The Photoconductive Properties of Pb_xS_{1-x} Films

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Abstract

Polycrystalline Pb_xS_{1-x} photocond- uctive detectors with both value of x(0.50&0.53) were fabricated using vacuum evaporation technique at room temperature and under vacuum 10^{-6} mbar. The thickness of films was 2.0 μm. The structure of the films has been examined by x-ray diffraction .The detection properties : [responsivity (R_λ) , quantum efficiency(η) ,signal –to–noise ratio (S/N) ,detectivity (D^*) and noise equivalent power (NEP)] have been measured for both value of x .It was found that the responsivity , η, D^* and S/N have increased while NEP decreased when the value of x increases from 0.50 to 0.53.

Introduction

Infrared (IR) radiation is an electromagnetic radiation generated by the vibration and rotation of atoms and molecules in any material at temperatures above absolute zero(0k) [1] .It is widely used in diverse technical and scientific fields including spectroscopy, optical communication, and other measurements applications [2]. In Recent years there has been an increasing emphasis on the research , design, development and deployment of various infrared devices and systems for military applications at night or during the day when vision is diminished by fog , haze, smoke, or dust. The wide varieties of semiconductor applications necessities the need to a high sensitive material that are easy to fabricate. PbS , PbSe Photoconductive detectors are among the earliest to be used in high performance and they are still widely used because of their cheep fabricating method [3] . PbS Photoconductive detector is almost used in near infrared, and thus comprehensive work has been carried out, because it is the most sensitive and rapid infrared detector [4] .It has a wide spread application in guidance system for air-to-air missiles, with spectral response up to 3.0 μm and capable for detecting 2.7 μm in the H_2O and CO_2 band in the plume of heated gas from hydrocarbon burning jet engine. It exhibits excellent performance at room temperature [5] . Two methods of preparing PbS infrared detectors exist: chemical deposition method and evaporation by vacuum method. In both methods the layer deposited is a polycrystalline film .

Lead sulfide detectors were first investigated in Germany before and during world war Π by B. Gudden and developed by Germany / military during the 2nd world war [6] .

During the ensuing 50 years, the major volume users of the detectors continued to be primarily military for applications in missile guidance and surveillance system.

During the past 14 years, another surge in the commercial

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applications has occurred and is continuing [7] .These advantageous characteristics of the PbS photoconductive cell opened the way for a number of applications in infrared techniques e.g infrared spectroscopy with high resolving power, dynamic spectroscopy and fast monitoring pyrometer.

From high sensitivity and high response, materials PbS compound is the most important infrared detectors available in every form of infrared network over the range (1-3 μm) [8] .

Figures of the merit

In order to compare the perfance of infrared detector , it is necessary to defined certain figure of merit.

1. Responsivity (R_λ):

The responsivity is defined as the dependence of the signal output of the detector on the input radiant power and it is commonly expressed as voltage respontivity or current responsivity [9]:

$$R_\lambda=\frac{V_s}{P}\ (V/W) \text{or}\ R_\lambda=\frac{I_{ph}}{P}\ (A/W) \text{ ---(1)}$$

Where V_s is the signal voltage ,p is the incident power and I_{ph} is the photcurrent.

2. Quantum Efficiency (η))))))

Is defined as the ratio of the number of elementary events contributing to the detector output to the number of incident photons .For photoelectric detectors , the quantum efficiency can be computed as [10] :

$$\eta= R_\lambda \frac{h\nu}{q} =1.239\frac{R_\lambda}{\lambda} \text{ ---------------(2)}$$

where $h\nu$ is the photon energy, λ is the wavelength.

3. Noise Equivalent Power (NEP):

The noise equivalent power is defined as the incident radiant power falling on the detector that is required to produces a signal voltage or current , it is expressed as [1]:

$$NEP=\frac{I_n}{R_\lambda}\ (\text{Watts}) \text{ -----------------(3)}$$

Where I_n is the noise current given by [11] :

$$I_n =(I_s^2 +I_j^2) \text{ -------------------------(4)}$$

Where I_s and I_j are shot noise and Johnson respectively and they are determined by following equations:

$$I_s = (2qI_d \nabla f)^{1/2} \text{ ---------------------(5)}$$

$$I_j = (4n K_B T\nabla f / R_{sh}) \text{ -------------(6)}$$

Where R_{sh} is the shunt resistance equal to $R_{sh}=V/I_d$.

