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The spectral responsivity enhancement for gallium-doped CdO/PS heterojunction for UV detector

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Despite the large number of studies on CdO, it was until very recently the system properties Ga-doped CdO/PS was not recognize well. In this paper, photodetector of Ga-doped CdO/Si and Ga-doped CdO/PS nanocrystalline with different Ga ratios (0, 3, and 7%) have been prepare by spray pyrolysis deposition (SPD). The structural properties of un doped CdO and doped films were characterized by X-ray diffraction, which refer to that the CdO thin films have cubic structure. The energy gap of un doped film and doped with Ga increased from 2.5 to 3.56 eV with increasing Ga ratios. I-V characteristics of Ga-doped CdO/PS photodiodes without illumination exhibit good rectification behavior compared with Si substrate, and the value of photocurrent increased with Ga ratios increased. The spectral responsivity curves (A/W) of all devices prepared allow acceptable sensitivity response in the visible wavelength region, and shifted toward ultra-violet region with increase Ga ratios.

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1. Introduction

In recent years, porous silicon (PS) has found high possibilities in various applications due to the designable chemical and physical characteristic compared with conventional Si fabrication process [1]. PS plays a remarkable role in photovoltaic characteristics by the improvement of light absorption and show a set of unparalleled properties like; direct wide energy gap, big surface area compared with volume ratio, and nearly similar crystalline structure of bulk silicon. This worthy features make of PS as engaging and promising material for excellent optoelectronic device fabrication [2][3]. Also optoelectronic devices like sensors, photodetectors, and light emitting diodes have been developed as well [4]. The chemical structure of single crystal silicon is ineffectual because of an irregular distribution of the grain orientations, however these problem was overcome via PS structure formation [2]. Cadmium oxide (CdO), is one of the important n-type semiconductor material with an indirect energy gap of 1.98 eV, and a direct energy gap a round 2.5 eV [5]. CdO have many features such as, high transmittance in the visible and UV area, and it is possess high conductivity [6]. It is a suitable material for optoelectronic or electronic application, like solar cells, gas sensors, and photodetectors [7]. UV photodetectors devices have different application such as confidential communication, flame detection, rocket early alarms, and ozone hole detection. Photodetectors devices have been expansion by several structures like, p–n junction, MSM, and Schottky barriers [8]. CdO thin film can be prepared by several technique like spray pyrolysis deposition (SPD) [9], pulsed laser deposition (PLD) [10], vacuum thermal evaporation [11], and R.F. magnetron sputtering [12]. Up to date, in spite of different research, which was taken out on CdO and PS, a little studies have been achieved on CdO/Si and CdO/PS models as photodetector. Dhār and Chakrabarti [13], presented the feasibility of invention of high sensitive CdO/PS/Si heterojunction by chemical bath deposition. The dark current was very small (38nA at 20V) and the ratio of photocurrent to dark current was 1000. Ortega et al [6] studied the optoelectronic properties of n-CdO/p-Si photodetector via chemical bath deposition (CBD). Gozeh et al[14] studied the photosensitivity of CdO/PS/Si photodetector made by sol-gel spin coating technique. The photo response of the photodetector was measured as approximately 2.65×10^3. Gallium (Ga) is relatively suitable dopants, because of their ionic radiu (0.62 Å) is minimal than

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that of Cd (0.96Å), so, it is simple to treatment Ga impurity in CdO structure without big lattice deformation. Moreover, these make to improvement the attractive optical and electrical characteristic after a partial Ga doping [15][16]. Ga regarded an active n-type material, which aid to rise the electrical conductivity by increasing the carrier density [17]. In this work, optical, structural, and electrical properties of Ga-doped CdO/Si, and Ga-doped CdO/PS as heterojunction photodetectors prepared by spray pyrolysis are investigated.

2. Experimental part

The electrochemical etching (ECE) method was used to prepared PS layers via mirror-like p-type silicon wafer with (111) orientation, the electrical resistivity was (1-4) Ω.cm, and 500 ± 25 µm thickness are used. ECE cell was made of Teflon. Si wafer was cut into square-shapes with area ($1cm^2$), and then anodized in a solution containing mix of 48% HF and ethanol at 1:4 ratios for 20 minute and current density of 25 mA/cm^2. In this cell, two-electrode was applied, where Si was utilized as anode and platen (Pt) as cathode. The silicon wafer cleaning process was done using ultrasound in distilled water and acetone. CdO:Ga thin film was prepared by spray pyrolysis method, which carried out in a locally made reaction closed chamber. In this work, 0.1 M concentration of cadmium chloride ($CdCl_2.H_2O$) was utilized to deposited CdO thin films, and 0.1 M of gallium chloride $GaCl_3$ was used as Ga source at the volume ratios (0, 0.03, and 0.07)% ml of Ga. X-ray diffractometer system (SHIMADZU XRD-6000) wasused to studied the structural properties, which included crystal structure and crystallite size. The optical properties of thin films were tested by (Shemadzu UV-160/UV-Visible recorder spectrophotometer). The hetrojunction was prepard via the metallization of specimens. The metal contacts (fingers-shaped) was from aluminum (Al) electrodes with thickness about 500 nm, where prepared using an E306A Edwards thermal evaporation system. In this work, the spectral response of the detector was measure by a detector experience system type (spectroradiometer, model of 746) which included the monochrometer, and halogen lamp, which operates within the spectral area of (200-900) nm. Standard silicon power meter was used for calibrate the results by measuring the power of all spectral line.

