Preparation and characterization of nanostructure high efficient CdS/Si hetrojunction by CBD

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Abstract

In this paper, CdS/Si hetrojunction solar cell has been made by Chemical Bath Deposition (CBD) of CdS thin film on to monocrystalline silicon substrate. XRD measurements approved that CdS film is changing the structure of CdS films from mixed hexagonal and cubic phase to the hexagonal phase with [101] predominant orientation. I-V characterization of the hetrojunction shows good rectification, with high spectral responsivity of 0.41 A/W, quantum efficiency 90%,and specific detectivity 2.9*1014 cmHz1/2W $^{-1}$.

Keywords
Cadmium sulphide;
Hetrojunction;
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Solar cell

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الخلاصة:

هذا البحث تم تصنيع خلية شمسية متعددة الطبقات CdS/Si باستخدام الترسيب بالحمام الكيميائي لاغشية كبرتيد الكادميوم المرسبة على قواعد من السيلكون الاحادي البلورة.حيث اظهرت قياسات حيود الاشعة السينية ان التركيب البلوري لاغشية كبريتد الكادميوم متكون من تركيب خليط سداسي باتجاهية [101] .و قد اظهرت خصائص تيار-فولتية للمتعددة الطبقات تضخيم جيد مع استجابية طيفية عالية بحدود 0.41A\W و ان الكفاءة الكمية 90% و الكشفية النوعية 2.9*1014 cmHz1/2W $^{-1}$

Introduction

Chemical bath deposition (CBD), also known as chemical solution deposition, is a technique which has been used to deposit semiconductors for more than 130 years. Yet only in the last decade or so it has seen a resurgence of growth, largely due to its success in thin film photovoltaic cells [1], where hetrojunction devices utilizing CdS thin films as one of the components continue to be of considerable interest in optoelectronic applications. Among various deposition techniques, (evaporation, sputtering, spray pyrolysis, and chemical bath deposition), chemical bath deposition (CBD) yields stable, uniform, adherent, and hard films with good reproducibility by a relatively simpler process. In addition, (CBD) process plays a role in the favorable properties of the heterojunction by decreasing interface recombination [2].

Another cause of interest in this technique is due to the fact that the crystal size in most as – deposited (CBD) films are very small. Considering the current interest in nanoparticales (CBD) as an excellent technique to deposit nanocrystalline films as was shown for (CBD) $(CdSe)$[3] and later for $(CBD)(CdS)$ [4]. More specifically, if the nanocrystals are small enough, they exhibit size quantization, the most obvious manifestation of which is an increase in the optical band gap with decrease in crystal size. Due to these facts a large amount of study was dedicated in the last years to nanostructure preparation using chemical methods these are less expensive and easier to implement. Some of the most known chalcogenides, such as (CdS), (PbS), and even ternary films can be prepared in nanometric forms using chemical methods [5, 6].

Experiment

Single crystal silicon wafers are used for fabricating CdS/Si heterojunction. They were p-type (111) orientation with resistivites of about (1.5 – 4 Ωcm) and (500 μm) thickness. They were rinsed in acetone and ethanol in order to remove dirt and oil, while native oxide layer was removed by etching in dilute (1:10) HF : H_2O.

Cadmium sulfide films were prepared from cadmium sulfate and thiourea by chemical bath deposition in alkaline solution. The deposition of CdS films is achieved from dilute solutions.

Films were deposited on Si wafer by, 30 ml of 0.1M ($3CdSO_4.8H_2O$), 30 ml NH_3 solution and distilled water were mixed slowly at room temperature with continuous stirring. Substrates were then immersed in a beaker containing the reaction mixture. The beaker was placed in a water bath at temperature ($80 \pm 2\ ^oC$). The solution was stirred with a magnetic stirrer type (MSH 300) as illustrated in Figure (1). Then, it was heated with continuous stirring to the required temperature of deposition, 30 ml of 0.2 M thiourea solution was then added with continuous stirring, and the pH measured with pH meter type (BIBBY). Substrates were then taken out after a suitable time, they were washed with distilled water and ultrasonic agitation to remove the porous cadmium sulfide overlayer, then dried. CdS of different crystalline size were grown by a precipitation technique using precursors as $CdSO_4$, thiourea, and NH_4OH. The different crystalline sizes were obtained by controlling the reaction time. All the samples were prepared at pH=12.

