

Fabrication of CdTe/Si heterojunction solar cell

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Abstract A simple cost effective method is preferred to grow nanoparticles of CdTe. Nanoparticles of CdTe are grown by simple chemical reduction route using EDA as capping agent and Sodium Borohydride as reducing agent. The grown nanoparticles are characterized using transmission electron microscopy (TEM), X-ray diffraction, optical absorption, and photoluminescence study. From optical absorption study, the band-gap was found to be 2.46 eV. From TEM study, the average particle size was found to be within 8–12 nm which confirms the formation of CdTe nanoparticles. PL spectra indicate the luminescence from surface states at 2.01 eV, which is less compared to the increased band-gap of 2.46 eV. The grown nanoparticles are used to fabricate a heterojunction of CdTe on P-Si by a spin coating technique for solar cell fabrication in a cost effective way. I–V characteristics of the grown heterojunction in dark as well as under light are measured. Efficiency and fill-factor of the device are estimated.

Keywords Nanostructures · Semiconductors · Chemical synthesis · Transmission electron microscopy (TEM) · Electrical properties

Introduction

Semiconductor nanoparticles, which exhibit properties different from bulk materials, are a new class of materials that hold considerable promise for numerous applications in the field of electronics and photonics. Nanoscale modification of the molecular design and morphology of such particles provides a powerful approach toward control of their electrical and optical properties (Whitesides et al. 2002; Duan et al. 2003; McAlpine et al. 2003; Wang et al. 2007; Mehta et al. 2005; Ernst et al. 2003; Yang et al. 2000; Ehsan et al. 2012; Pinheiro et al. 2006). Among the colloidal nanocrystals, CdTe (generally Gr-II to Gr-VI) is studied because of the efficiency of its synthesis, the high quality of the resulting sample, and the fact that the optical gap lies in the visible range. Also it is an important semiconducting material with unique electrical properties, which makes it a promising material in the field of optoelectronic devices such as light emitting diodes, solar cells, photo detectors, biosensors, etc. (Singh et al. 2003, 2004; Dai et al. 1995; Duan et al. 2001; Holmes et al. 2000; Gates et al. 2001; Martin et al. 1994; Peng et al. 2000; Nicewarner-Pena et al. 2001; Yu et al. 2000). In the present work, a simple chemical reduction method is followed to grow CdTe nanoparticles. In the last few decades, continuously increasing demand of alternative renewable energy sources has stimulated new scientific researches in the field of photovoltaic devices (Alnajjar et al. 2009). The use of silicon (Si) as substrate material has many advantages, it is an obvious goal due to its mechanical strength, low price, and compatibility with standard Si-based device processing (Suela et al. 2010). On the other hand, material-related issues like including thermal expansion mismatch could also have an impact on dislocation densities or other important defects in CdTe/Si composite (Jacobs et al.

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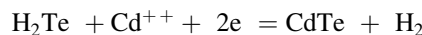
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2008). Solar energy is one particularly relevant application due to the rising monetary and environmental cost of fossil fuels (Garnett et al. 2008). One of the primary barriers to widespread photovoltaic (PV) used, is PV cell production cost, nearly half of which is imbedded in the initial Silicon wafer (Garnett et al. 2008). CdTe has been shown to be the most promising polycrystalline thin film material for producing PV solar cells because of its high absorption coefficient ($\alpha > 10^4 \text{ cm}^{-1}$) and optimum band gap (1.5 eV). Several research works are going on to increase the efficiency of inorganic PV devices. An attempt is made here to fabricate heterojunction solar cells of CdTe nanoparticles, coated on P-Si by a simple spin coating technique (Jacobs et al. 2008; Suela et al. 2010; Garnett et al. 2008).

Experiment

Anhydrous CdCl_2 (molecular weight 201.32 g/mol) (603.96 mg), Tellurium (molecular weight 127.6 g/mole) (382.8 mg) powder and sodium borohydride (molecular weight 37.83 g/mole) (113.49 mg) have been taken to prepare CdTe. Ethylenediamine has been used as a capping agent. Sodium borohydride has been taken to initiate the

reaction at room temperature. The prepared solution is taken in a beaker. The solution is stirred for 3 h at a particular speed (6000 rpm) using a magnetic stirrer. The reactions are as follows.