3. Results

3.1. XRD analysis

X-ray diffraction style of nanostructure CdO and Ga-doped CdO thin films deposited on PS at different ratios of Ga are illustrate in Fig. 1. It is clear from the Fig, that all films prepared are polycrystalline structure with diffraction peaks at 2θ = 32.82°, 38.00°, 54.85°, and 65.39°, which corresponding to diffraction planes (111), (200), (220), and (311) respectively according to card no. (01-075-1529), which refer to cubic structure[18]. From the same Fig, it can be observe, increase the intensity of all diffraction peaks intensity of CdO as Ga ratios increase, and show a small shifted of 2θ toward higher value comparing with CdO. These result may be because of occupation the ions of Ga at the Cd sites [15], or may be due to a strain [19]. No any other phase or impurities were observed from XRD patterns except for one peak refer to PS at 2θ = 28.43 corresponding to the (111) plane. The crystalline size (D) of CdO and Ga-doped CdO can be estimated by Scherrer's formula [20].

$$D = \frac{k\lambda}{\beta cos\theta} \tag{1}$$

where λ, β, FWHM, and θ represent: the wavelength, full width at half maximum of a diffraction peak in radians, and Bragg's angle respectively. The crystal size of CdO was found to 24.6 nm from the preferred orientation, and this value decrease with increase of Ga ratios as Table. 1. This result may be due to the ionic radius of adsorbed Ga3+ is small compared with Cd, which occupy interstitial positions into the structure of CdO [19].

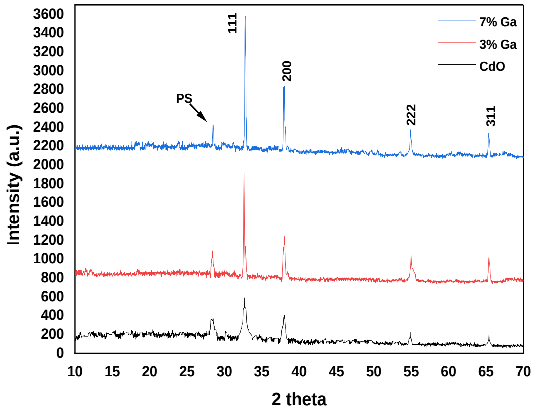

Fig. 1. XRD spectra of the Ga-doped CdO/PS at (0, 3, and 7)% of Ga.

Table. 1. XRD parameters of pure CdO and Ga-doped CdO thin films.

CdO:Ga	Pos. [°2Th.]	FWHM (Deg.)	D (nm)	hkl	Cry. System	Card no.
0% Ga	32.8232	0.3362	24.6	111	cubic	01-075-1529
	38.0024	0.2362	35.5	200	cubic	01-075-1529
	54.856	0.3149	28.4	220	cubic	01-075-1529
	65.3967	0.1574	59.9	311	cubic	01-075-1529
3% Ga	32.8249	0.3984	20.7	111	cubic	01-075-1529
	38.0005	0.2787	30.1	200	cubic	01-075-1529
	54.9786	0.2787	32.1	220	cubic	01-075-1529
	65.3743	0.2984	31.6	311	cubic	01-075-1529
7% Ga	32.8317	0.4184	19.7	111	cubic	01-075-1529
	38.0471	0.294	28.5	200	cubic	01-075-1529
	54.8723	0.2887	30.9	220	cubic	01-075-1529
	65.3522	0.2984	31.5	311	cubic	01-075-1529

3.2. Optical properties

The optical energy gap of CdO and Ga-doped CdO thin films with different ratios of Ga has been calculated from plot the photon energy (hυ) versos the linear part of the $(\alpha h\upsilon)^2$, by assuming a direct transition between valence and conduction bands as shown in Fig. 2, and by using Tauce equation. The results indicated to that, the pure CdO has energy gap about 2.5 eV, which corresponding in with [21]. When Ga ratios increased, the optical energy gap increased to be 2.71, and 3.65 eV. Several reasons have led to the extending of the band gap, possibly due to an increase in charge carriers concentration, which mark to the Burstein-Moss effect [11]. Or may be due to the decrease of density of localized state in the conduction band [9]. Also, these may be because of the reduction to nanosize as refer in XRD results, which support the charge carrier quantum confinement [22], and sometime these increased occur due to, changes the periodic crystal potential, especially at direct transition, which leading to an increase energy band gap, where the Fermi level lies within the conduction band with energy position build on the density of the free electrons [19].

