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Neutron Radiation Effects on the Performance of the CdSe Thin Film for Photodetector Applications

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Abstract

Cadmium Selenide CdSe thin films were deposited on (7.5×1.3×0.1 cm^3) glass substrates and (1×1 cm^2) p-type silicon substrates using pulsed laser deposition technique (Nd: YAG laser beam with 80 mJ energy, λ = 1064 nm). Then, they were annealed at 300 °C for 1 h to get diodes as visible light detectors. Some of these samples (diodes) were exposed to different intervals (5, 7, 9, 12) days of neutron radiation using (^{241}Am -^{10}Be) source with a flux of 3×10^5 n/cm^2.s and energy of 5.71 MeV. For comparison purposes, the other diodes were kept without any irradiation The morphological and electrical properties of these samples were studied by XRD, FE-SEM and I-V measurements. Results have shown all these thin films exhibit a hexagonal structure. However, there is a slight shift in the preferred orientation (100) for the irradiated films. Also, there was a new (102 - SiO_2) peak that appeared in the irradiated thin film pattern. The crystallite size of pristine and (5, 7, 9, 12) days irradiated CdSe thin films were (26.9, 18.3, 24.9, 20.3 and 24.5) nm respectively, whereas, the mean particle size of the pristine film was 37 nm whereas for the irradiated films 53, 64, 73 and 92 nm. Results also show that the band gap of these samples increased from 2.17 eV for pristine thin films to 2.3, 2.48, 2.25, and 2.3 eV for the irradiated thin films. On the other hand, the results of I-V characteristics show the dark/light current. The current under illumination increases when exposed to small values of neutron radiation then it decreases with higher values of exposure. In contrast, the dark current decreases significantly with the irradiation. The effect of the irradiation was clear on the response/recovery period for all devices. Nevertheless, it was more profound in the response/recovery time of pristine devices. Also, the photo-responsivity of the pristine device was larger than the other devices and it was decreased with increasing absorbed doses.

Keywords: CdSe, PLD, Neutron flux, Responsivity, Thin film, Dark current, Crystallite size, Nd: YAG laser

Introduction

Silicon optoelectronics have been extensively studied in optical communication, sensors, night vision, etc. [1,2]. as well as the II-IV compound semiconductors have been widely studied because of their special optical and electrical properties such as their band gap in between (1 - 3 eV) which is located in the visible region with a wide spectral response. II-IV compound semiconductors have firm stability, high sensitivity and short response time which play an important role in photonics fields and optoelectronics and nanoelectronics devices [3-5]. Cadmium selenide (CdSe) is preferred in the fabrication of different optoelectronic devices such as photodetectors, light-emitting diodes and solar cells [6,7]. It has a small direct band gap (E_g = 1.7 eV) and it is classified as an n-type semiconductor [8-11]. The preparation of cadmium selenide nanomaterials includes thin films, quantum dots and core/shell structures. This is done by different methods such as chemical bath deposition, spray pyrolysis, and pulse laser deposition [12,13]. The pulse laser deposition technique is widely used to prepare thin films of CdSe because it is quite suitable for gaining uniform thin films with enhanced electric and optical features [14,15]. Optoelectronic devices are very sensitive to high-energy radiation doses such as gamma rays, neutrons, high-energy proto electrons, and ions [16,17]. Neutrons can cause several significant damages in semiconductors (such as CdSe) through elastic collisions with lattice atoms creating atomic displacement and crystalline imperfections, each point defect introduces an energy state within the forbidden gap. This might cause conductivity modulation, minority lifetime degradation and mobility degradation [16,18]. In this study, we investigate the effects of neutron radiation on the surface morphology and electrical properties of the CdSe thin film deposited on (p-type) silicon substrates using the PLD technique by XRD, FESEM and I-V characteristics.