4. The Detectivity D^*:

The detectivity is defined as the signal to noise ratio produced with unit radiant flux incident on the detector , or also defined as the reciprocal of the noise equivalent power (NEP) [12]:

$$D^*=\frac{(A\nabla f)^{1/2}}{NEP} \text{ ----------------------(7)}$$

where A is the sensitive area, Δf is the amplifier band width

Experimental

The PbS alloy was prepared from pure lead and sulphur powders whose purity is about (99.999%).The material was weighted according to their atomic percentages and sealed in evacuated quartz tube to 10^{-5} torr .The tube was placed inside electric furnace of type (Haraeui). The temperature was slowly raised to 1387 k and the tube was kept at this temperature for 24 hours. The tube was finally quenched rapidly in cold water.

Pb_xS_{1-x} photoconductive detectors with both value of x (0.50 and 0.53) were prepared by thermal evaporation method at room temperature under vacuum 10^{-6} mbar in an inert Argon gas and an electric glow discharge (GD) for about 15 minutes. The thickness of films was 2.0 μm. X-ray diffraction (XRD) and atomic absorption spectroscopy were employed to examine the structure and composition respectively.

Spectral responsivity was measured using detector test system DSR 500 from optoronic Inc.The incident power on to the Pb_xS_{1-x} was obtained from this is detector and it should be a light source.

3-Results and Discussion

Figs.(1) and (2) show the X-ray diffraction patterns obtained for Pb_xS_{1-x} films prepared by thermal evaporation method at RT and thickness of 2.0 μm. For x=0.50 and 0.53 respectively it was observed that the films kept their polycrystalline cubic structure with strong peak at [200] direction for both values of Pb content . This means that this plane is suitable for crystal growth. Also one can observe from Fig.(2) that the film is affected by increasing the value of Pb content i.e. rise in recrystallization of film structure this in agreement with results of Elbad and Stecki [13] and Judita [14].

The Hall measurement was confirmed by thermoelectric power, where $Pb_{0.5}S_{0.5}$ films were found to be p-type while the $Pb_{0.53}S_{0.47}$ films were n-type and to calculate the carriers concentration it was used the eq. ($R_H=\frac{1}{nq}$) where R_H is the Hall coefficient given by ($R_H=\frac{V_H t}{I.B}$), V_H is the Hall voltage , t is the thickness of film, I the applied current and B is the magnetic filed equal to 0.254T.It was found that the carrier concentration increased from ($80 * 10^{17} - 50 * 10^{18}$) cm^{-1} when x increased from 0.5 to 0.53.

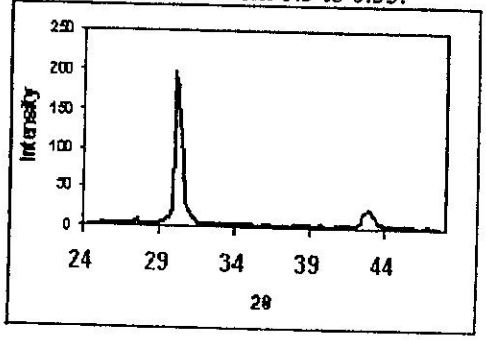

Fig.(1) X-ray diffraction for $Pb_{0.5}S_{0.5}$ films.

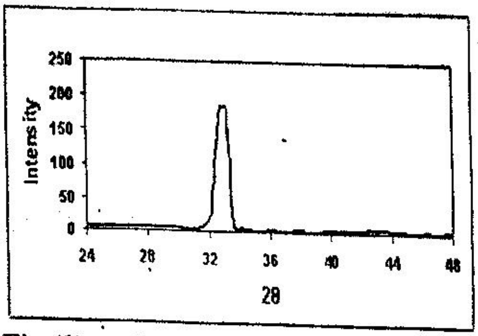

Fig.(2) X-ray diffraction for $Pb_{0.53}S_{0.47}$ films.

