Materials for Renewable and Sustainable Energy (2018) 7:28
https://doi.org/10.1007/s40243-018-0135-7

ORIGINAL PAPER

Enhancement of CdS nanoparticles' photoconductive detector by adding TPD conductive polymer

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Received: 6 January 2018 / Accepted: 3 October 2018 / Published online: 9 October 2018

Abstract

CdS nanoparticles have been prepared by a chemical method and deposited as a thin film on both P-type silicon and porous silicon (PS) substrates by spin coating technique as a photoconductive detector. The Hall measurements show that the nanoparticles are n-type with carrier concentration of about (-5.45×10^{10} cm^{-3}). The response time of the fabricated detectors on Si, PS and (CdS + TPD/PS) substrates was measured (by illuminating the sample with Halogen lamp 250 W) and its values are 5.2 ms, 2.1 ms and 1.3 ms, respectively. The specific detectivity and photoresponsivity of the fabricated detector on PS are found to be (9.9×10^{12} $Watt^{-1}$ $Hz^{1/2}$ cm^{-1} and 0.043 A/W). The surface functionalization of the CdS nanoparticles film deposited on porous silicon (PS) substrate by triphenyldiamine (TPD) has highly improved the photoresponsivity and response time of the detector to 0.059 A/W and 1.3 ms.

Keywords CdS nanoparticle · TPD polymer · Porous silicon · Photodetector · Detectivity · Response time

Introduction

II–VI nanocrystalline semiconductor materials had been under severe studies because of their exciting particular characteristics that are absent in bulk materials since nanoparticles have an extensive quantity of surface atoms than that of bulk [1].

Cadmium sulphide CdS is an essential semiconductor due to its high photo-sensitivity and has many optoelectronic implementation inclusive of solar cells, photodiodes, light emitting diodes, nonlinear optics and heterogeneous photocatalysis [2, 3].

Porous silicon photodetector is used for UV detection; it has many advantages over the alternative substances, consisting of excessive absorption coefficient for UV location. It does no longer require anti-reflective coating and low value and needs easy fabrication technology [4]. Porous and non-porous Si nanowires have won a great deal of attention as they are made of Si. Their unique dimensions with high aspect ratio for the solid wires and high porous surface vicinity for the porous wires offer inimitable optoelectronic and thermoelectric characteristics [5].

Polymers, with no difficulty of creation, are best framework layouts for inorganic nanoparticles. Hence, different nanoparticles were changed with polymers to tailor their surface and interface properties. The production of the CdS nanoparticles can be more advantageous through joining them into polymer supports. Given that CdS nanoparticles are immobilized onto widespread supports, their stability is progressed as wishes be. In this manner, polymers with functional group act as particular stabilizers for the solution of CdS nanocrystals, control their size variety and enhance their surface structure. Broad studies had been completed in the adjustment of CdS composite nanoparticles utilizing polymer supports [6].

Conductive polymer TPD, *N′*-diphenylbenzidine (alkyl-TPD), is a common material which has an ionization potential of (5.5 eV) and good hole transport mobility of 10^{-3} cm^2/Vs [7, 8]. TPD is usually used as a blue-violet light emitting material or host material on the phosphorescence organic light emitting diodes because its wide energy band is about (3.2) eV with highest occupied molecular orbital

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(HOMO) and lowest unoccupied molecular orbital (LUMO) − 5.5 eV and − 2.3 eV, respectively [9].

In this work, the improvement of the photoresponsivity of the CdS nanoparticles visible detectors was done by surface treatment of the CdS thin film. The mixing the CdS nanoparticles with the conductive polymer we enhanced the detector performance.

Experimental work

Cadmium sulphide was prepared in accordance with procedures in a previous study by Adnan [2, 10, 11].

To manufacture the photodetector, 1×1 cm^2 P-type silicon wafer (1.5 Ω cm and 508 + _15 μm thickness) is used as a substrate. Also, the substrate is photo-chemically etched in diluted (10%) HF acid for manufacturing another detector in order to study the role of silicon-etched substrate. Tungsten halogen lamp of 250 W was used as the photo etching source. Etching time was chosen to be 10 min [12].