Thickness of deposition film was calculated from optical interferometer method. After the depositon of CdS,frontal and back metal electrodes were formed by depositing (200)nm of In and Al respectively .The sensitive area was about $(0.2)cm^2$.The deteriment of the nature quality of the grown layer was investigated with aid of XRD diffraction of the wavelength of 1.54A Cu-Kα .The average grain size (G.S) of the polycrystalline material can be estimated from the X-Ray spectrum by means of Full Width at Half Maximum (FWHM)method (Scherrer relation)[7].

$G.S=A\lambda/\Delta\theta\cos\theta$ …(1)

Where $\Delta\theta$ is the full width at half maximum of the XRD peak appearing at the diffraction angle θ, representing the shape factor ,the value of which depends on the crystalline shape .Current –Voltage measurement under dark and illumination was achieved by a Halogen lamp type “philps”,120w,which connected to avarice and calibrated by AM illuminator power density by Si powermeter .Spectral responsivites of CdS/Si was measured by using a monochrometer model in the rang (360-1000)nm .The result were measuring of each spectral line using astandard power meter.

Results and Discussion

The X-Ray diffraction (XRD) pattern of CdS/Si heterojunction is shown in Figure (2). The figure shows predominant orientation peak at $2\theta=28.4^{o}$ indicating a preferred orientation along H [101] plane of reflection corresponding to the hexagonal (wurtzite) phase. Using the monccrystalline Si with [111] orientation as a substrate has influence on the structure of the CdS films, by the way of changing the structure of CdS films from mixed hexagonal and cubic phase to the hexagonal phase with [101] predominant orientation.

Referring to the reference data of the CdS single crystal, the peaks in the XRD diffraction shift into the region of higher θ (smaller lattice parameters), indicating stress in the grains. The a-lattice constant of Si is 0.5261 nm, while a-parameter of CdS is 0.4102 nm. The lattice mismatch hence is 11%.

To describe any junction, we need to now the current-voltage and capacitance- voltage to determine the built in potential, ideal factor, and other parameters. The forward bias current contexture is from two regions. At low voltage, the recombination current is dominant because the concentration of injected charge carriers is greater than the concentration of intrinsic charge. Therefore recombination process will take place. At high voltage, the forward current increases exponentially because the bias voltage exceeds the potential barrier. This bias voltage gives the electrons energy to overcome the barrier height and flow that is called diffusion current. In reverse bias, it is clear that the curve contains two regions; the first is the generation current where the reverse current is slightly increased with the applied voltage and this leads to generation of electron-hole pairs at low bias. In the second region, a significant increase can be recognized, the reverse bias is increased. In this case, the current results from the diffusion of minority carriers through the junction. I–V curve of our CdS/p-Si heterojunctions shows good rectification.

Figure (3) represents the current-voltage characteristics for nano CdS/p-Si prepared at different times and for CdS/p-Si as prepared. It can be noticed that current flow is higher in case of nano-CdS/p-Si compared to the bulk- CdS/p-Si junction. The current in the case of the nano- CdS/p-Si junction rises rapidly above 0.3 V, whereas for bulk- CdS/p-Si junction the rapid rise with current is just above 0.7 V. This suggests the presence of a high density of surface/interface traps at the nano- CdS/p-Si interface due to a thin oxide layer. Also, note that the ideality factors, of the nano- CdS/p-Si range from 3 to 4. An ideality factor exceeding 3 has been often found with nanostructure devices, where the interface layer is in oxide [8]. Table (1) states the values of ideal factor, saturation current, and rectification ratio for CdS/p-Si junction. This indicates that nano CdS incorporation with Si is capable of making good contact for device application.