Materials and methods

CdSe powder preparation

CdSe powder is collected from depositing thin films of CdSe on glass slides in dimensions (7.5×2.5×0.1 cm^3) as a substrate. Before the deposition, the substrate was rinsed well with deionized water then it was put in an alcoholic solution. Later, it was immersed in acetone and dried at room temperature. In chemical bath deposition, to make CdSe films, 0.876 g Se and 2.65 gNa_2So_3 were dissolved in 10 mL of deionized water in a reflux system and it was heated with stirring for about 90 min to obtain the Na_2SeSo_3 solution. An 1.75 g $CdCl_2$ was dissolved in 10 mL of deionized water with 2 mL NH_3 and 3 drops from TEA (Tri ethanol amine). Then, the Na_2SeSo_3 solution is added to the ($CdCl_2$) solution by adding deionized water until we get 100 mL of the final solution (PH = 9). Finally, it was heated with the aid of stirring for 15 min. Afterwards, glass slides were placed vertically in the solution in the chemical bath at 70 °C for 3 h. The glass slides were removed carefully and dried at room temperature for 7 days at least. The CdSe powder was collected from these slides and was pressed mechanically with a force of 7 tons to get a disk of 1.3 cm in diameter and 2 mm in thickness as a PLD target.

PLD film deposition

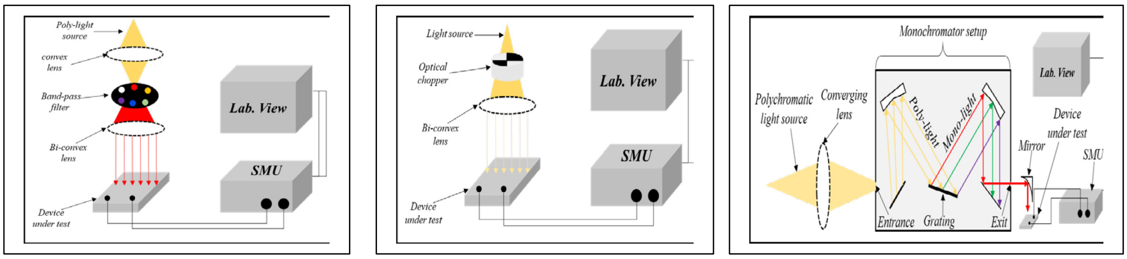
CdSe thin films with thicknesses of 300 - 400 nm were deposited on 7.5×1.3×0.1 cm^3 glass substrates and 1 cm^2 p-type silicon (100) (1 - 10 **Ω**.cm) substrates after cleaned well. Silicon substrates were immersed in 1:9 HF (40 % purity) for (30 s) followed by distilled water and alcohol. After drying, the substrate is placed at a distance of 3.5 cm from the CdSe target which has been irradiated via 1064 nm by Nd: YAG laser with an angle of 45 ° (with a repetition frequency of 6 Hz and pulse duration of 10 ns). The energy of the laser beam used during the deposition was 80 mJ. These samples are annealed at 300 °C for 1 h. Silver electrodes are made on top of the thin films to obtain the device structure.

Irradiation parameters

Some of the prepared samples were irradiated by (^{241}Am-^{10}Be) neutrons source with a flux of 3×10^5 $n/cm^2.s$ with an energy of 5.7 MeV with intervals (5, 7, 9, 12) days of the neutron's radiation.

Characterization

Structural and morphological properties of samples were examined using XRD-6000 SHIMADZU and (FE-SEM JSM 7600F). The optical and electrical measurements were carried by (SHIMADZU, UV-3600) and Keithley source meter 2400 in conjunction with the band-pass optical filter (λ = 460 nm) and (p = 10 mW/cm^2) tungsten halogen light source. **Figure 1** illustrates the diagrams of the (I-V), response/recovery, and photo-responsivity measurements. Response/recovery, and photoresponsivity measurements.



(a) (b) (c)

Figure 1 Diagrams (a) (I-V) characteristic measurement, (b) switching behaviour measurement, and (c) spectral response measurements.