After the etching process, the sample has been rinsed with ethanol and stored in a glass container filled with methanol to avoid the formation of oxide layer above the porous silicon film. The CdS nanoparticles are deposited on the substrate with thickness of 1 μm to obtain the photodetector. A micro mask of (0.4 mm) electrodes spacing is used to deposit the Aluminum electrodes on the surface of the detector as shown in Fig. 1.

The TPD polymer is used by mixing it with the CdS nanoparticles to form the active layer of the photodetector. The mixture is deposited on the PS substrate in order to fabricate the enhanced photodetector. The sensitive area of the detector is prepared as follows:

- Preparation of [TPD–chloroform] solution: 0.07 gm of TPD dissolved in 1 ml of chloroform and the mixture was putting on the stirrer till dissolving was complete.
- preparation of [CdS–chloroform] solution, 0.02 ml of CdS was dissolved in 1 ml of chloroform and the mixture was kept on the stirrer till dissolution was complete
- Deposition synthesis is done by mixing the CdS–chloroform solution and TPD–chloroform with mole ratio 2:1 and then deposition on porous silicon substrate by spin coating technique to obtain the enhanced detector.

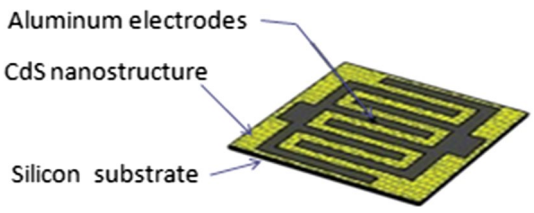

Fig. 1 CdS nanoparticles photodetector sample

Results and discussion

Optical properties of CdS nanoparticles

The optical properties of the CdS nanostructure have been measured by UV–Vis spectroscopy and photoluminescence (PL) spectrum. The absorption spectrum shows a peak at 455 nm as shown in Fig. 2. The absorption spectrum shows a blue shift relative to the peak absorption of bulk CdS indicating quantum size effect.

The optical band gap energy (E_g) of the semiconductor is calculated from Tauc relation [13]. A plot of $(\alpha h\nu)^2$ versus $h\nu$ shows an intermediate linear region; the extrapolation of the linear part can be used to calculate the E_g from the intersect with the ($h\nu$) axis as shown in Fig. 3. The resultant values of E_g for CdS are found to be about (2.7 eV) and this value shows a good agreement with the values presented by other researchers [14, 15].

At room temperature, PL spectra of sample are shown in Fig. 4. The sample is excited with 300 nm source. Two peaks of Gaussian shape are fitted in the PL spectra and denoted as sub-bands I and II which are centered at about 460 nm and 565 nm, respectively.

Electrical properties of CdS nanoparticles

Hall effect

The Hall Effect setting type (HMS3000) is used to study the electrical properties of CdS (conductivity, carrier mobility, charge concentration) and the results are illustrated in