C – V is important, since it determines different parameters such as built- in potential, junction capacitance and junction type. Figures (4) show the variation in nano- CdS/p-Si . These figures show that junction capacitance decreases with increased reverse bias voltage; this behavior is due to an increase in the width of depletion layer with increase reverse biased voltage.

In the curve we plot C^{-2} –V, from which we found that junction is abrupt. The higher capacitance for the nano-CdS/p-Si, compared to bulk- CdS/p-Si, suggests a larger interfacial contact area for a nano- CdS/p-Si junction.

The photocurrent is a very important parameter in photo detector, its affects the spectral responsivity and quantum efficiency. Figures(5) explain the I – V characteristic CdS/p-Si under various levels of illumination, at different times for nano junctions. Under external reverse bias, depletion region of the detector extends and as a result more incident photons will contribute to the electron – hole pairs generation that takes place in the depletion region and in the two regions (n and p) where the minority carriers are able to diffuse to the edge of the depletion region before recombination. The internal electric field in the depletion region causes the electron – hole pairs to separate from each other and with the external reverse bias which becomes larger. We can see from in figure the increase in the photocurrent with increasing incident beam intensity, where the large intensity refers to increase in the absorbed photon number and a large number of electron – hole pair is generated.

The spectral responsivity for both bulk and nano junction CdS/p-Si in Fig.(6), can be divided into three distinct regions, the first one at short wavelength where responsivity increases with increasing wavelength and this increase relates to the high absorption coefficient. This leads to lower absorption depth and fast recombination process which is related to the large surface recombination processes. The second region between 520 nm and 800 nm illustrates a semi-flat response, where responsivity in this region is due to the contribution of CdS and Si, in this region the generated electron-hole pairs move due to the internal electric field besides the negligible recombination process. In the third region, the incident light is absorbed within the material where the bulk recombination processes take place, leading to lower responsivity.

Figure (6) shows the variations in responsivity as a function of wavelength for nano CdS/p-Si, where the spectrum extends to the blue region, due to widening the window band gap, as a result of quantum confinement.

Figure (7) show the variation in quantum efficiency for CdS/p-Si prepared in different conditions for both bulk and nano structures. All the explanations mentioned on responsivity can be drawn to the quantum efficiency because quantum efficiency is a function of spectral responsivity.

Conclusion

CdS was deposited by a CBD method from an aqueous solution of $CdSO_4$, $CS(NH_2)_2$ and NH_4OH. The CBD CdS thin film had good coverage on all substrates. XRD and might be nanocrystalline with a cubic structure. For nano CdS/p-Si, a quantum efficiency of 90 % was obtain.

Table (1): Experimental results.

Prepared conditions	**I_s (μA)**	**RF**	**n**
As-prepared 2 min 3 min 4 min 5 min	0.5 0.2 3 0.1 0.4	11.1 5.87 8.58 20 11.5	4 4.8 4.4 3 4.1

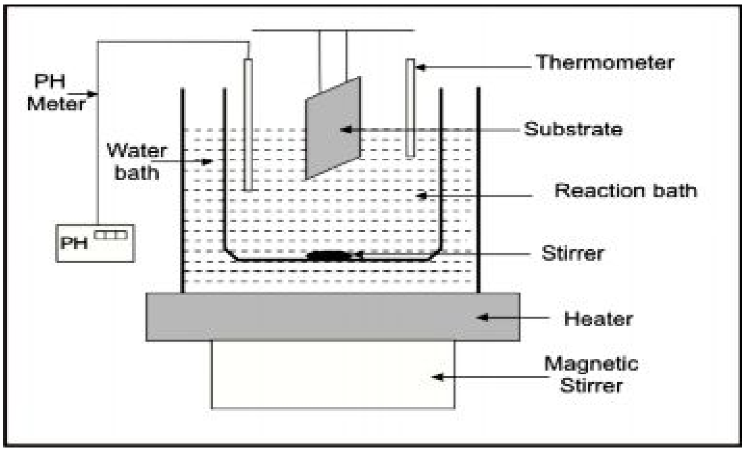


Figure (1): Experimental arrangement for the deposition of CdS/p-Si device.