The transmission electron micrograph of the as-prepared samples has been taken using a JEOL-JEM-200 transmission electron microscope operating at 200 kV. The particle size is found to be within 8–12 nm. The size can be varied by varying the growth temperature (Saha et al. 2013). Optical absorption measurements of the dispersed samples have been studied in the range of 300–700 nm using a Shimadzu Pharmaspec 1700 UV–VIS Spectrophotometer. Photoluminescence study is done in the range of 200–900 nm using Perkin Elmer LS-55 PL spectrometer. The photovoltaic devices in this study comprises of a heterojunction layer of n-CdTe/p-Si(100). p-Si wafer is cleaned using standard RCA process followed by etching in 1 % dilute hydrofluoric acid (HF) solution to

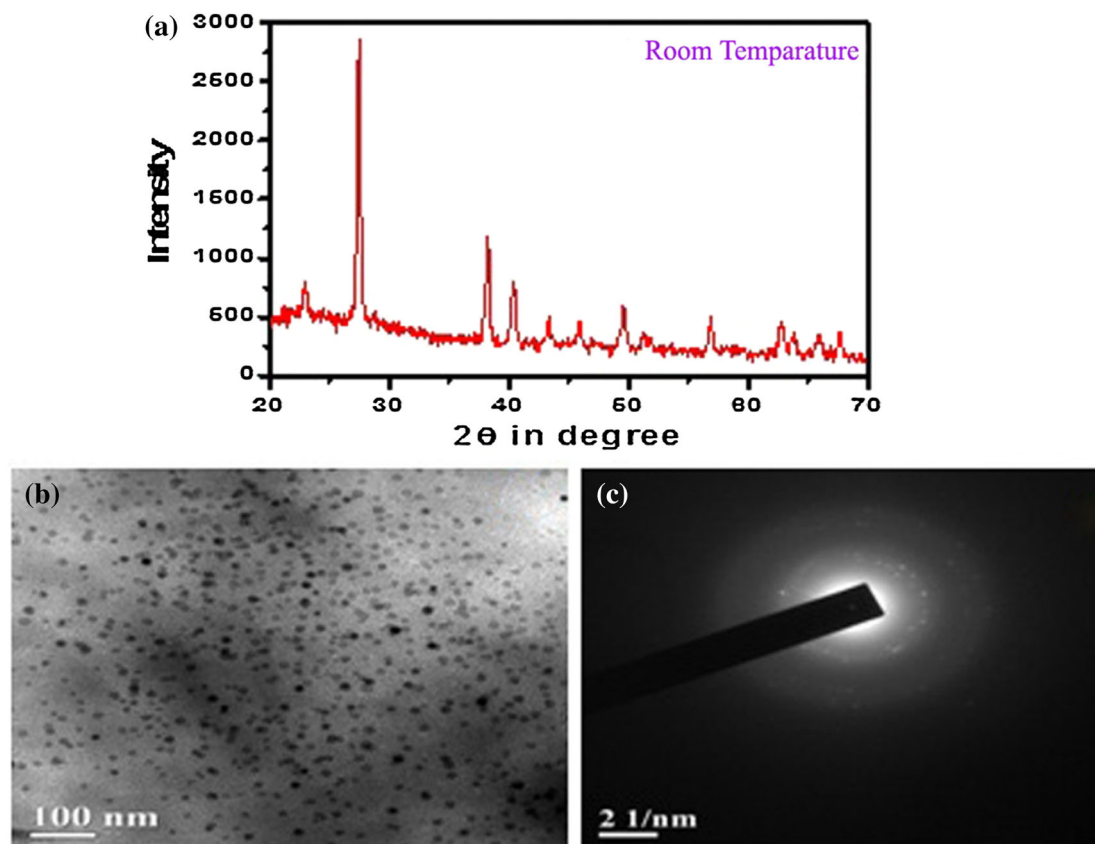


Fig. 1 a XRD pattern of CdTe- nanoparticles, b HRTEM image of CdTe-nanoparticles, c SAED pattern of CdTe nanoparticles

