Photoconductive Detector Based on CdTe Nanorods

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Abstract

CdTe nanorods have been prepared with the different reaction time period from 1hour to 3 hours. CdTe nanorods visible photoconductive detector films have been prepared on porous silicon layer with etching time 10 min. The CdTe nanorods crystallization has been studied, the crystalline structure appears hexagonal when the samples dried under vacuum at 400C° for 1h. The Hall measurements show that all samples were p – type semiconductor. The response time of the fabricated CdTe detector with different reaction time was measured by illuminating the samples visible light (Halogen lamp) and its values were decreased from 0.411ms for 1hour to 0.364 ms for 3 hours, the photoresponsivity of the detector for reaction time 3hours was to be 3.25×10^{-6} A/W and specific detectivity is found to be $1.05\times10^{6}W^{-1}Hz^{1/2}cm$.

Keyword: CdTe nanorods, photodetector,sensitivity, detectivity.

كاشف التوصيل الضوئي المستند على القضبان النانومتريه CdTe

الخلاصة

تم تحضير قضبان CdTe النانومتريه بازمان تفاعل مختلفه من ساعه واحده الى ثلاث ساعات. ثم تم تصنيع افلام كاشف التوصيل الضوئي على طبقه من السيلكون المسامي بزمن تنميش عشر دقائق. تم دراسة التركيب البلوري للماده المحضره وبينت النتائج ان CdTe له تركيب سداسي عندما جففت العينات تحت الفراغ بدرجه حراره $400C^{o}$ لساعه واحده. قياسات هول الكهربائيه بينت ان الماده المحضره شبه موصل نوع P . كما تم قياس زمن الاستجابه لكاشف التوصيل الضوئي المحضر بازمان مختلفه وذلك بتعريضه لضوء هالوجين(250W) وبينت النتائج ان زمن الاستجابه يقل من ms 0.411 لساعه واحده الى 0.364 ms لثلاث ساعات وكانت استجابيه الكاشف لزمن تفاعل 3 ساعات 3.25×10^{-6} امبير/واط والكشفيه النوعيه 1.05×10^{6} سم.واط$^{-1}$.هرتز$^{1/2}$

الكلمات المفتاحيه : قضبان النانومتريه , كاشف توصيل الضوئي., التحسيسه , الكشفيه.

INTRODUCTION

Semiconductor nanoparticles, which exhibit properties different from bulk materials that hold considerable promise for numerous applications in the field of electronic devices, sensors and photonics materials [1,2]. Nano scale modification of the molecular design and morphology of such particles provides a powerful approach toward control of their electrical and optical properties such as narrow, symmetric, and particle size dependent fluorescence, which is characterized