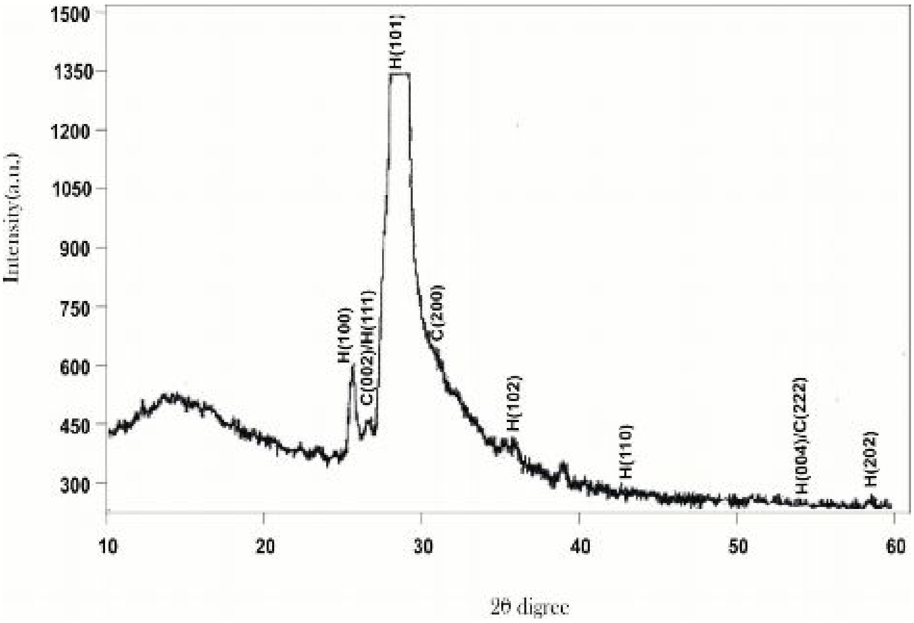


Figure (2) X – ray diffraction of CdS/Si.