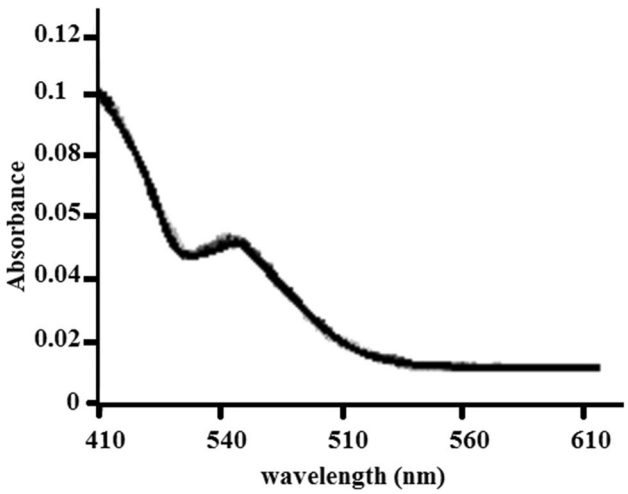

Fig. 2 The absorption spectrum CdS nanoparticles

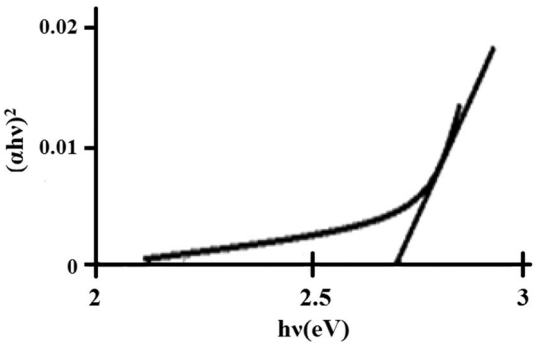

Fig. 3 The energy gap of CdS nanoparticles

Table 1. The table shows that the CdS film deposited on silicon and PS substrates is n-type semiconductor, conductivity and mobility for CdS deposited on PS has better values.

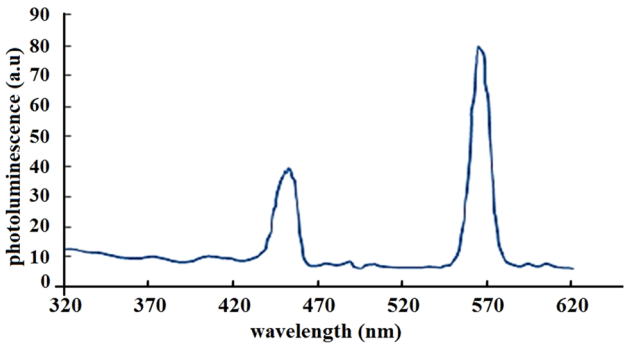

Fig. 4 PL spectrum of CdS nanoparticles

This behavior indicates that the porous silicon substrate is beneficial to improve the crystalline quality of CdS film in lattice mismatch heteroepitaxy due to its sponge-like structure.

Current–voltage measurements

The current–voltage (I–V) characteristics of the photodetector as a function of the bias voltage at dark and under illumination of Tungsten halogen lamp of 250 W are tested.

The overall increase in current was observed at room temperature. Figure 5 shows the I–V characteristics of CdS nanostructure photodetectors based on both silicon substrate and porous silicon substrate. The current–voltage curves are the most commonly used characterization tool for the devices.

The current voltage characteristics of such type of sample in which the polymer TPD is deposited on to the same sample indicate very interesting different type of conduction mechanism as shown in Fig. 6.

Table 2 shows the figure of merit for CdS nanostructure photodetector deposited on silicon, porous silicon and coated by TPD polymer.

The photoconductive gain (G) which is calculated from the ratio between the photocurrent to the dark current at the same bias voltage is given by $G = \tau/T$, where $\tau =$ is the charge carries life time and T is the transient time between the detector electrodes. The transient time is related to the electrode spacing and the carrier mobility by the relation; $T = L^2/\mu V$, where L is the electrodes spacing, μ is the

Table 1 Hall measurement for CdS nanoparticles

Materials	Si	PS	CdS	CdS/Si	CdS/PS	TPD + CdS/PS
Concentration (1/cm^3)	7.89×10^{16}	7.89×10^{14}	-5.45×10^{10}	-1.06×10^{14}	-4.86×10^{22}	-3.4×10^{24}
Conductivity (1/Ω cm)	2.11	6.9×10^{-6}	4.814	10.4	1.39×10^{6}	1.29×10^{10}
Mobility (cm^2/Vs)	1.8×10^{2}	5.4×10^{-2}	5.512	6.14×10^{5}	1.7×10^{2}	1.16×10^{5}
Resistivity (Ω cm)	4.7×10^{-1}	1.40×10^{5}	2.077	9.58×10^{-2}	7.15×10^{-7}	7.7×10^{-9}

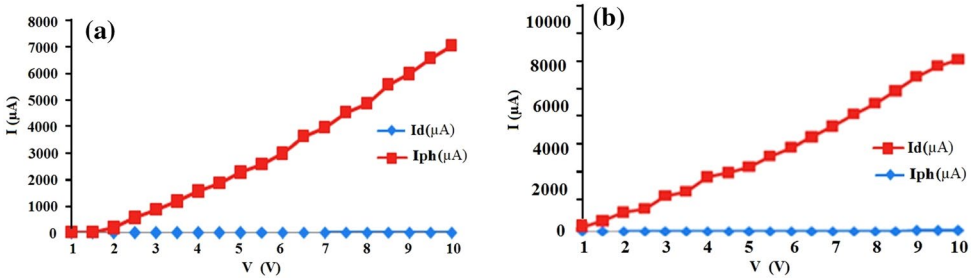

Fig. 5 I–V characteristics of CdS photodetector on **a** silicon substrate, **b** PS substrate

