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Improving the Qualitative Detection of Porous Silicon Using CdO NPs

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ABSTRACT: This research describes a successful fabrication process for CdO NPs using pulsed laser ablation. It also describes a photodetector with heterojunction. A rapid analysis of the morphological, structural, and optical properties was performed. The production of cadmium oxide thin films was confirmed through structural and morphological characterization. The nanofilms were 10.84 nm thick. X-ray diffraction patterns showed a match with the material used. The surface properties and shape of the cadmium oxide were analyzed using atomic force microscopy. The laser ablation process produced very small, regularly arranged, hemispherical, pointed, and uniformly distributed nanoparticles with few single columns. The detector's response spectrum showed good selectivity for detecting visible and near-infrared light. Therefore, CdO NPs could be a promising candidate material for photovoltaic applications.

KEYWORDS: CdO, porous silicon, heterojunction, photodetector

1. INTRODUCTION

Ag/CdO/PSI/Si/Ag photo detectors have shown great promise in a variety of applications in recent years because to their designable physical and chemical properties and compatibility with traditional Si fabrication processes. For instance, the PSi layer's tunable optical characteristics, like the index of refraction and different luminescence phenomena, are used in solar cells, waveguides, reflectors, and LEDs [1-4]. Moreover, chemical and biological sensing applications are made possible by the PSi layer's large specific surface area [5,6]. These materials' vast optical bandgap makes them useful for detecting ultraviolet (UV) light, while silicon's (Si) narrow bandgap makes it useful for detecting visible and near-infrared spectra [6]. One common optically transparent n-type semiconductor present in TCO materials is cadmium oxide. At room temperature, it crystallizes as a cubic with an indirect band gap of 1.98 eV and a direct energy gap of 2.5 eV [7]. Due to its promising optical, photocatalytic, and electrical qualities, cadmium oxide has been the subject of much research. Because of its intriguing electrical and optical characteristics, CdO NPs represent a second choice for metal oxides in bimetallic nanoparticles. In the energy gap, CdO has the ability to both emit and absorb radiation [[8], [9], [10].These characteristics make CdO nanoparticles popular in many optoelectronic applications, including solar cells, gas sensors, photocatalytic processes, biosensors, photodiodes, and photodetectors [10,11]. Sol-gel is one method that can be used to create CdO nanoparticles. [12] Chemical bath deposition [15], thermal evaporation [14], and heat treatment technique [13] In this manuscript, cadmium oxide particles made by laser ablation in liquid were used to enhance the specific response of porous silicon.

2. THE EXPERIMENTAL PORTION

P-type orientated silicon wafers were electrochemically etched to create porous layers on crystalline silicon samples (100). Pure ethanol was introduced to the electrolyte solution due to the hydrophobic nature of the smooth, polished silicon wafer surface. Ethanol facilitates the electrolyte's penetration of the pores and improves the substrate's wetting capacity. With a platinum plate serving as the cathode and a solution made up of 40% hydrofluoric acid and pure ethanol in a 1:1 volumetric ratio, anodizing was carried out for 15 minutes at a current density of 20 mA/cm². After synthesis, each sample was submerged in ethanol and kept in pentane in a different container. A pulsed Nd:YAG laser with a fundamental frequency of 1064 nm, a repetition rate of... Hz, a pulse energy of 600 mJ, and a pulse duration of 10 ns was used to ablate cadmium oxide targets. The size of the spot was 2.3 mm². The targets were powdered cadmium oxide compacted for one hour with five tons of material.

3. RESULTS AND DISCUSSION

As shown, the cadmium oxide film has a crystalline structure, and the annealing process increases the grain size. The sharp peaks at 2θ = 32.89° and 2θ = 37.62° are associated with the (111) and (200) planes of the cubic structure of cadmium oxide and the Other peaks also appear at the (220) and (311) planes of reflection. Improving the crystalline nature of the films significantly enhances the optical transmittance, as shown in Figure 1. The crystallite size can be determined from the X-ray diffraction spectrum using the Scherrer equation as follows: $D = 0.9\lambda / \beta\cos\theta$, (14 nm) where D is the crystallite size , λ is the X-ray wavelength, β is the width of half the maximum peak height, and θ is the Bragg angle.