Results and discussion

The preferred orientation of all these films was (100) plane corresponding to 2θ = 23.93, 24.45, 23.88, 24.30, and 24.42 ° for pristine and (5, 7, 9, 12) day neutron irradiated respectively as shown in **Table 1**, it also shows the time of irradiated fabrication samples. The XRD patterns of the pristine "pure" and irradiated CdSe thin films on (p-type) silicon substrates reveal that all the thin films exhibit the hexagonal structure. **Figure 2** shows the obtained pattern that matched to (JCPDS-892944). It was clear that the main diffraction peaks were slightly shifted from 23.93 to 24.45 °. Also, it is clear that no diffraction peak disappeared in all these films but instead there was (102 SiO_2) peak emerged in all the irradiated thin films corresponding to 2θ = 38.60, 38.15, 38.49, and 38.58 ° for (5, 7, 9, 12) days irradiate, respectively. This peak may be formed during the irradiation process in the presence of oxygen in the ambient, and this result with agreement with [19]. The crystallite size was calculated using Debye-Scherrer formula [20,21]:

$$D = 0.9\lambda/\beta \cos\theta \qquad (1)$$

where D: Is crystallite size, λ: Is the wavelength of X-ray(1.54Aº), β is the (FWHM) of the peak intensity and θ is the diffraction angle. The crystallite size was 26.9 nm for the pristine film while they were 18.3, 24.9, 20.3 and 24.5 nm for (5, 7, 9, 12) days of irradiated films respectively. The reduction of crystallite size for irradiate films as well as the increase of the micro strain values indicate the degradation of crystalline structure.

Table 1 Some of the factors were obtained from XRD results of pristine and irradiated samples.

Sample	**2-theta (deg.)**	**d-spacing (Å)**	**FWHM (deg.)**	**Crystallite (Å)**	**Micro Strain**
***Pure* (0 day)**	23.93	3.71	0.27	269	0.69
***N1* (5 day)**	24.45	3.63	0.39	183	0.99
***N2* (7 day)**	23.88	3.72	0.28	249	0.74
***N3* (9 day)**	24.30	3.66	0.36	203	0.90
***N4* (12 day)**	24.42	3.64	0.27	245	0.74

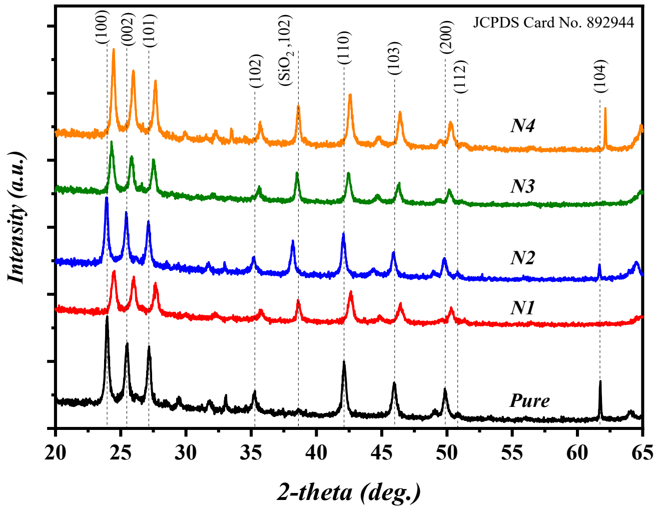


Figure 2 XRD pattern of pristine(pure) and irradiated samples.

Figure 3 shows the FE-SEM images for pristine and irradiated thin films. The mean particle size of pristine film was 37 nm while in irradiated films was 53, 64, 73 and 92 nm for (5, 7, 9, 12) days, respectively. The images obtained from FE-SEM show that surface morphology was influenced by neutron radiation and reveal differences in the shape and size of crystallites for each dose.