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by broad excitation ranges and excellent robustness against photo bleaching [1,3]. The research on nanostructures has become a flourishing field in chemistry, physics and material science [4]. Cadmium Telluride (CdTe) is II-VI semiconductor that has been widely used for a variety of applications. The direct bandgap energy 0f 1.44 eV at room temperature and the high optical absorption coefficient in the visible spectrum make CdTe an ideal material for photovoltaic (solar energy) applications or by band gap engineering of CdTe in the form of $Cd_{1-x}Zn_xTe$ and $Hg_{1-x}Cd_xTe$ provide exciting applications in x-ray, gamma ray and infrared detectors [5,6]. In recent years, it has been found that low dimensional nanostructures such as nanoparticles, nanowires and nanorods may have strong quantum confinement effects and improved photoelectric property [7]. By controlling one diameter of the nanoparticle down to a few nanometers, CdTe nanoparticles offer a wide range of band gap energy in the visible spectrum [5]. So far, two successful wet chemical routes of synthesis, including organic (non-aqueous known as TOP-TOPO method) and aqueous synthesis have been developed for the preparation of Nano CdTe [3,4,8]. Aqueous synthesis is more reproducible, cheaper, less toxic, water-soluble and bio-compatible [9].The aqueous synthetic method for thiol-capped Nano CdTe have been reported recently including the hydrothermal synthesis [10], solvothermal decomposition [2] or microwave irradiation [11], in which various functional groups (e.g. polar and unipolar thiols, amines and others) are employed to stabilize the particles [12]. These stabilizing (capping) agents covalently binds to the surface atoms of the nanocrystallite and has the ability to control the size and shape of the growing particles through charge transfer [13], the stabilizing ligands consist of a polar anchoring group and either a polar hydrocarbon chain (synthesis in organics) or a charged group (synthesis in water to provide water solubility [14]). These ligands must dynamically adsorb on/desorb from the surface of the nanocrystals at the synthesis temperature in order to allow for growth while the nanoparticles are stabilized against aggregation [9].In most of aqueous synthesis also ours Te powder [1,4,9] or TeO_2 [8], Na_2Te[3], Al_2Te_3 lumps [13]is often used as tellurium sources, which needs a pretreatment to synthesize the instable tellurium precursor (NaHTe or H_2Te) and the process of preparing Nano CdTe requires nitrogen or argon as the protective gas at the initial stage. In this work, synthesize Cysteine-CdTe nanorods by wet chemical aqueous route and characterized by UV-visible, XRD and SEM was studied, also CdTe nanorods layer was deposited on porous silicon to fabricate a visible photo detector.

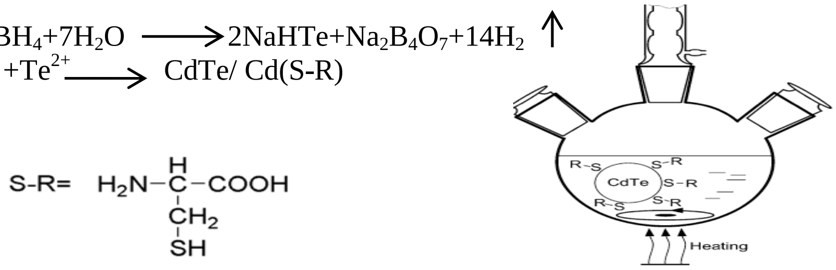
Experimental section

Synthesis of Nano CdTe:

All chemicals used were of the highest purity available. Distilled water was used in all experiments. CdTe nanoparticles were prepared in aqueous solution in the presence of L-cysteine acid (molecular weight 121.16 gm/mole) as the effective stabilizing agent using different refluxing times. In a typical synthesis, the hydrous $CdCl_2.H_2O$ (molecular weight-201.3 gm/mole), Tellurium (molecular weight-127.6 gm/mole) powder and sodium borohydride (molecular weight-37.83 gm/mole) have been taken to prepare different samples, the amounts of L-cysteine: $CdCl_2$: Te : $NaBH_4$ were taken in the ratios of 4:2:1:2. Briefly, the sodium hydrogen tellurite (NaHTe) was prepared by the reaction of tellurium powder with $NaBH_4$ and 3ml of distilled water to be used as tellurium ions source. The reaction mixture was set to little heat, stirred and kept open to discharge the pressure from the resulting hydrogen, until it turned to a dark violet solution. The precursor $CdCl_2.H_2O$ was dissolved in 25ml of water, to become a clear solution followed by adjusting the pH to the appropriate value (10.6) by drop wise addition of 1M solution of NaOH, the solution can remain slightly turbid at this stage, and an appropriate amount of the thiol stabilizer (L-cysteine) was added under stirring. The solution is placed in a three-necked flask fitted with a septum and valves and is aerated by Ar gas bubbling for 30 min., the NaHTe solution added to the $CdCl_2.H_2O$solution. CdTe precursors are formed at this stage, which is accompanied by a change of the solution color to orange. The precursors are converted to CdTe nanocrystals by refluxing the reaction mixture at 45°C for 3h under atmospheric conditions with a condenser as in figure 1, according to the following chemical reaction [15]:

$$2Te+4NaBH_4+7H_2O \longrightarrow 2NaHTe+Na_2B_4O_7+14H_2 \uparrow$$

$$Cd^{2-}(S\text{-}R) +Te^{2+} \longrightarrow CdTe/ Cd(S\text{-}R)$$



$$S\text{-}R= H_2N-\overset{H}{C}(CH_2SH)-COOH$$

Figure (1) Schematic of CdTe synthesis using an aqueous method [16].