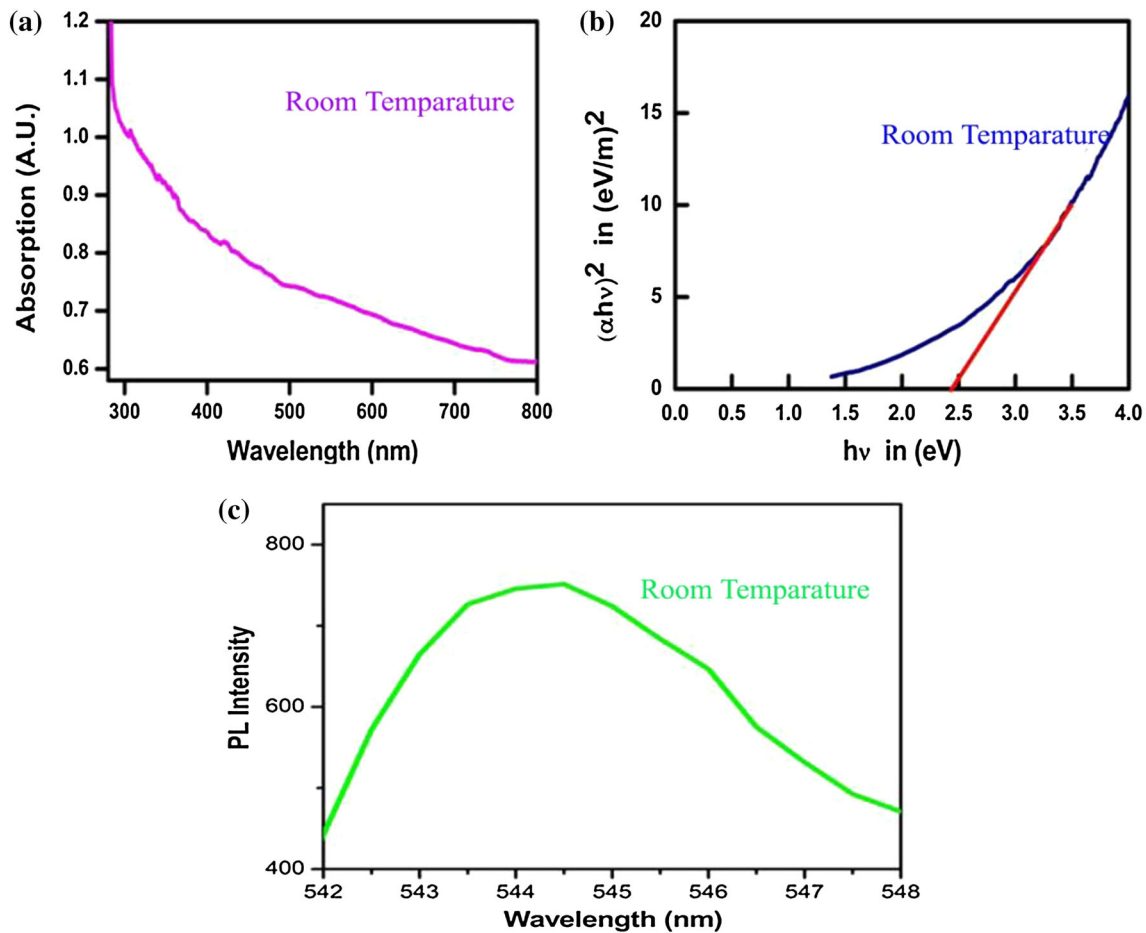


Fig. 2 a Plot of optical absorption with wavelength for CdTe nanoparticles, b Plot of $(\alpha hv)^2$ vs. energy ($h\nu$) to determine band gap, c Plot of photoluminescence intensity vs wavelength for CdTe nanoparticles