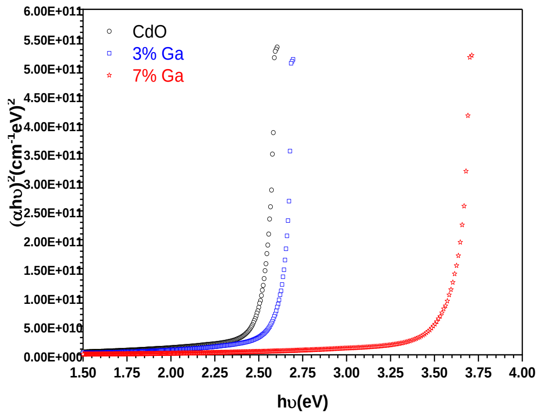

Fig. 2. Optical energy gap of Ga-doped CdO/glass at (0, 3, and 7)%.

3.3. Electrical characteristics of Ga-doped CdO/Si, PS heterojunction

Fig. 3, display the darkness current as a function of the voltage of aniso-type heterojunction CdO/Si, and CdO/PS. Fig. 3a, represent the forward and reverse bias voltage under the dark of CdO/Si, and Ga-doped CdO/Si at 3, and 7% of Ga. The heterojunctions exhibited accepted rectification characteristics and these characteristics improvmented with increase the Ga ratios. The Figure shows, there are two regions in the forward bias, the first area occur at low voltage because of the recombination current, other area at altitude voltage, due to the diffusion current. In addition, two regions are observed in the reverse bias. The first area at the minimum voltage, in which electron hole pairs are create because of generated reverse current with increasing voltage. The reverse current arises In the second region from the diffusion of minority carriers through the junction, which caused major increases in the reverse bias. [23]. Fig. 3b represented the forward and reverse bias voltage of CdO/PS, and Ga-doped CdO/PS at 3, and 7%. All the samples based on PS exhibited perfect rectification characteristics comparing with Si substrate. The forward current for 7% of Ga was higher than others, this may be due to lower resistance. The value of the photocurrent versus the bias voltage of heterojunction n-(Ga-doped CdO/p-Si, and n-(Ga-doped CdO)/p-PS under ambient illumination of 100 mW/cm2 at doping ratios (0, 3, and 7) wt. %. of Ga, are illustrated in Fig. 4a, and b, respectively. It is clear the photocurrent increased with Ga ratios increased. The figures display the behavior of the photocurrent as a function of the reverse bias voltage under outer revers bias causes increase the depletion region, therefore the big number of the fallen photons will transmitted via the CdO layer and absorbed in the depletion layer, which will creating the pairs (electron –hole), which incorporate in photocurrent generation. The maximum photocurrent was found for 7% Ga-doped CdO/PS photodetector compared with Si substrate, this is may be due to the improvement in crystallinity of CdO film, which in turns reduced the interface structural defects.

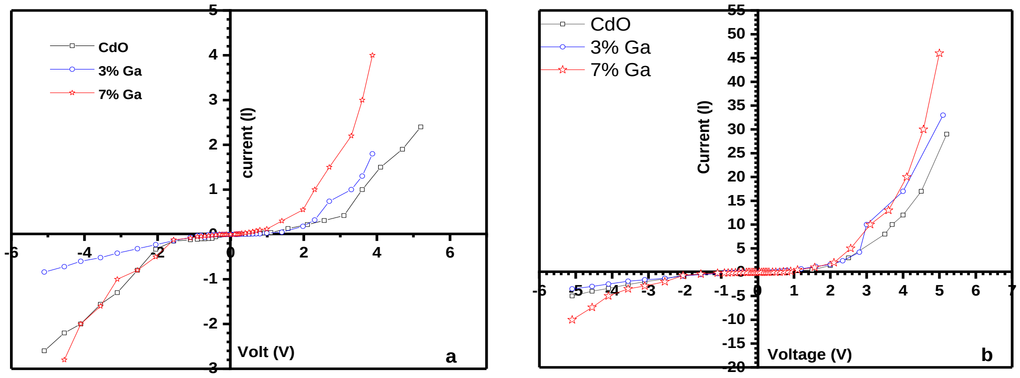

Fig. 3. I-V characteristic in dark of (a) Al/Ga-doped CdO/Si, (b) Al/Ga-doped CdO/PS at 0, 3, and 7% of Ga.