The samples were taken at different time intervals, (1h, 2h and 3h) and use them to record X- ray diffraction, UV-visible. Porous silicon (n-types) was used as a starting material in order to fabricate CdTe photoconductive detector. The resistivity of the wafer was (1.5 Ωcm) and its thickness was (508+-15 µm). CdTe thin films were prepared by drops wise on porous silicon, and then dried them in vacuum with heating (400°C).

Results and discussion:

The CdTe Nanorods crystallization has been studied with different heating time period (1, 2 and 3 hours). The XRD spectra was carried out by using a XRD-6000 Labx, supplied by SHIMADZU, X-ray source is Cu Kα X-ray diffractometer with radiation (λ = 1.5406 Å). The crystalline structure appears hexagonal when the samples dried under vacuum at 400˚C for one hour, as shown in fig. (2).The average grain size of the X-ray peaks calculated according to the Scherer's formula are (22.16, 11.619, 10.72 nm) corresponding to the prepared nanoparticles at (60, 120, 180 min). These results agree with reports of the references [7], [2], [17], and [1].

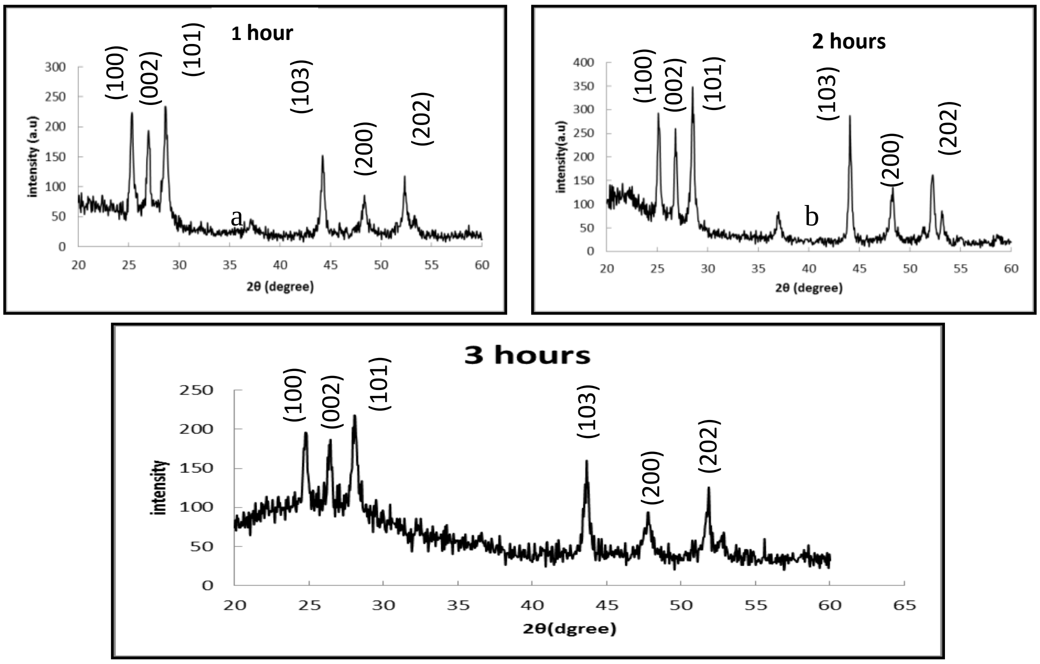
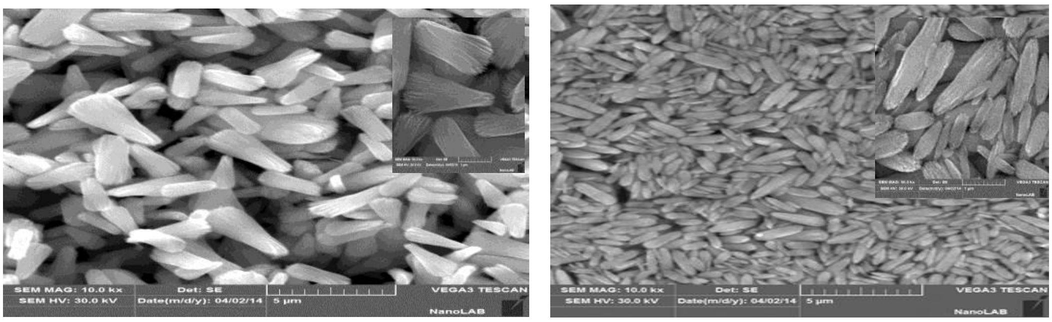