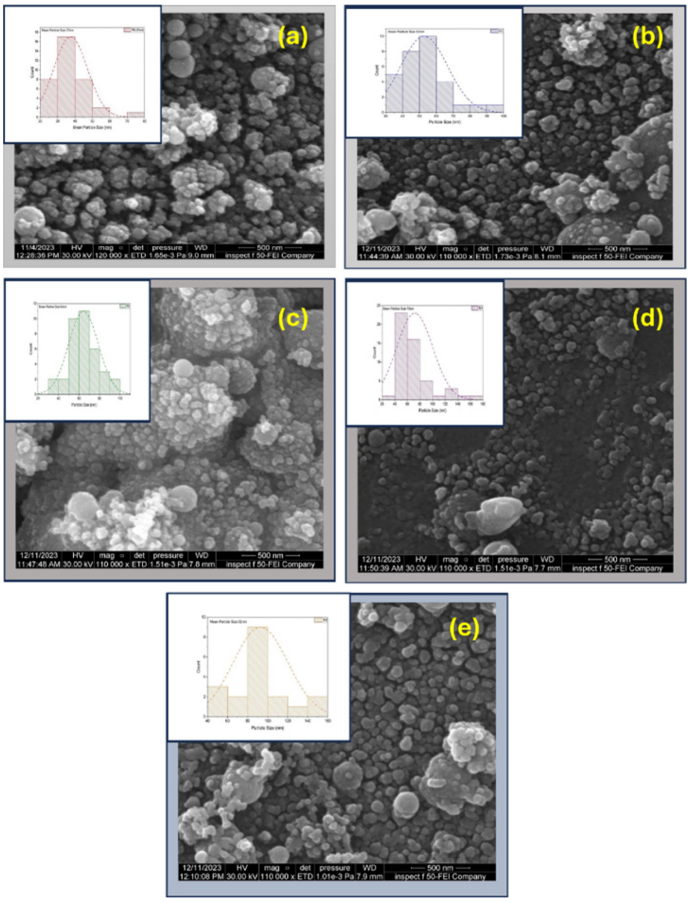


Figure 3 FE-SEM images and distribution histogram for (a) pristine, (b) 5 days irradiate, (c) 7 days irradiate, (d) 9 days irradiate, and (e) 12 days irradiate samples.

The optical measurements were carried out in the wavelength range of 300 - 800 nm. **Figure 4(a)**. Shows that there was a blue shift of the absorption edge of the irradiated films towards a lower wavelength. This indicates an increase in the optical band gap. The absorption coefficient α as well as the investigated optical band gap using Tauc relation $\alpha h\nu = A(h\nu - E_g)^n$ as shown in **Figure 4(b)**, where A is constant, hν is the photon energy, n = 1/2 for direct transition [22,23]. The band gap energy values increase from 2.17 eV for a pristine thin film to (2.3,2.48,2.25,2.3) eV for irradiated thin films as shown in **Table 3**. The neutrons irradiated thin films have resulted in higher optical band gap which led to low detection of UV light. This result is in agreement with [24].

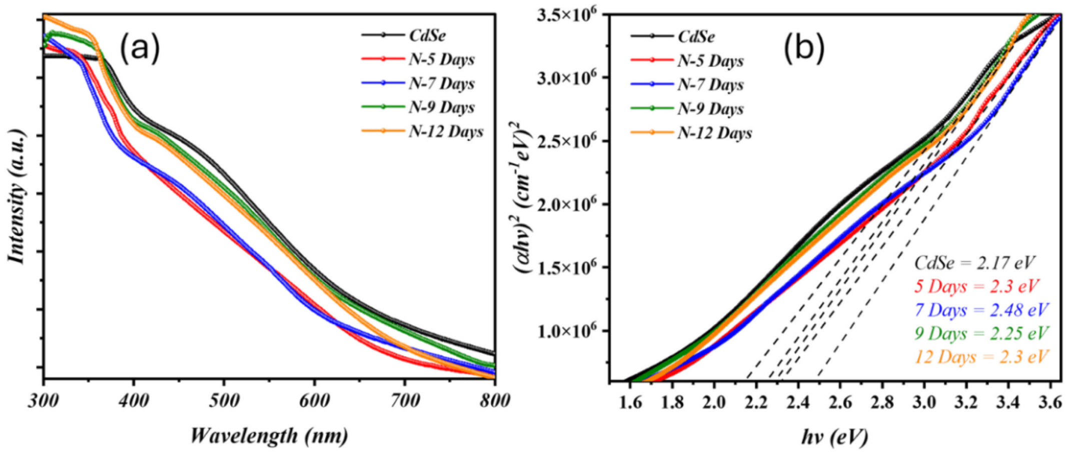


Figure 4 Optical properties of samples. (a) The absorbance versus wavelength of pristine and irradiated samples, and (b) the variation of $(\alpha h\nu)^2$ as a function of photon energy hν for all samples.

Table 3 Band gap energy values of samples.