3-1 Photoconductive measurements

3-1-1-*Spectral Responsivety measurement*

One of the most important characteristics of a photoconductive detector is its spectral response.

Fig.(3) shows the spectral responsivety (R_λ) of Pb_XS_{1-X} films to radiation of wavelengths range from (1-3) μm .at room temperature for both value of Pb content (x =0.50,0.53).

It was found that the highest value of spectral responsively occurred at λ=2.2 μm for both values of x (0.50 and 0.53) .The two cutes for Pb_XS_{1-X} films give an indication of increasing responsivety, and the films become more sensitive when the value of x increases from 0.50 to 0.53.

The increase is due to the increase in the amount of Pb content which enhances the absorption coefficient when the value of x is increased leading to a higher quantum efficiency (η) according to the eq (2).

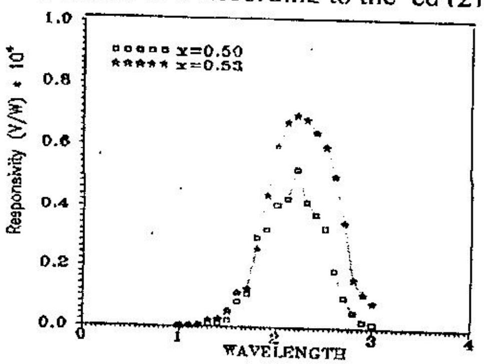

Fig. (3)The variation of respontivity & relative responsivity with wavelength for Pb_xS_{1-x} films.

3-1-2- Quantum Efficiency Measurement

Fig.(4) shows the dependence of quantum efficiency (η) on the wavelength at RT for Pb_xS_{1-x} films when x=0.50 and 0.53.It is seen from this figure that the quantum efficiency increases when rising x from 0.50 to 0.53.This can be attributed to the increase in the absorption coefficient when increasing the Pb content .This will increase the localized states due to the increase in the packing density allowing higher absorption and consequently higher quantum efficiency.

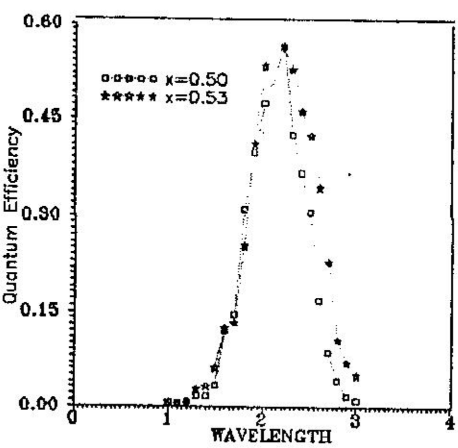

Fig. (4)The variation of quantum efficiency with wavelength for Pb_xS_{1-} films.

3-1-3-The Detectivity Measurement

Fig.(5) shows the dependence of specific detectivity on the wavelength for Pb_xS_{1-x} films. Also we can see that D^* increases when x increases from 0.50 to 0.53 and the maximum value occurred at λ=2.2 μm. Our results are in fair agreement with the reference [6] for stoichiometeric PbS films and Al-Miyali [15] was found that D^* for PbS which prepared by chemical deposition was equal to 0.44* 10^9 cm $Hz^{1/2}$ w^{-1} . Also Chopra and Pandya [16] found that the detectivity of PbS photoconductivity device increase at low temperature and D^* as high as 10^{12} cm $Hz^{1/2}$ w^{-1} at 77k while D^* at room temperature is 4.4* 10^8 cm $Hz^{1/2}$ w^{-1}.

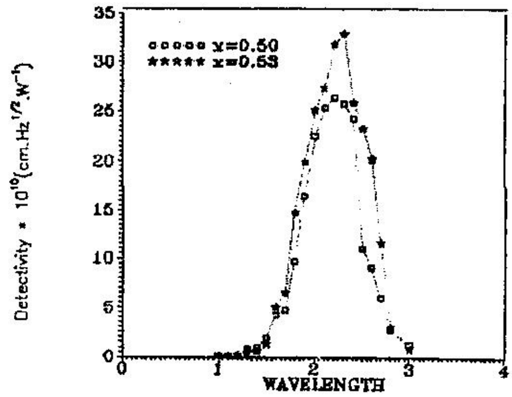

Fig. (5)The variation of detectivity with wavelength for Pb_xS_{1-x} films.