Figure (2) The XRD Pattern of CdTe Nano rods after Drying at 400^{0}C for One Hour under Vacuum.

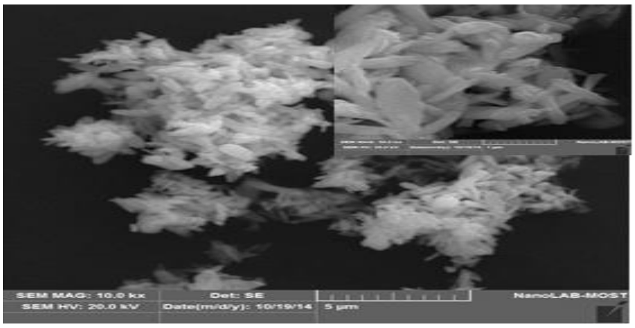
Scherer's formula [5]:

$$D = \frac{K\lambda}{\beta \cos\theta} \qquad \ldots(1)$$

To study the morphology of the prepared CdTe nanorods a Scanning Electron Microscope (SEM) images were taken using VEGA3 TESCAN, mode SE from TESCAN ORSAY HOLDING,a.s.,Czech Repuplic to show that they are nanorods with different dimensions depending on the reaction time periods, each rod seems to become posed of number of nanorods stacking along the rod growth direction. These results agree with the reports of the references [7], [2], and [17]. The nanorods average dimensions was for sample after 3 hours is the best as shown in figure (3c) have a magnification power 10Kx while the inert image have magnification Power 50Kx. Table (1) illustrates the average dimensions of CdTe nanorods.



(a) 60 min **(b)120 min**



(c) 180 min

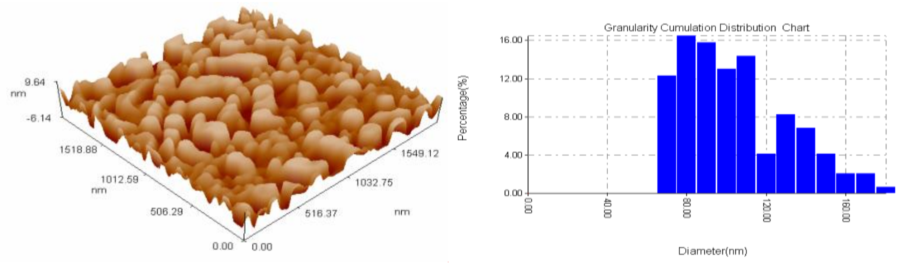
Figure (3) The SEM Images of CdTe Nano rods for time reaction periods a: 1h, b: 2h, c: 3h.