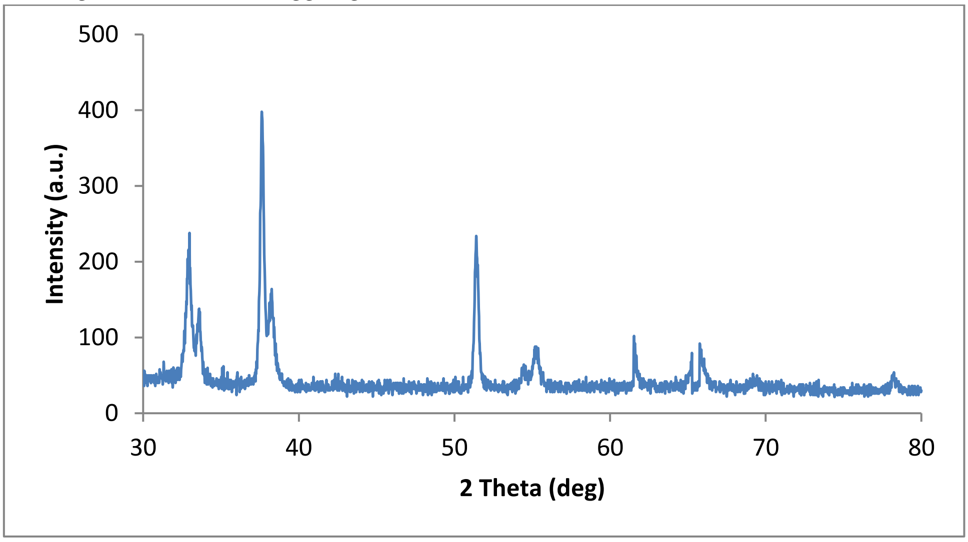

Figure 1: XRD pattern of of CdO thin film.

Figure (2) shows a scanning atom microscope (AFM) image of a thin film of cadmium oxide (Cdo) prepared by laser liquefaction in water. The surface of the room-temperature prepared Cdo thin film is arranged vertically in small hills, and horizontally in a slant pattern with small peaks pointing upwards within a (2 × 2) µm scan area. The Gaussian distribution indicates that the average granular size is no more than 30 nm.

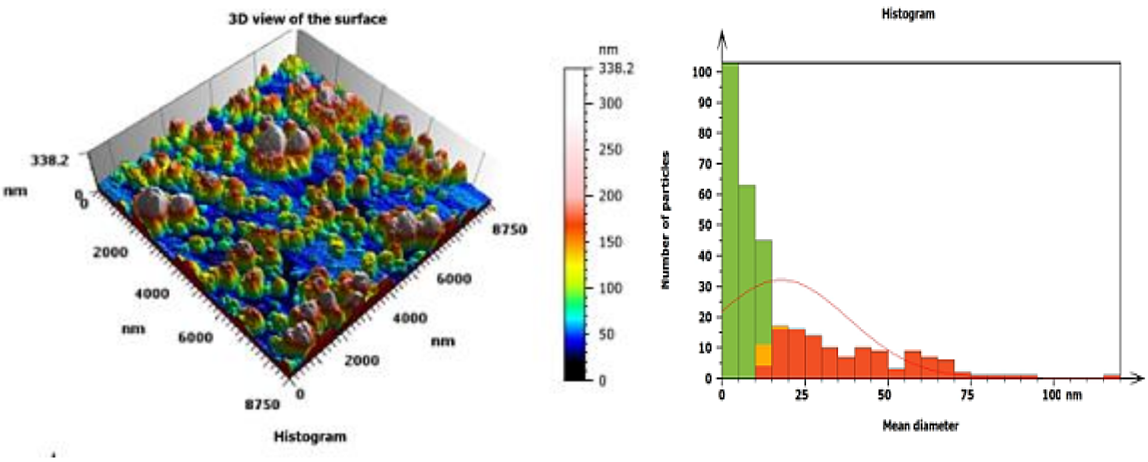

Fig 2. AFM image of the CdO thin film

Figure (3) illustrates the change in optical absorbance as a function of wavelength for the pulsed uranium oxide film. As can be seen from the figure, the absorbance decreases towards longer wavelengths, meaning that the highest absorbance occurs in the ultraviolet region, with a distinct region at a wavelength of 369 nm. The figure also shows the

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relationship between (αhυ)2 and hυ for the direct band gap, which was determined by extrapolating the linear component against the photon energy axis. It can be observed that the energy gap value is approximately 2.75 eV. The increase in the energy gap value indicates a quantum size effect.