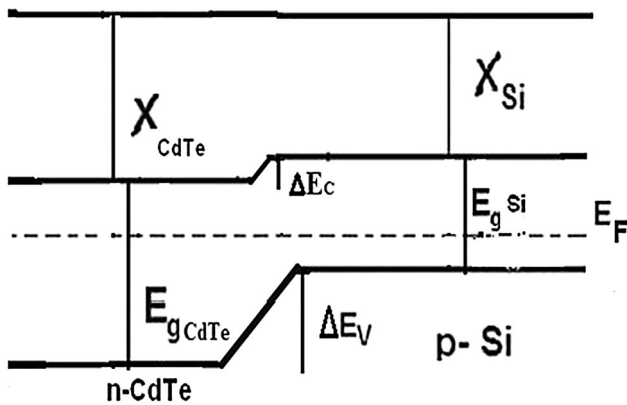


Fig. 3 Energy band diagram for n-CdTe/p-Si(100) heterojunction

remove the native oxide layer. CdTe nanoparticles dispersed in ethanol are slowly injected on to the Si wafer rotating with a constant speed (1500 rpm). A uniform layer of CdTe nanofilm is coated on to P-Si wafer. The thickness of the CdTe layer is measured using

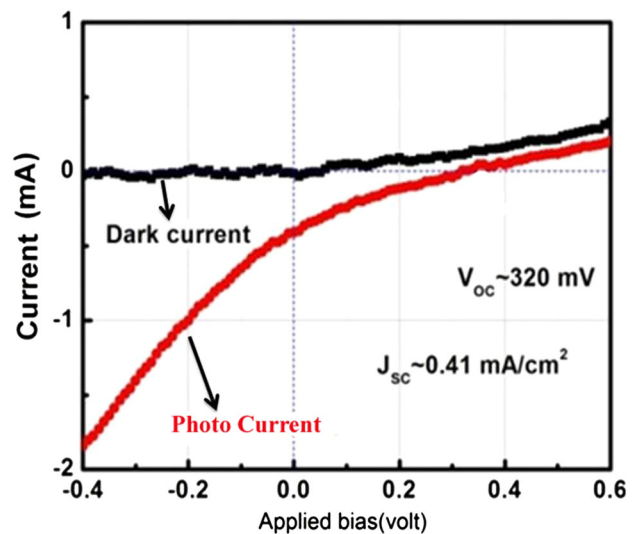


Fig. 4 I–V characteristics of n-CdTe nanoparticles/p-Si(100) heterojunction

Surfometer. The sample is baked for few minutes at 40 °C temperature and the device is formed. Al is deposited by vacuum evaporation on CdTe nanofilm with a contact area of $4 \times 10^{-3} \text{ cm}^2$. Hence the device area is $4 \times 10^{-3} \text{ cm}^2$. Current density–voltage (J – V) characteristics of the devices in dark and under air mass (AM) 1.5 illumination (XES-151S) with a power density of 100 mW/cm^2 were measured using Agilent B1500A semiconductor device analyzer.

Result and discussion

Structural determination using XRD

The powder X-ray diffraction (XRD) pattern of CdTe sample was recorded by a X-ray diffractometer (miniflex II, desktop-X-ray diffractometer) using Cu- $k\alpha$ radiation in the range of Bragg angle (2θ) from 20° to 70° . Figure 1a shows the XRD patterns of the sample. The peaks are identified comparing with ICDD data (Tiwari et al. 2013; Saha et al. 2013). The nanoparticles formed are of CdTe which is confirmed. X-ray diffraction pattern of blackish powder of CdTe nanoparticles, obtained by chemical reduction method, is shown in Fig. 1a. The XRD pattern of nanoparticles matches with JCPDS file No. 75-2083, which again have face centered cubic structure of crystallites with same lattice parameter as estimated for nanoparticles obtained.