Table (1) The Average Dimensions of CdTe Nanorods estimated from Image J optical microscope program

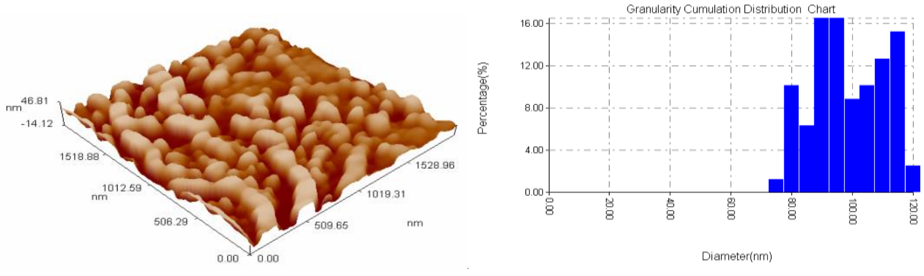
Sample no.	Reaction time period(min)	Length of Nanorods(µm)	Width of Nanorods(nm)
1	60	2.49	24
2	120	1.5	20.8
3	180	1.538	16

The table result shows that the width of nanords was reduce with increasing reaction time.

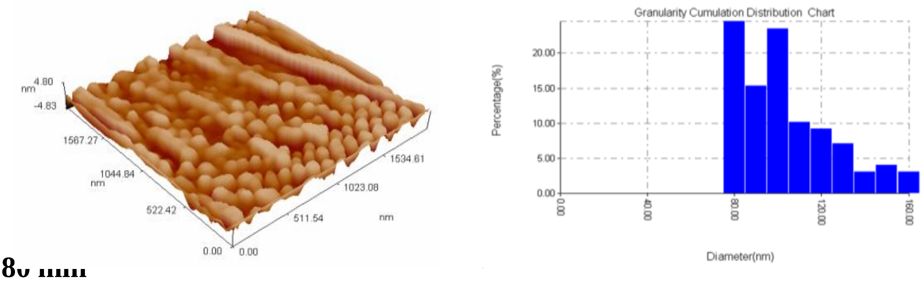
The surface morphology of CdTe nanorods is taken by the Atomic Force Microscope (AFM) of CdTe Nanorods shown in fig. (4) using CSPM AA3000 AFM supply by Angstrom Company, and table (2) show the average dimension and particles sizes of CdTe nanorods.



a) 60 min



b) 120 min



c) 180 min

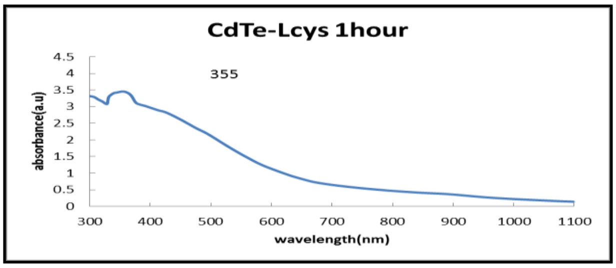
Figure (4) The AFM image of CdTe Nanorods for time periods (60-180 min).

Table (2) the Average Dimension of CdTe Nanorods from AFM

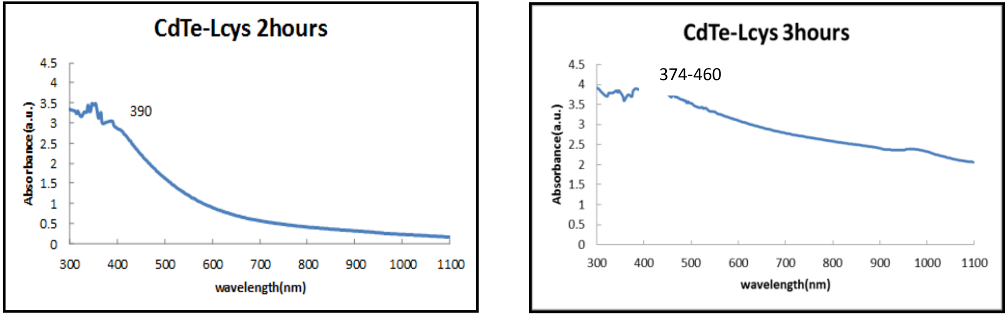
Sample no.	Time duration (min)	Average dimension (nm)	Particle size from AFM (nm)
1	60	99.00	62
2	120	83.76	36
3	180	80.00	33

AFM results indicated the previous measurements; the average dimension and particle size was reduced with increasing reaction time period.