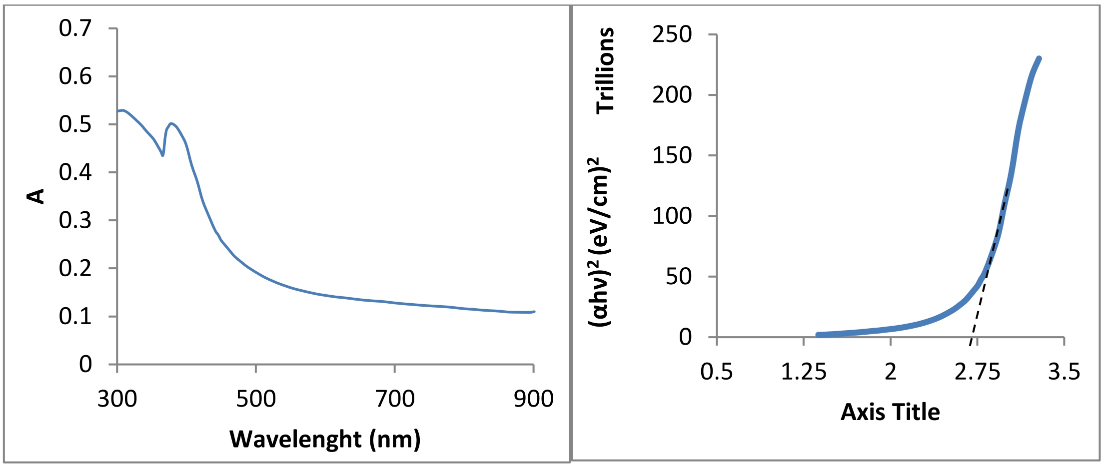

Fig 3. The Absorption and energy gap of the CdO thin film

Figure 4 shows the dark current as a function of the asymmetric heterojunction voltages. Figure 4a shows the forward and reverse bias voltages in the dark for CdO/PSI/Si .The heterojunction exhibited acceptable rectifying properties. The figure shows two forward bias regions: one at a low voltage, where the electrical properties of the porous silicon are enhanced by the recombination current, and another at a high voltage due to the diffusion current. Additionally, two reverse bias regions were observed. The first, at the lowest voltage, is where electron-hole pairs are generated due to the reverse current that increases with the voltage. The reverse current in the second region arises from the diffusion of minority charge carriers across the junction, causing significant increases in reverse bias. The heterojaction exhibited optimal rectifying properties compared to the silicon substrate. The figure 4b shows the photocurrent behavior as a function of the reverse bias voltage. Outward reverse bias leads to an increase in the depletion region, and consequently, a large number of incident photons will pass through the CdO layer and be absorbed in the depletion layer, leading to the formation of electron-hole pairs that contribute to the generation of the photocurrent.

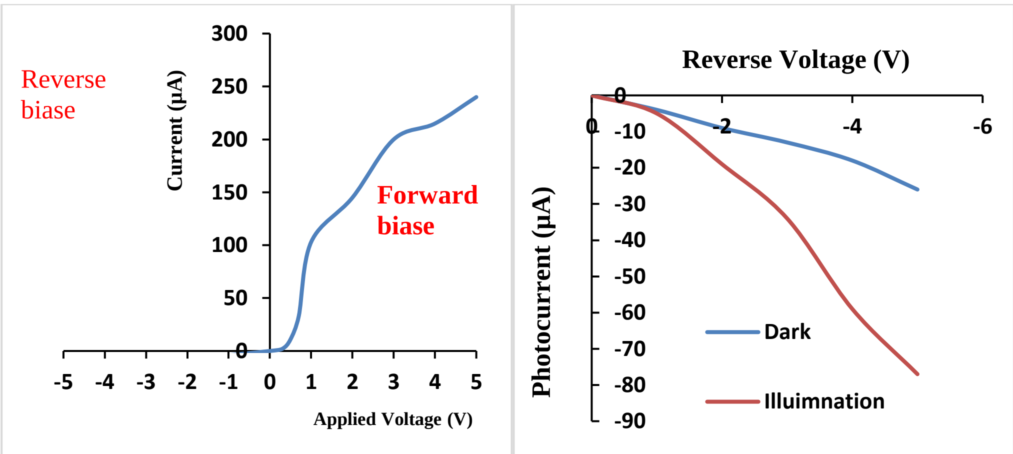

Fig. 4. I-V characteristic in dark of CdO/PSI/Si

The two most important measurements used to evaluate optical detectors are response (R) and detection capability (D). The ratio of photocurrent (Iph) to incident photopower (Popt) was calculated as a function of wavelength to determine the response (R) [15]:

$R = I_{ph}/P_{in}$ (A/W) ………….(1)