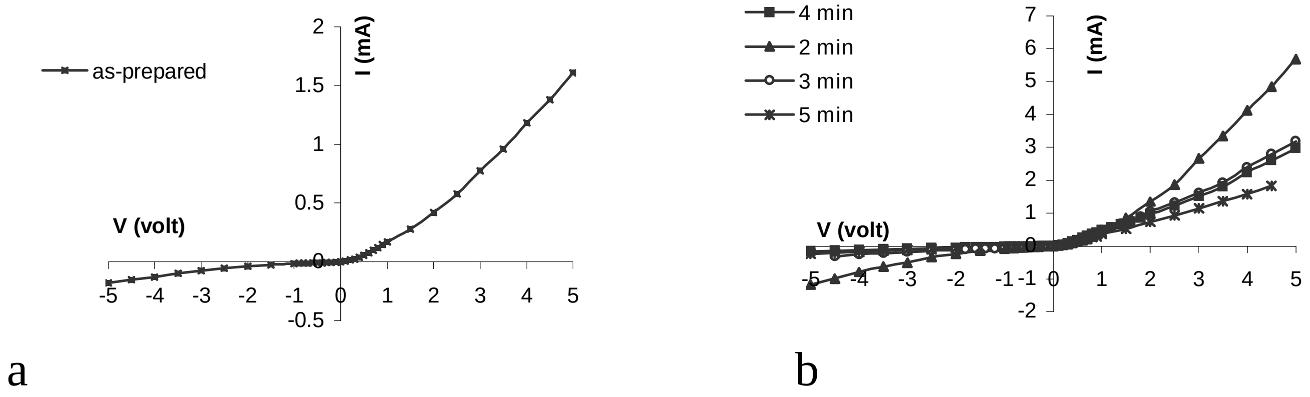
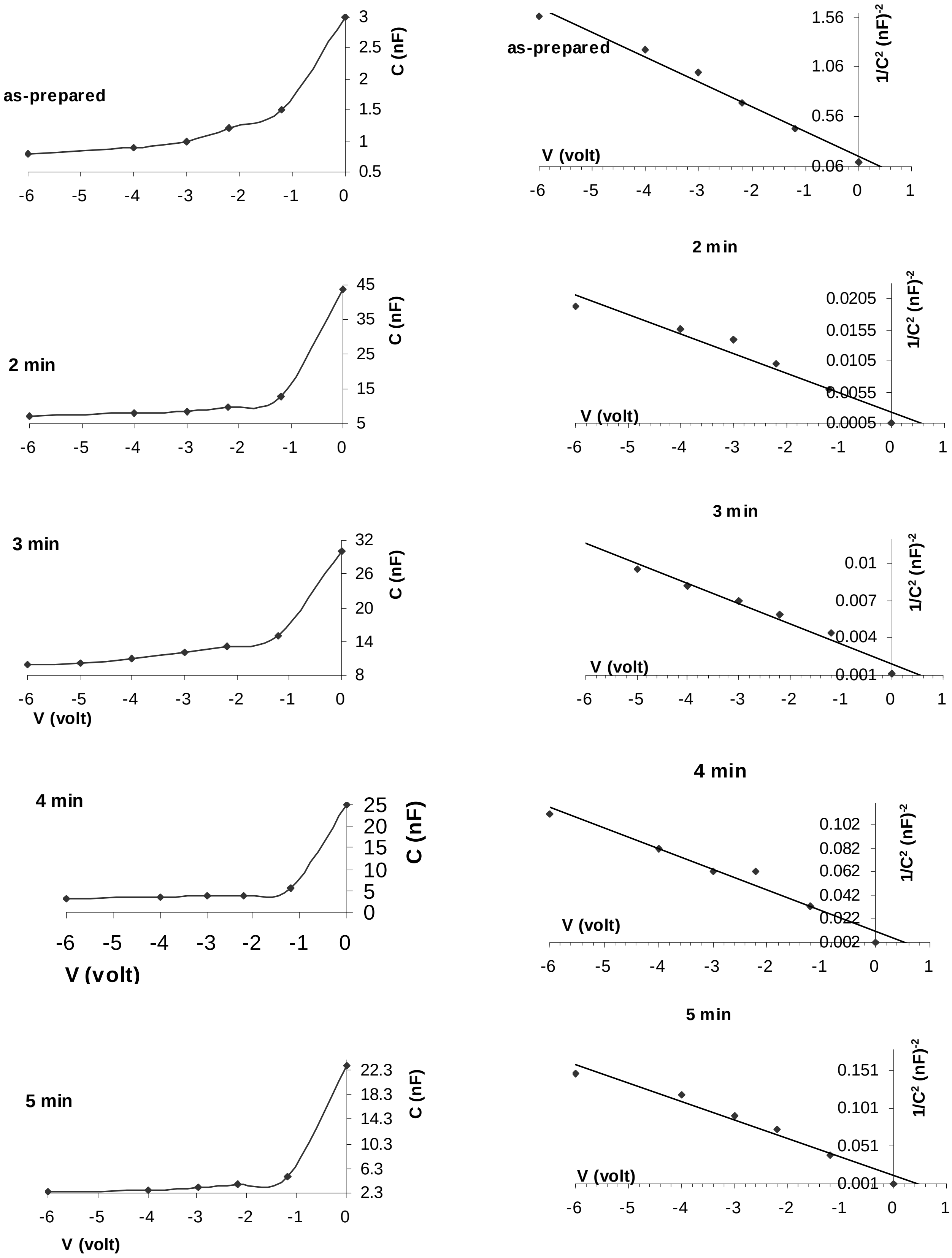


Figure (3: (a) I– V characteristic for CdS/p-Si as prepared .
(b) I – V characteristic for CdS/p-Si prepared at different time



Figure(4): C – V characteristics for nano CdS/p-Si heterojunction at different time and for CdS/p-Si as prepared .