Sample name	Bandgap (Eg)
pure	2.17 eV
N1	2.3 eV
N2	2.48 eV
N3	2.25 eV
N4	2.3 eV

Figure 5 shows the I-V characteristics for pure pristine and irradiated thin films exposed to various levels of neutron radiation doses. The light/dark currents are measured in forward and reverse directions, it was clear from these plots the semiconducting behaviour of the CdSe thin film deposited on (p-type) silicon. It is also shown that the current under illumination increases when exposed to small values of neutron radiation and then decreases with higher values of exposure, however, the dark currents decrease greatly with irradiation.

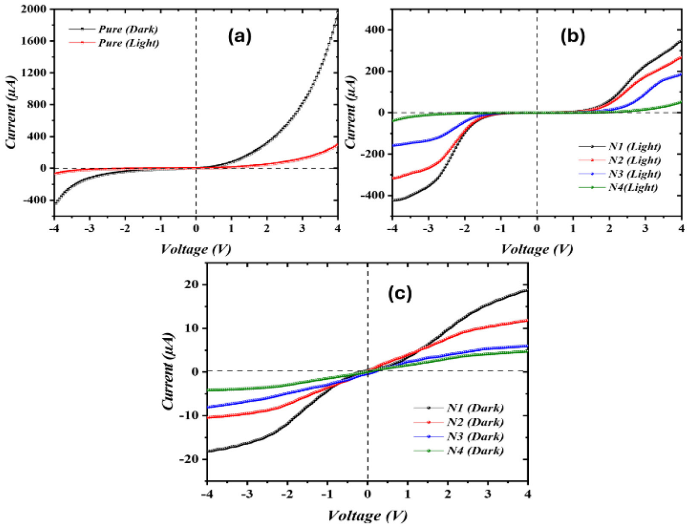


Figure 5 The I-V characteristics of pristine and irradiated samples under (a) dark and light current of the pristine sample, (b) light current of irradiated samples, and (c) dark current of irradiated samples.

As in the inset in **Figure 6**, the response and recovery time for all the fabricated photodetectors were calculated from 10 - 90 % of the peak amplitude using 460 nm monochromatic light source, $p = 10$ mW/cm^2 with biasing the photodetectors at 2V. These fabricated photodetectors have exhibited a stable profile under 3 complete cycles with ~25 sec pulse width proving the consistency of the fabricated devices under the testing protocol. It can distinguish the effect of neutron irradiation on the devices. The response time of pristine was 310 msec and the recovery time was 557 msec while the response time of the (5) days irradiated device was 445 msec and the recovery time was 860 msec. On the other hand, the response time of the (7) days irradiated device was 370 msec and the recovery was 775 msec. However, the response time of the (9) days irradiated device was 650 msec and the recovery was 550 msec, finally, the response time of the (12) days irradiated device was 440 msec and the recovery time was 370 msec.

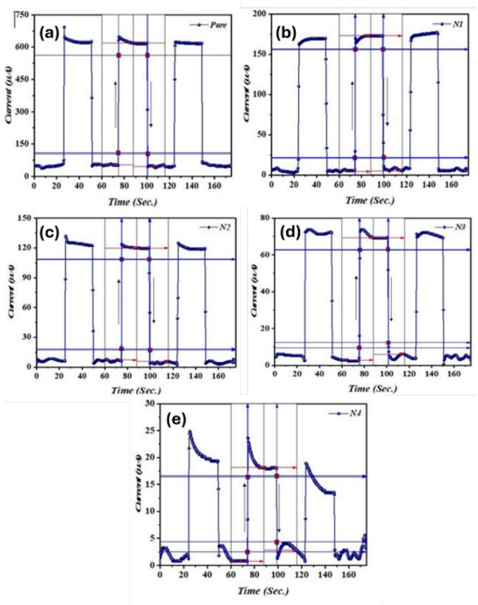


Figure 6 Response/recovery time of (a) pristine sample, (b) 5 days irradiated sample, (c) 7 days irradiated sample, (d) 9 days of irradiated sample, and (e) 12 days irradiated samples.