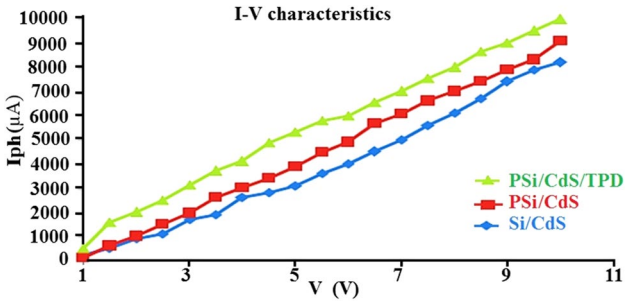

Fig. 6 *I–V* characteristics of CdS nanoparticles (CdS deposited on PS and coated with polymer, CdS deposited on PS, CdS deposited on Si)

carrier mobility and V is the bias voltage. Using the value of gain G and mobility for CdS as found from Hall measurement, $l = 0.04$ cm and $V_B = 10$ V. The carries life time (τ) was found to be about 5.2 ms, 2.1 ms and 1.3 ms for CdS deposited on silicon, porous silicon and coated by TPD polymer. The specific detectivity D^* which is sometimes called the normalized detectivity is the reciprocal of the noise equivalent power (NEP) normalized to the detector area of 1 cm^2 and a noise electrical band width Δf of 1 Hz can be written as:

$$D * = R_\lambda (A\Delta f)^{1/2} / I_n, \quad (1)$$

where R_λ is the photoresponsivity of the photoconductive detector in (A/Watt), A is the detector sensitive area and I_n is the noise current which is estimated from the dark current by the following relation:

$$I_n = (2eI_d\Delta f)^{1/2}, \quad (2)$$

where I_d is the dark current, e is the electronic charge and Δf is the noise bandwidth, leading to noise current of about 1×10^{-10} A, 3.9×10^{-12} A and 1.1×10^{-14}, at $\Delta f = 1$ Hz. Using the value of photoresponsivity $R = 0.03$, 0.04 and 0.059 A/W, A = 0.23 cm^2, the specific detectivity of the fabricated CdS visible detector deposited on silicon, porous silicon layer and TPD polymer is found to be 9×10^{11}, 9.9×10^{12} and 1.2×10^{14} cm Hz$^{1/2}$ W^{-1}.

The additions of the etching process and TPD polymer to this devise have increased the response time. This means that additions are beneficial for enhancing the devise.

Conclusion

CdS visible photoconductive detector was prepared by chemical method and deposited on silicon and porous silicon. The photoconductive gain has improved by substrate changes from Si to PS, then CdS embedded in TPD polymer highly improved the photoconductive gain from 18 to 80.5. The increase in the sensitivity of PS/CdS and PS/CdS/TPD can be attributed to the improved silicon surface using electrochemical etching to obtain porous silicon, which increases the surface area of silicon; the responsivity was increased from 0.03 to 0.059 for PS/CdS and PS/CdS/TPD photodetector and response time from 5.2 to 1.3 ms.

Table 2 The figure of merit for CdS nanoparticles' photodetector

Composition	Gain	T (ms)	I_n (AMP)	R_λ (AMP/Watt)	NEP (Watt)	D (Watt)$^{-1}$	D^* (cm Hz$^{1/2}$ Watt^{-1})
Si + CdS	18	5.2	1×10^{-10}	0.03	1.04×10^{-12}	9×10^{11}	9×10^{11}
PS + CdS	66	2.1	3.9×10^{-12}	0.04	8.2×10^{-12}	9.9×10^{12}	9.9×10^{12}
PS + CdS + TPD	80.5	1.3	1.1×10^{-14}	0.059	1.2×10^{-14}	1.2×10^{14}	1.2×10^{14}

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