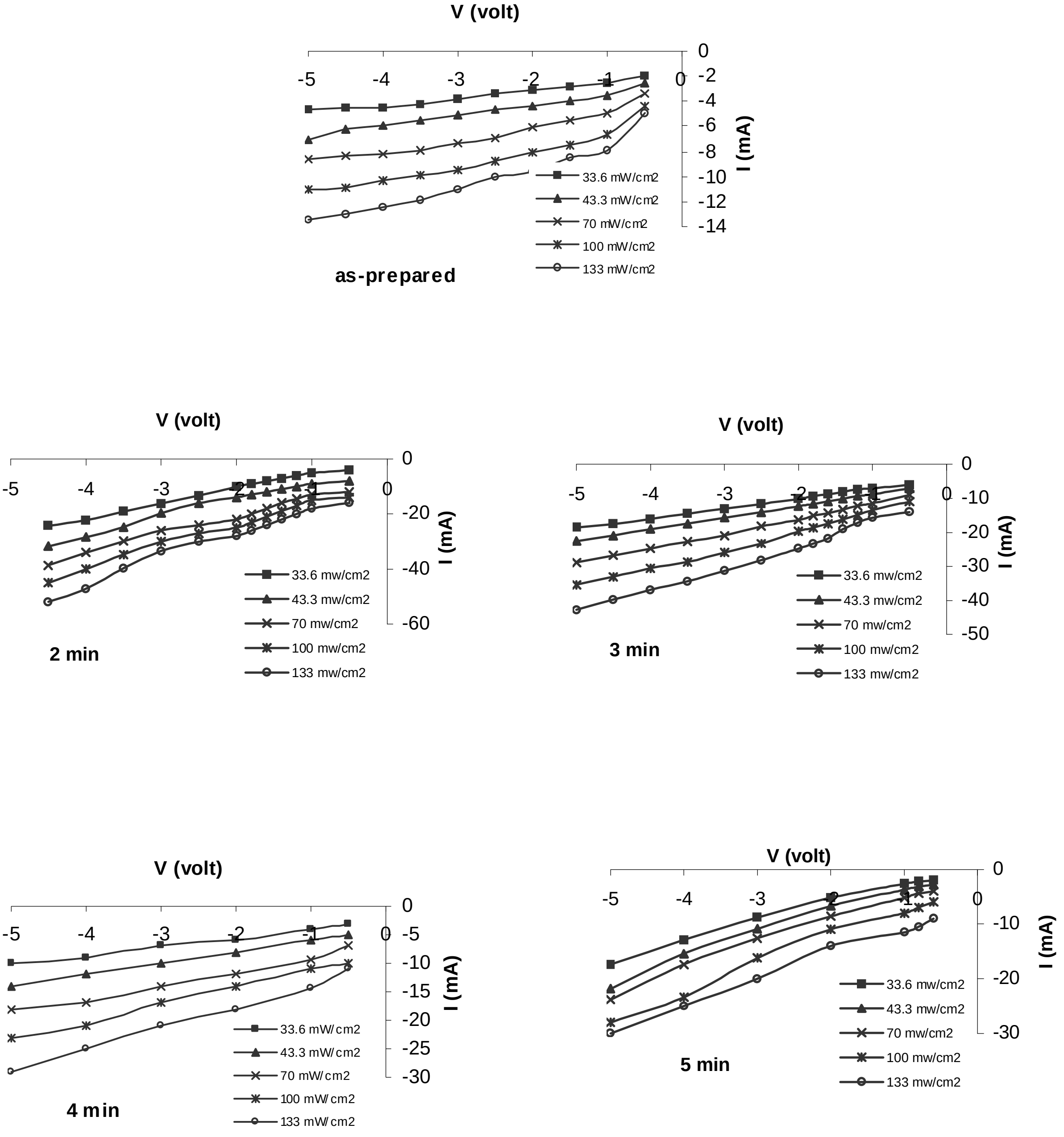


Figure (5) I – V characteristic for nano CdS/p-Si and for CdS/p-Si as prepared under various levels of illumination

