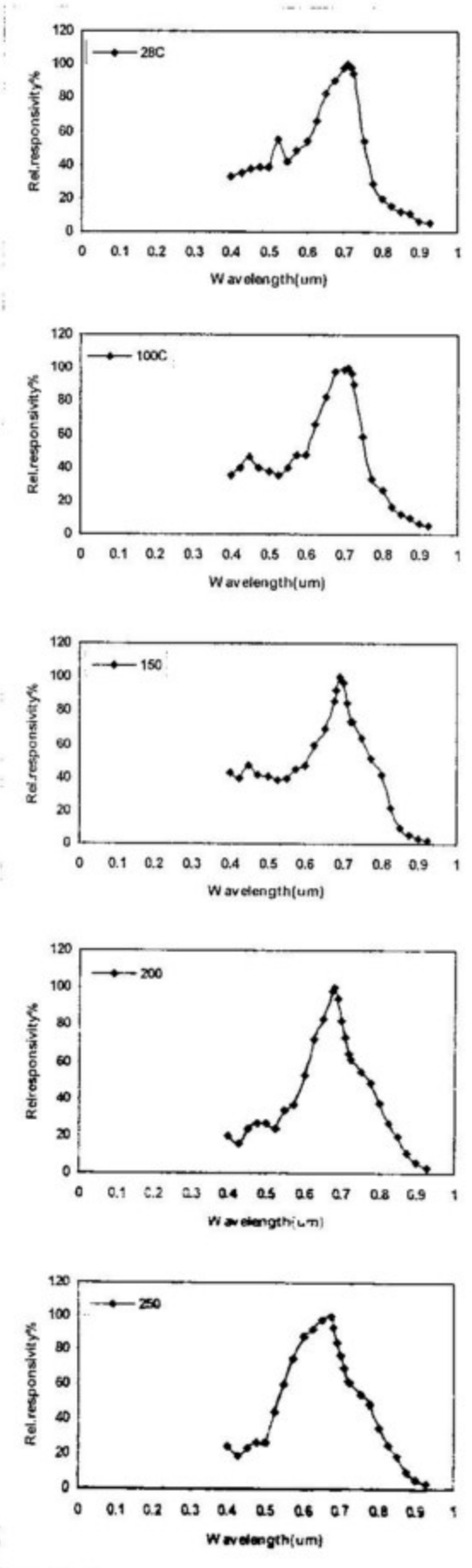

Fig.(7B)Represent the variation of rel.responsivity as a function of wavelength for CdSe:Cu at different T_s.

The quantum efficiency (η) are related to R_λ results, and it was calculated by the equation[19]:

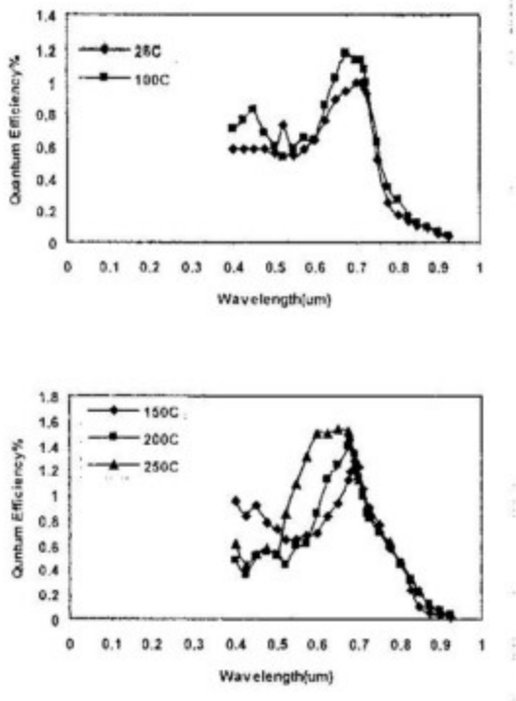

Fig.(8)Represent the variation of η as a function of wavelength for CdSe:Cu at different T_s.

The noise equivalent power (NEP) in photoconductive detectors exhibit several types of noise, it is determined by the equation[19]:

$$I_n=(2qI_d \Delta F)^{1/2} \text{----------(4)}$$

$$NEP = I_n / R_\lambda \text{----------(5)}$$

Fig.(9) shows the variation of NEP as a function of wavelength for CdSe:Cu(5wt%) at different T_s (28, 100, 150, 200, 250) °C. The value of NEP decreases with increasing T_s from $(0.97\text{-}0.68\times10^{-12})$W as shown in Fig.(10) and Table (1). Also we can observe that at the wavelength less than (0.6 μm), the value of NEP is very high, while at the range(0.6-0.8 μm), the value of NEP is very low, and after the wavelength 0.9 μm, it is increased to maximum, this means that the maximum responsivity occurs when NEP at the minimum value, then we must make the noise as less as possible in the detector. The detectivity can be calculate for CdSe:Cu(5wt%) at different T_s (28, 100, 150, 200, 250) °C from the equation[19]:

$$D^* = R_\lambda (A \Delta F)^{1/2} / I_n \text{ ----------(6)}$$

We can see from Fig.(10) and Table (1), the dependence of D^* on the wavelength and it increases with increasing the wavelength up to highest detectivity at near the cut off , after that, it reduce sharply. The reason for increment is the same as above for the spectral responsivity. The maximum value of D^* occurs at λ=(0.71, 0.71, 0.69, 0.68., 0.675)μm was equal to (1.023×10^{12}, 1.157×10^{12}, 1.27×10^{12}, 1.39×10^{12}, 1.46×10^{12})Cm.Hz$^{1/2}$W^{-1} for T_s (28, 100, 150, 200, 250) °C respectively as shown in Fig.(10) . It is also found that the detectivity for pure CdSe is about[20] 4.1×10^{10}Cm.Hz$^{1/2}$W^{-1}. The increasing in this obtained value is attributed to the existence of Cu impurity in CdSe and improvement of the structure by increasing T_s as we mentioned before.

Table(1) The parameters of CdSe:Cu photoconductor detectors.

	λ_{peak} (μm)	R_λ (A/W)	Quantum efficiency %	NEP(W) x10^{-12}	$D^*\times10^{12}$ cm.Hz$^{1/2}$ /W
28	0.710	0.573	1	0.977	1.023
100	0.710	0.648	1.132	0.864	0.157
150	0.690	0.711	1.279	0.787	1.271
200	0.680	0.778	1.42	0.719	1.391
250	0.675	0.818	.503	0.684	1.461

4-Conclusions:

In a previous work we have prepared pure CdSe films detectors at room temperatures substrate and with Cu impurity of (5wt%) at different phase(002) direction and hexagonal structure with lattice constant(c=7.02)A. The average grain size of this sample are varied between (80-81.4nm).

2. From I-V characteristics the I_d and I_{ph} increase with increasing the substrate temperatures. The

photoconductivity increase with increasing of substrate temperature. The high value of gain coefficient is $G=6.7X10^3$.

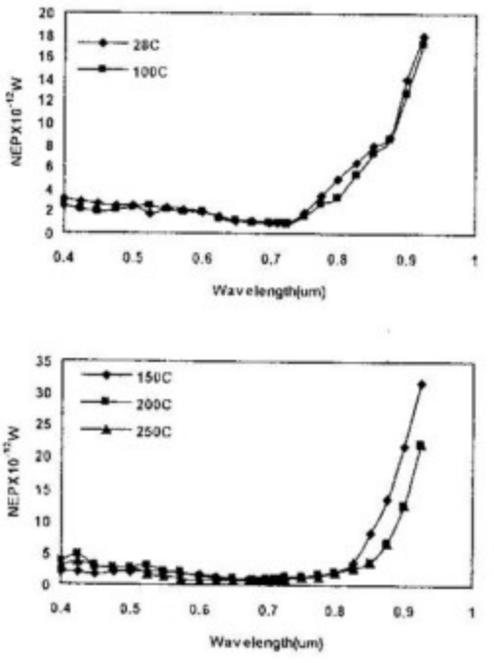

Fig.(9)Represent the variation of NEP as a function of wavelength for CdSe:Cu at different T_s.

3. The maximum value of R_λ were at (0.71, 0.71, 0.69, 0.68., 0.675)μm for films prepared at substrate temperatures(28, 100, 150, 200, 250) °C respectively. The peaks of R_λ shift to lower wavelength. The η increases with the increasing T_s .

4. The value of NEP decreases with increasing T_s from $(0.97\text{-}0.68x10^{-12})$W.

5. The maximum value of D^*occurs at λ=(0.71, 0.71, 0.69, 0.68., 0.675)μm was equal to ($1.023X10^{12}$, $1.157 X10^{12}$,$1.27 X10^{12}$,$1.39 X10^{12}$,$1.46 X10^{12}$)$Cm.Hz^{1/2}W^{-1}$ for T_s (28, 100, 150, 200, 250) °C respectively. The increasing in this obtained value is attributed to the existence of Cu impurity in CdSe and improvement of the structure by increasing T_s.