3-1-4-Noise Equivalent Power Measurement

The variation of noise equivalent power for Pb_xS_{1-x} films for both value of (x=0.50 and 0.53) at RT is shown in Fig.(6).

This figure shows that the value of NEP decreases when x increases from 0.50 to 0.53 and the minimum value occurred at λ=2.2 μm. It is found that the value of NEP is $2*10^{-7}$ W for PbS which is prepared by

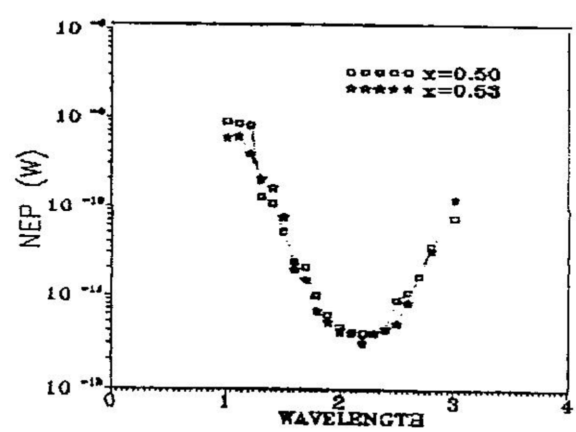

Fig. (6)The variation of noise equivalent power (NEP) with wavelength forPb_xS_{1-x} films.

3-1-5-Signal to Noise Ratio (S/N) Measurement

The variation of signal to noise ratio with the wavelength is shown in Fig.(7) for Pb_xS_{1-x} films. The maximum value of S\N occurred at λ=2.2 μm and the value of S\N increases when x increases from 0.50 to 0.53.

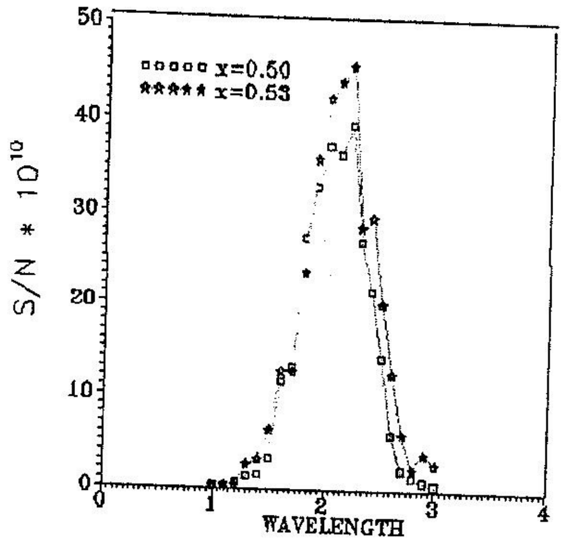

Fig. (7)The variation of signal –to-noise ratio (S/N) with wavelength for Pb_xS_{1-x} films.

4-Conclusion

In this work the sensitivity of Pb_xS_{1-x} films is revalent is good when used as a Photoconductor in the range (1-3) μm. Improvement in sensitivity and quantum efficiency could be achieved by increasing the value of x. The noise equivalent power decreases with increasing x but the detection and S/N increase with increasing the value of x.

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خصائص التوصيلية الضوئيةلاغشية PbS

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الخلاصة:

تم تصنيع كاشف ضوئي Pb_xS_{1-x} بنسب X=0.50, 0.53 باستخدام تقنية التبخير الحراري في درجة حرارة الغرفة تحت ضغط 10^{-6} mbar بسمك 2.0µm . تم فحص تركيب الأغشية بواسطة حيود الأشعة السينية . درست خصائص الكشفية : الاستجابية R_λ ، الكفاءة الكمية η، نسبة الإشارة الى الضوضاءS/N ، الكشفية D^* ، والقدرة المكافئة للضوضاء NEP . وجد ان الاستجابية ، الكفاءة الكمية ، الكشفية ونسبة الإشارة إلى الضوضاء تزداد بينما القدرة المكافئة للضوضاء تقل بزيادة قيمة x من 0.50 to 0.53 .