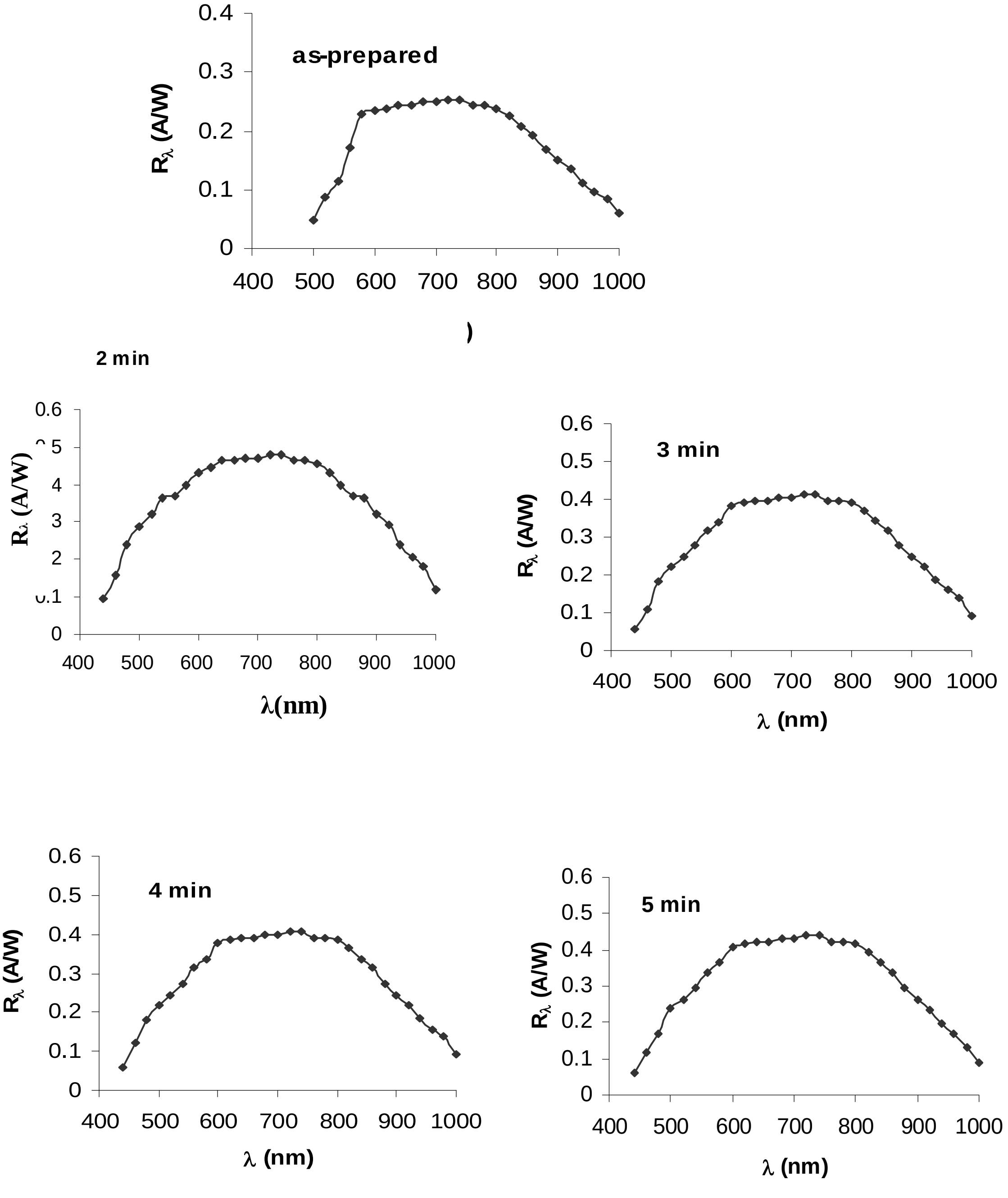


Figure (6) Spectral responsivity of CdS/p-Si for different conditions and for CdS/p-Si as prepared