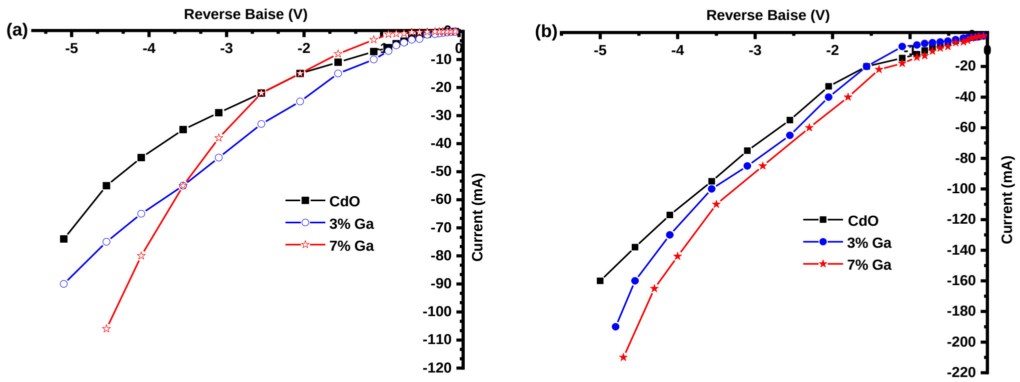

Fig. 4. Photo I-V characteristics under reverse bias for (a) Al/Ga-doped CdO/Si, (b) Al/Ga-doped CdO/PS at 0, 3, and 7% of Ga.

3.4. Spectral responsivity

The responsively (Rλ) versus the wavelength at the reverse bias voltage (1volt) of the Ga-doped CdO/Si, and Ga-doped CdO/PS, are illustrated in figure 5a, and b respectively. The spectral response of CdO/Si at 550 nm was about 0.122 A/W. It is clear, the effect of Ga appear in improving the top of the spectral response, and shifting to the less value of wavelength. These wavelengths are absorbed in the depletion layer (active region), which is equal to the depth of the diffusion of the minority carriers. This area can separate the generated electrons (electron-hole) in the internal electric field. In addition, there is little recombination operation in this area. The other few response areas are because of the recombination of the electrons and the hole, leading to a reduction for charge carriers generated, and thus less response. The photoresponse of the Ga-doped CdO/PS, with 0, 3, and 7% of Ga are shown in Fig. 5-b. it is obvious from the figure, there are two response peaks, the low peak located at 520 nm convenient nearly to band gap of CdO. The other peak at 740 nm, which refer to the absorption edge of the PS, the responsivity of PS peak was found to be 0.19 A/W. The upper value of responsively of thin films was set to be (0.156A/W) at λ = 490 nm for 3% of Ga, but the maximum shifting toward ultra-violet ray in peak response of photodetectors was found at 7% of Ga.

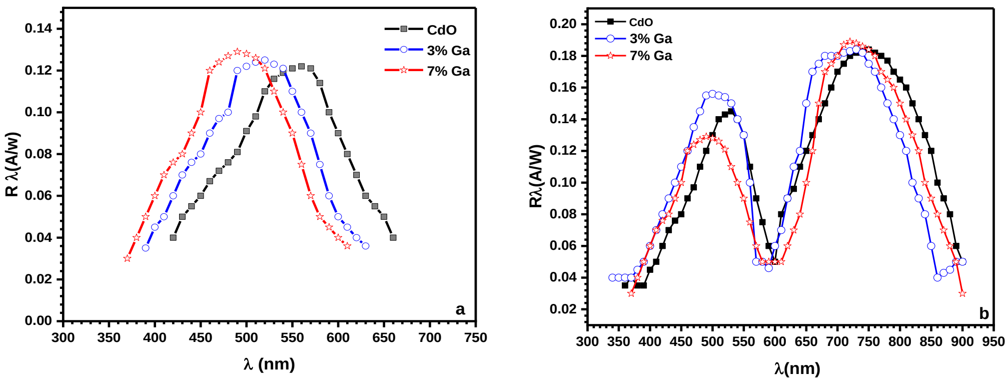

Fig. 5. Spectrum response of (a) Ga-doped CdO/Si, (b) Ga-doped CdO/PS at 0, 3 and 7% of Ga.

4. Conclusion

SPD method was used to manufacture photodetector Ga-doped CdO/Si, and Ga-doped CdO/Si, the results show good spectral response at visible region, and increased toward UV region. XRD pattern of films prepared on PS show that the doping leads to increase intensity of diffraction peaks. The optical properties of CdO thin films were affected by Ga doping, and this clear by increase the energy gap. The electrical results of CdO/PS compared with Si improvement via increased the Ga ratios, which exhibit good rectification characteristics, photocurrent, and dark current. Finally, can be deduction that Ga-doped CdO/PS films were a good candidate for UV detector.

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