The optical Properties of CdTe Nano rods realized from the Absorption spectrum for the three samples are shown in fig.(5) using Shimadzu UV-1800 spectrophotometer. The absorption peaks for CdTe are in the visible spectrum range and it has a wide range of absorbance for all the visible range. These results agree with reports of the references [8], [10] and [13].



a) 60 min



(b) 2hours **(c) 3 hours**

Figure (5) The UV-Vis Absorption Spectra for CdTe Nano rods for for reaction time a)1h, b)2h and c)3h.

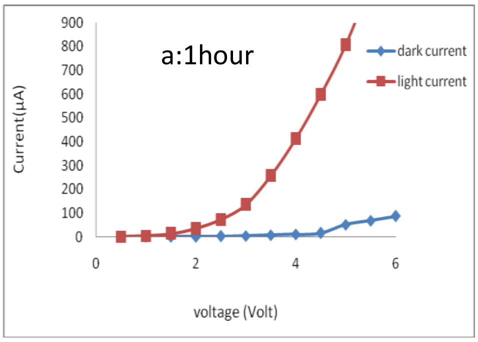
The electrical properties of the prepared films were estimated from Hall measurements as follow: the average Hall coefficient, the carrier mobility and the bulk concentration of the samples (60,120,180 min) respectively as shown in table 3. Interdigitate Al ohmic metal contacts were deposited on the CdTe nanorods films that deposited on (n-type) porous silicon by vacuum evaporation.

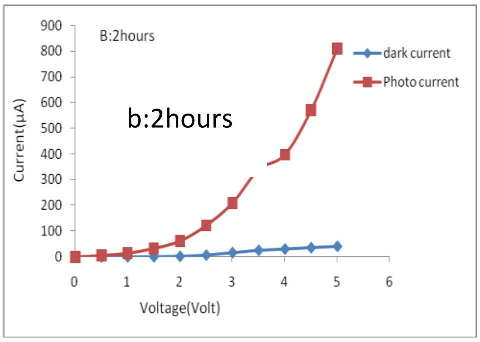
The Hall measurements show that the CdTe nanorods deposited on silicon substrates are p-type semiconductor, whereas the mobility and conductivity increase with increasing reaction time and reducing the particle size of CdTe nanorods. For CdTe nanorods deposited on n-type porous silicon substrate, the reduction in nanocrystalline dimension has helped in maximizing the surface to volume ratio**.** The increase of the surface to volume ratio has led to the increase in the overlap of the electron and hole wave functions. Since the increasing of the overlap functions accounts for the reduction in the carrier recombination lifetime and the speed of response of the CdTe visible detector is improved for the CdTe nanorods deposited on porous silicon layer.

Table (3): Hall measurements of CdTe nanorods for for reaction time 1h, 2h and 3h.

Parameter	1h	2h	3h
Bulk concentration 1/cm^3	1.7×10^{15}	1.17×10^{15}	1.535×10^{20}
Conductivity 1/ Ω cm	1.381×10^{-2}	3.33×10^{-2}	7.877×10^{3}
Mobility Cm^2/Vs	$3.33*10^{-2}$	177	320.4
Average Hall coefficient m ^{2}/C	$7.877*10^{3}$	5.319×10^{3}	4.068×10^{-2}

The detector performance is characterized by the responsivity, the response time and the specific detectivity (D^*) of the fabricated detectors. In order to determine the detector parameter of the CdTe nanorods deposited on PS photoconductive visible detectors, a suitable setup is prepared for this purpose. The current-voltage (I-V) characteristic of CdTe nanorods visible photoconductive detector for different time period (60, 120, 180 min) with the bias voltage at dark and under the illumination by a Tungsten Halogen lamp (250Watt) is illustrated in figures (6a,b,c).