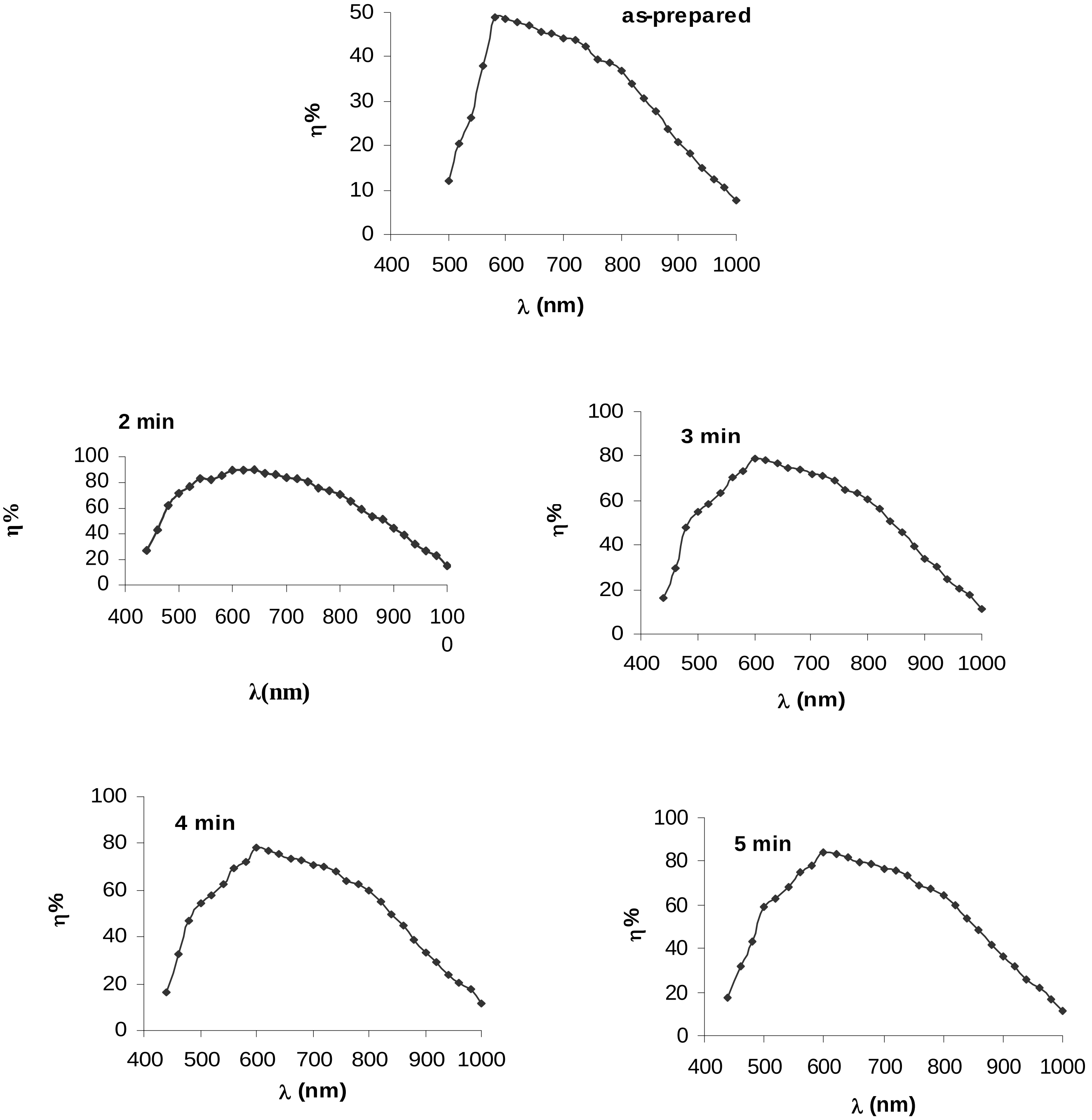


Figure (7) Quantum efficiency of nano CdS/p-Si prepared in different time deposition and for CdS/p-Si as prepared.

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