Average particle size of crystallites is calculated by Debye Scherer equation.

$$P = k\lambda/(\beta \cos \theta) \quad (1)$$

where k is the shape factor, the dimensionless shape factor has typical value 0.9, λ is the X-ray wavelength 0.154 nm, β is the line broadening at half the maximum intensity (FWHM) in radians, and θ is the Bragg angle; P is the mean size of the ordered (crystalline) domains. Average sizes of crystallite calculated from Debye Scherer equation, is 27.57 nm for CdTe.

Morphological study using TEM

Morphologies of the products synthesized at 300 K are shown in Fig. 1b. HRTEM image shows particles like nano structure of CdTe grown at 300 K. The average particle size estimated from the HRTEM is found to be within 8–12 nm (Saha et al. 2013; Perez-Conde et al. 2001; Milleron et al. 2005; Neretina et al. 2008). SAED pattern is shown in Fig. 1c. Diffraction pattern indicates single crystalline phase is present.

Optical properties of CdTe-nanostructure

The CdTe nanoparticles were dispersed in spectroscopic grade Toluene for optical absorption measurements. Optical properties of CdTe nanoparticles were determined through UV–VIS absorbance spectroscopy. Figure 2a shows the optical absorbance spectra of CdTe samples. Optical absorption coefficient has been calculated in the Wavelength

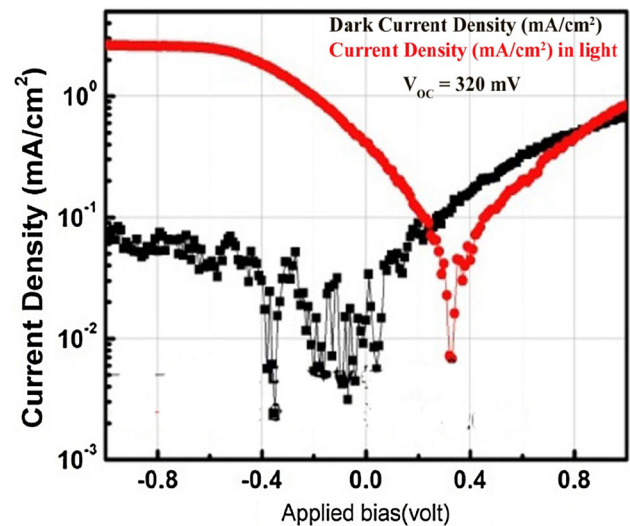


Fig. 5 J – V characteristics of n-CdTe nanoparticles/p-Si(100) heterojunction

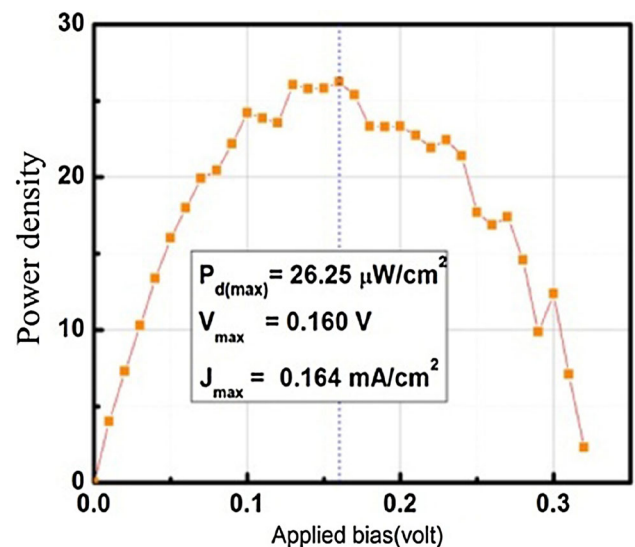


Fig. 6 Variation of power density of n-CdTe nanoparticles/p-Si(100) heterojunction

Table 1 Structural, optical parameters of n-CdTe nanoparticles and electrical parameters of n-CdTe/p-Si heterojunction