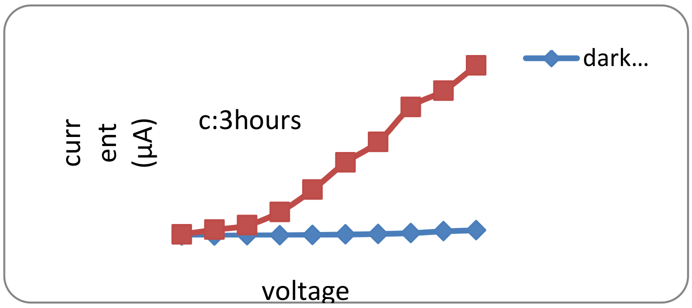


Figure (6) I-V characteristic of CdTe photoconductive detector illuminated by Tungsten Halogen lamp for reaction time a)1h, b)2h and c)3h.

The current-voltage (I-V) characteristics of the fabricated device are illustrated in figures (7a,b,c) at different reaction time(60,120,180 min). The dark (I_d) and photo illuminated currents are increased with increasing in the bias voltage. The linear behavior may be related to the ohmic nature of the detector sample. All samples used in the experiments of the photoresponsivity measurements of the prepared detectors

are carried out under identical experimental conditions. It can be observed that the dark current is very low under dark, whereas the photocurrent is highly increased under the illumination by tungsten Halogen lamp.
Furthermore the photoelectric current gain (G) is a function of the electrode geometry as follows;

$$G = \frac{\tau . \mu . \upsilon}{I^2} \qquad \ldots (2)$$

Where
τ is the carrier lifetime, µ is the charge carrier mobility, *v* is the applied voltage and *l* is the distance between the electrodes. This photoelectric current gain could be given by the equation;

$$G = \frac{I_{photo}}{I_{dark}} \qquad \ldots (3)$$

Where
I_{photo} is the light current and I_{dark} is the dark current which can be obtained from the I-V relation at fixed applied voltage (5Volt), so from these two equations the carrier life time calculated. The detector resonsivity (R_λ)can be determined from the equation:

$$R_\lambda = \frac{I_{photo}}{power_{in}} \qquad \ldots (4)$$

Where
$power_{in}$ is equal to 250 Watt.
The noise equivalent power (NEP) is given by the following equation:

$$NEP = \frac{2e.I_{dark}.\Delta f}{R_{\lambda}} \qquad \ldots (5)$$

Where

e is the electron's charge ($1.6*10^{-19}$) and Δf is electrical bandwidth equal to 1 HZ. The detector detectivity (D) is equal to the reciprocal of NEP, but the spesific detectivity (D^*) or called the normalized etectivity depends on the detectivity (D), the detector's area A ($=0.86\ cm^2$) and the electrical band width Δf as follow:

$$D^* = D(A.\Delta f)^{1/2} \qquad \ldots (6)$$

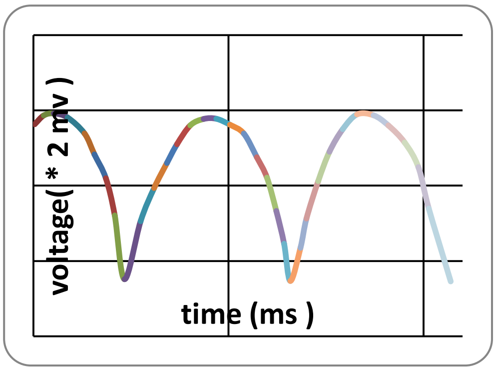
Table 4 represents the results from the equations above;