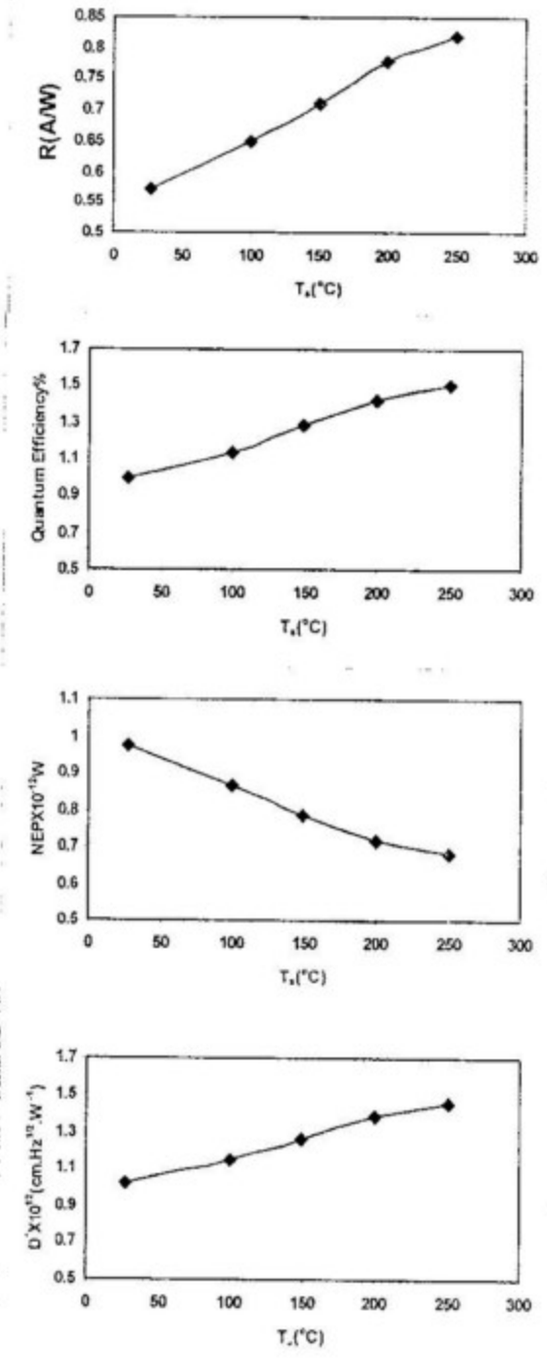

Fig.(9)Represent the variation of R_λ, η. NEP and D^* as a function of wavelength for CdSe:Cu at different T_s.

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تأثير درجة حرارة الأساس على خصائص كاشف CdSe:Cu

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الخلاصة

صنع كاشف التوصيلية الضوئية CdSe:Cu بواسطة تقنية التبخير الحراري في الفراغ على قواعد زجاجية وبدرجات حرارة اساس مختلفة. درس تأثير تغير درجة حرارة الأساس للاغشية المحضرة على الخواص التركيبية، I-V ، التوصيلية الضوئية، الأستجابية الضوئية، الكفاءة الكمية، القدرة المكافئة للضوضاء، الربحية و الكشفية. درست الخواص التركيبية للاغشية المحضرة بأستخدام حيود الأشعة السينية. وجد بأنة يتحسن التركيب البلوري بزيادة التطعيم ودرجات حرارة الأساس للاغشية المحضرة. امكن الحصول على افضل خصائص للتوصيلية الضوئية عند زيادة درجة حرارة الأساس من درجة حرار الغرفة الى 250°C . يكون تركيب الاغشية المحضرة النقية في درجة حرار الغرفة عشوائيا مع وجود قمة صغيرة جدا بالأتجاة (002) ، ومتعدد البلورات للاغشية المشوبة بالنحاس مع شدة عاليةا بالأتجاة (002) وقمة صغيرة بالأتجاة (102) والتي تشير الى ان التركيب يكون من النوع السداسي والمكعبي وبثوابت شبيكةA(a=4.27, c=7.02) . بعد ذلك يتحسن التركيب البلوري البلوري بزيادةدرجات حرارة الأساس من متعدد البلورات الى الطور المفرد بالأتجاة (002) السداسي وبثوابت شبيكةA(c=7.02) وجد بأن عامل الربحية يزداد بزيادة درجة حرارة الأساس و افضل نتائج عند درجة حرارة 250°C، وكانت قيمتة $6.7x10^3$ عند تسليط ضوء ابيض بالشدة 1000Lux . وكانت اعظم قيمة للاستجابية الضوئية عند الأطوال الموجية (0.71, 0.71, 0.69, 0.68., 0.675)μm للاغشية المحضرة بدرجات حرارة أساس (28, 100, 150, 200, 250) °C على التوالي. وهذا يعني زيادة الأستجابيةالطيفية بزيادة الطول الموجية و اعظم قيمة عند درجة حرارة 250°C، وتقل بنقصان T_s وكذلك بزيادة T_s. تزداد الكفاءة الكمية وتقل القدرة المكافئة للضوضاء . حصلت اعظم قيمة للكشفية عند الأطوال الموجية (0.71, 0.71, 0.69, 0.68., 0.675)μm وكانت مساوية الى $(1.023X10^{12}, 1.157\ X10^{12}, 1.27\ X10^{12}, 1.39\ X10^{12}, 1.46\ X10^{12})Cm.Hz^{1/2}W^{-1}$ عند T_s (28, 100, 150, 200, 250) °C على التوالي.