The photo-responsivity for all fabricated devices was measured at (320-800) nm using a monochromator device. **Figure 7** shows that the photo-responsivity of the pristine device was larger than the other devices and it decreases with increasing absorbed doses.

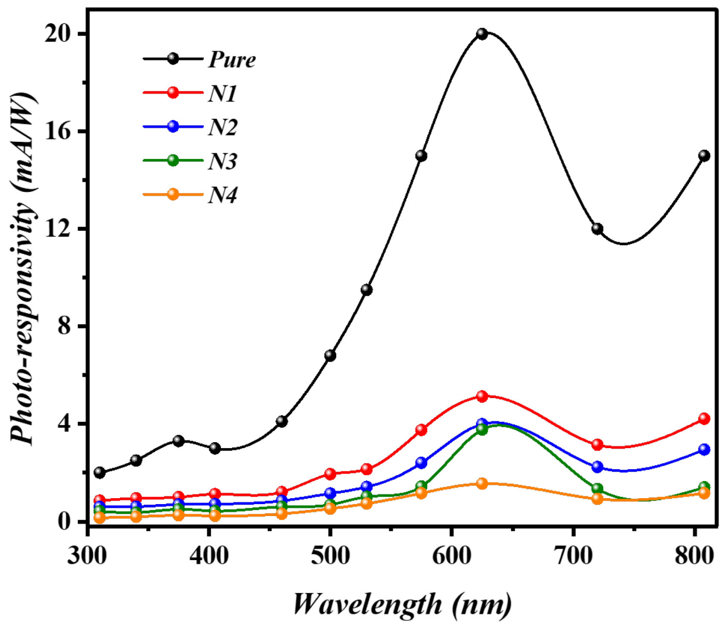


Figure 7 Photo-responsive characteristics of pristine and irradiated samples.

Conclusions

CdSe thin films fabricated by the PLD technique on the p-type silicon substrates were employed in fabricating efficient photodetectors. Photodetectors were exposed to neutron radiation from (^{241}Am-^{10} Be) for (5, 7, 9, 12) days. The last one was kept without any radiation to identify radiation damage through several measurements. Our results have shown the conclusion as below:

- XRD measurements show that the structures of all pristine and irradiated films were hexagonal.
- Irradiation by neutrons causes the appearance of a (102 SiO_2) peak in all irradiated thin film patterns.
- The band gap is also affected by neutron radiation and becomes larger than its initial value.
- Crystalline and grain sizes are also affected by neutron radiation.
- Finally, the electric properties coincided with the typical semiconductors as well as showed significant changes after radiation.

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References

[1] MBA Bashir, EY Salih, AH Rajpar, G Bahmanrokh and MFM Sabri. The impact of laser energy on the photoresponsive characteristics of CdO/Si visible light photodetector. *J. Micromech. Microeng.* 2022; **32**, 085006.

[2] RA Soref. Silicon-based optoelectronics. *In*: Proceedings of the IEEE, New York. 1993. p. 1687-706.

[3] AA Yadav, MA Barote and EU Masumdar. Studies on cadmium selenide (CdSe) thin films deposited by spray pyrolysis. *Mater. Chem. Phys.* 2010; **121**, 53-7.

[4] HH Abed, HM Abduljalil and MA Abdulsattar. Structural, optical and humidity sensitivity for CdSe nanocrystalline thin films. *J. Adv. Pharm. Educ. Res.* 2018; **8**, 25-31.

[5] NT Shelke, SC Karle and BR Karche. Photoresponse properties of CdSe thin film photodetector. *J. Mater. Sci. Mater. Electron.* 2020; **31**, 15061-9.

[6] I Feraru, CR Iordanescu, M Elisa, C Vasiliu, A Volceanov, S Stoleriu, A Peretz and M Filipescu. CdSe-doped phosphate glassy films obtained by PLD on a silicon substrate. *Chalcogenide Lett.* 2013; **10**, 509-17.

[7] G Perna, V Capozzi and M Ambrico. Structural properties and photoluminescence study of CdSe/Si epilayers deposited by laser ablation. *J. Appl. Phys.* 1998; **83**, 3337-44.