Structural and optical results of the CdTe nanoparticles				Electrical results of the n-CdTe/p-Si heterojunction					
Growth temp.	Shape of particles	Average diameter of the particle (nm)	Band Gap (eV)	V_{\max} (V)	J_{\max} (mA/cm ²)	V_{OC} (V)	J_{SC} (mA/cm ²)	Fill factor (%)	Efficiency (%)
300 K	Spherical	10	2.46	0.16	0.164	0.32	0.41	20	0.026

region 300–700 nm. The band gap of the as-prepared nanoparticles is determined from the relation $(\alpha h\nu)^2 = c(h\nu - E_g)$, where c is a constant. E_g is the direct band gap of the material and α is the absorption coefficient. Figure 2b shows the plot of $(\alpha h\nu)^2$ vs. energy ($h\nu$) and the band gap of the sample is found to be 2.46 eV. The band gap is greater than the bulk CdTe (Perez-Conde et al. 2001; Manna et al. 2003; Wuister et al. 2004) band gap. Thus there is a blue shift relative to the peak absorption of bulk CdTe.

Photoluminescence of CdTe-nanostructure

The study of photo luminescence spectra is an effective method that evaluates defect states. The PL spectra of the CdTe nanoparticles were measured with excitation wavelength 360 nm (Fig. 2c). The peak arises at 545 nm due to luminescence from surface states (Saha et al. 2013; Wuister et al. 2003; Mohammed et al. 2013) just below the conduction band.

Behavior of n-CdTe/p-Si Heterojunction

The possible heterostructure of n-CdTe/p-Si are shown in Fig. 3. The conduction band edge and the valence band edge are estimated using the relations $\Delta E_C = \chi_{1CdTe} - \chi_{2Si} = (4.40 - 4.05) = 0.35$ eV while $\Delta E_V = (E_{g(CdTe)} - E_{g(Si)}) - \Delta E_C = 1.36 - 0.35 = 1.01$ eV. The band gap of CdTe nanoparticles is 2.46 eV. When light falls on CdTe, the minority carriers holes are generated on n-CdTe due to transition of electrons from valence band to conduction band. The hole feels the electric field at the junction and constitutes the photocurrent.

The electrical characteristics of the photovoltaic cells were investigated in the dark and light under different bias conditions. The dark I–V and I–V curve under light is measured in forward and reverse directions as shown in Fig. 4. In the forward biasing condition, there is a small shift of the I–V curve under light with respect to the dark. The important solar cell parameters like short circuit current density I_{sc} , open-circuit voltage V_{oc} , and maximum output power (P_m) were determined. During dark I–V measurements, a light-proof cover shields the cell under test. The devices exhibit conventional rectifying diode characteristics as expected from any heterojunction devices. J–V characteristics under AM 1.5 (100 mW/cm²) solar

irradiation conditions of the same devices are displayed in Fig. 5. Figure 6 shows a variation of power density of n-CdTe nanoparticles/p-Si(100) heterojunction structure. A maximum, 0.026 % power conversion efficiency is achieved for the cell having 50 nm layer of the device was measured using the relations:

$$FF = (I_m \times V_m) / (I_{SC} \times V_{OC}) \text{ and } \eta = (V_{OC} \times I_{SC} \times FF) / P_{in}$$

where V_{oc} is the open-circuit voltage, I_{sc} is the short circuit current, FF is the fill factor, η is the power conversion efficiency and P_{in} is the incident light power density, I_m and V_m are the current and voltage at the maximum power point. The lower efficiency is probably due to the loss of carriers due to recombination within CdTe layer (Mohammad et al. 2012; Romeo et al. 2004; Bonnet et al. 2002; Romeo et al. 1998). This is possibly due to surface states which are present in the nanostructured CdTe film. The different parameters extracted from the device are shown in the Table 1.

Conclusions

The nanoparticles are grown at room temperature in a cost effective way. The chemical reduction route is a simple cost effective way to grow nanoparticles of CdTe compared to other conventional method of growing nanocrystals of CdTe. The grown nanoparticles are characterized structurally and optically. The nanofilm of CdTe is grown on P-Si by using nanoparticles applying a simple technique, i.e. a spin coater. The fabricated heterojunction shows photovoltaic effect. The small photovoltaic properties are largely due to the lattice mismatch which is responsible for structural defects that reduce device performance.

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