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Figure 5(a-c) shows the wavelength-dependent spectral response (Rλ) of the inhomogeneous junction (CdO/PSI) at 5 V in the 350–1000 nm range. The response spectrum of CdO/PSI shows that this detector has good selectivity for detecting visible light at wavelengths between 450 ,700 and 850 nm, and in the near-infrared region between 850 and 900 nm. For D1 (CdS/Si), the maximum photoresponse peaked at approximately 550 and 900 nm, at 0.34 A/W and 0.50 A/W, respectively. Since cadmium sulfide (CdS) is a window to visible light, the photoelectric properties exhibited CdS/Si exhibits a strong response in the VIS and NIR ranges due to the short circuit formed by the silicon substrate. The 2.75 eV band gap of CdS corresponds to a cutoff at 450 nm . Due to the silicon absorption edge, the response increases at 850 nm after decreasing at higher wavelengths as a result of increased surface recombination and decreased transmitted light. The response spectrum of example D2 shows a single, distinct peak at 850 nm . This indicates that the photodetector reacts only to near-infrared light with a wavelength of approximately 850 nm. Its maximum photoresponse is 0.78A/W, due to parasitic light. CdO Nanoparticles absorbs light via two-band absorption, so it rarely reacts to ultraviolet and visible light.

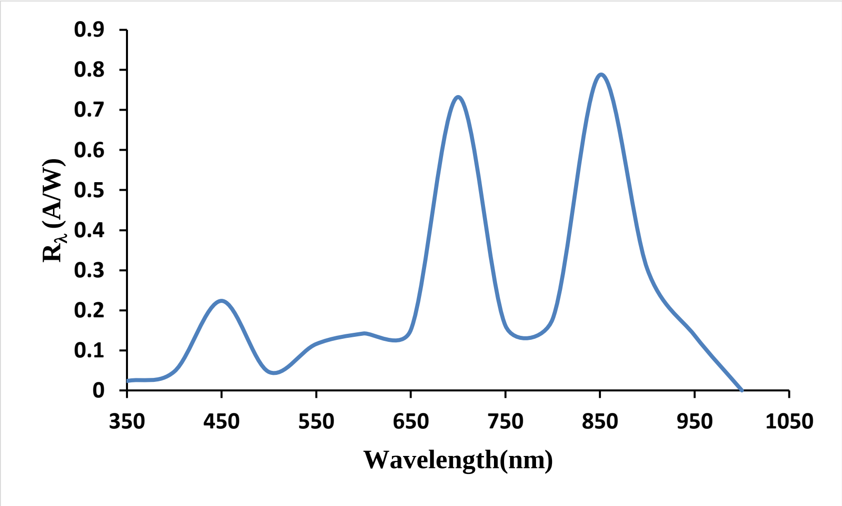

Fig. (5) Responsivity as a function of wavelength ffor CdO/PSI/Si

Figure 6 shows the detection activity of CdO/PSI/Si photodetectors as a function of wavelength. The figure clearly demonstrates that the response directly affects the detection. The highest measured value of D* were 1.86 × 10^{11} Jones and 2 × 10^{11} Jones at wavelengths of 700 nm and 850 nm.

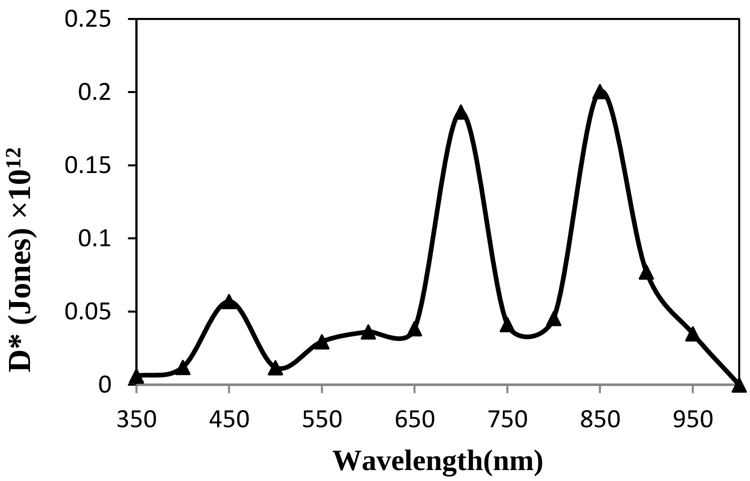

Fig. (6) Detectivity as a function of wavelength for CdO/PSI/Si

CONCLUSIONS

In general, laser ablation is the best and most important physical method for preparing nanoparticles for water-insoluble targets, yielding particles with dimensions no larger than 30 nm. We also demonstrate for the first time how to fabricate photodetectors using cadmium oxide, which offers unique advantages that improve upon the use of porous silicon by increasing charge carrier density and expanding the absorption spectrum. Our research shows that these heterogeneous junctions achieve good specific response and high detection efficiency in certain regions of the electromagnetic spectrum. Structural defects, such as material mismatch or thinness of the layers, may cause a decrease in specific response and the observed detection efficiency in the visible light region. To obtain suitable filters for potential applications in photodetection, sensors, and photocatalysis, these issues can be addressed through heat treatment or grafting.

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