[8] RB Konda, R Mundle, H Mustafa, O Bamiduro, AK Pradhan, UN Roy, Y Cui and A Burger. Surface plasmon excitation via Au nanoparticles in n-CdSe⁄p-Si heterojunction diodes. *Appl. Phys. Lett.* 2007; **91**, 191111.

[9] R Choudhary and RP Chauhan. Gamma irradiation induced modifications in spin-coated CdSe thin films. *J. Mater. Sci. Mater. Electron.* 2016; **27**, 11674-81.

[10] P Kumara, D Kumara, A Kumar and RS Katiyarc. Effect of post growth annealing process on optical properties of CdSe thin films on Si p-type substrate deposited by pulsed laser deposition technique. *Int. J. Anal. Exp. Modal Anal.* 2021; **13**, 3016-28.

[11] M Ashry and S Fares. Radiation effect on the optical and electrical properties of CdSe (In)/p-Si heterojunction photovoltaic solar cells. *J. Semicond.* 2012; **33**, 102001.

[12] MA Hernandez-Perez, JR Aguilar-Hernandez, JR Vargas-Garcia, GS Contreras-Puente, E Rangel-Salinas, F Hernandez-Santiago and M Vargas-Ramirez. Influence of the fluence and substrate temperature on the structural and optical properties of CdSe thin films prepared by Pulsed Laser Deposition. *Mater. Sci. Forum* 2011; **691**, 134-8.

[13] MA Hernandez-Perez, J Aguilar-Hernandez, G Contreras-Puente, JR Vargas-Garcia and E Rangel-Salinas. Comparative optical and structural studies of CdSe films grown by chemical bath deposition and pulsed laser deposition. *Phys. E Low Dimens. Syst. Nanostruct.* 2008; **40**, 2535-9.

[14] EY Salih, MBA Bashir, AH Rajpar, IA Badruddin and G Bahmanrokh. Rapid fabrication of NiO/porous Si film for ultra-violate photodetector: The effect of laser energy. *Microelectron. Eng.* 2022; **258**, 111758.

[15] Z Bao, X Yang, B Li, R Luo, B Liu, P Tang, J Zhang, L Wu, W Li and L Feng. The study of CdSe thin film prepared by pulsed laser deposition for CdSe/CdTe solar cell. *J. Mater. Sci. Mater. Electron.* 2016; **27**, 7233-9.

[16] DHA Refaei, LA Najam and LMA Taan. The Effect of neutron irradiation on optical, structural and morphological properties of cadmium selenide thin films. *J. Rad. Nucl. Appl.* 2021; **6**, 207-16.

[17] M Kumari, P Rana and RP Chauhan. Modifications in structural and electrical properties of gamma irradiated CdSe nanowires. *Nucl. Instrum. Methods Phys. Res. Section A* 2014; **753**, 116-20.

[18] M Kaleli, SA Ali, M Koc, S Akyurekli and CA Yavru. Studying the effects of thermal neutrons irradiation on CuInGaSe2 thin film. *JMAUC* 2020; **12**, 186-97.

[19] Z Hammo, L Najam and L Al-Taan. Gamma radiation effects on the performance of the CdSe thin film for photodetector application. *Int. J. Eng. Appl. Phys.* 2024; **4**, 977-83.
[20] EM Noori. Irradiation effect in CdSe thin films. *J. Coll. Educ.* 2019; **1**, 69-76.
[21] C Narula and RP Chauhan. High dose gamma ray exposure effect on the properties of CdSe nanowires. *Radiat. Phys. Chem.* 2018; **144**, 405-12.
[22] TH Mahmoud. Study the effect of thickness on the structural and optical constant of CdSe thin films. *J. Coll. Educ.* 2017; **18**, 249-64.
[23] H Metin, S Erat, ME Ari and M Bozoklu. Characterization of CdSe films prepared by chemical bath deposition method. *J. Optoelectron. Adv. Mater.* 2008; **2**, 92-8.
[24] LA Najam, LMA Taan and DHA Refaei. Preparation and study of the physical properties of CdSe films deposited by a chemical bath method and exposed to neutron irradiation: Effect of neutron Irradiation on a CdSe film prepared. *Int. J. Eng. Appl. Phys.* 2023; **4**, 909-18.