Table (4) figure of merit the photodetector parameters

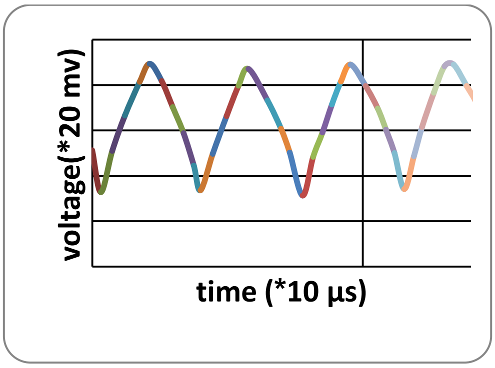
Samples reaction time period	**Gain (G)**	**Response time (τ)**	**Responsivity (R_λ) (A/Watt)**	**NEP (Watt)**	**Detectivity(D) (1/Watt)**	**Specific detectivity (D*) cm. $Hz^{1/2}$. W^{-1}**
60 min	15.6	149.9ms	3.22×10^{-6}	1.26×10^{-6}	0.793×10^{6}	7.3×10^{7}
120 min	20.2	36.5 µs	3.24×10^{-6}	1.1×10^{-6}	0.909×10^{6}	0.842×10^{6}
180 min	31.3	31.2 ms	3.25×10^{-6}	0.88×10^{-6}	1.1×10^{6}	1.05×10^{6}

Figure7. Represent I-V characterization that reflects good visible radiation sensitivity, with an increase in photoconductive gain (G) when the reaction time increases as shown in table 4. The table also shows that the carrier life time (τ) for sample 2 (with reaction time 2hours) has the lowest response time 36.5 µs, whereas the resposivity increases with increase the reaction time. Also, it can be shown that the specific detectivity of the fabricated CdTe detectors deposited on porous silicon layer increases for reaction time 3hours to 1.05×10^{6} cm. $Hz^{1/2}$. W^{-1}.

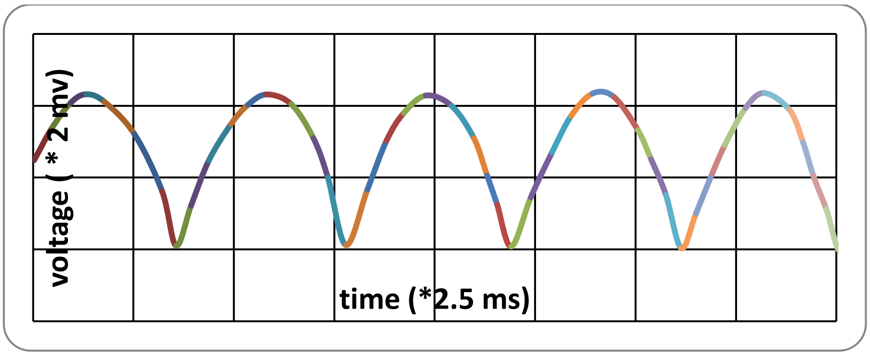
The rise time of the fabricated CdTe nanorods photodetector on PS layer is tested by visible light source 250 W incident power. The trace of the output pulse on the digital oscilloscope is illustrated in fig (7).



a) 60 min



(b) 120 min



(c) 180 min

Figure (7) the output pulse on the digital oscilloscope.

From the output pulse of the digital oscilloscope the rise time and fall time could be measured, The following table (5) illustrates these results. It can be shown that the rise time of sample 2 has the lowest rise time which coresspond with low response time it also has the lowest fall time.

Table (5): Rise time measurement of CdTe nanorods for different reaction time.

Sample's reaction period time	Rise time (10% -90%)	Fall time (90% - 10%)
60 min	1.162 ms	1.069 ms
120 min	7.4 µs	6.52 µs
180 min	1.03 ms	0.882 ms

Conclusion:

CdTe nanorods visible photoconductive detectors was fabricated. CdTe was prepared with different reaction time (1,2 and 3hours). The result shows that the particle size of the prepared CdTe nanorods decreases with increasing reaction time. The fabricated detectors reflected a good visible detector with response time in microseconds and detectivity reach to 1.05×10^{6} cm. $Hz^{1/2}$. W^{-1}.

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