I-V characteristics and Room Temperature Hall Measurement of CdTe Nano-rods Synthesized by Hydrothermal Method

Meera Ramachandra Gumaste1  Gururaj Anand Kulkarni2  and  K N Anuradha3

1 Department of Physics,  Dayanandasagar College of Engineering, Bangalore, India
2 Department of Physics,  UBDT College of Engineering, Davangere, India
3 Department of Physics,  Dr. Ambedkar Institute of Technology, Bangalore, India

Abstract. CdTe Nano-rods have been synthesized using Hydrothermal method. For the confirmation of formation of CdTe in nano metric dimension XRD technique is employed. The diameter of CdTe nano-rods is calculated to be 35.04 nm. SEM image reveals that nano CdTe possess rod shaped morphology. The compositional data is collected with EDAX spectra. Successful capping of thioglycolic acid (TGA) on the surface of CdTe nano-rods is well endorsed by FTIR spectroscopy technique. Band gap is calculated to be 1.65 eV from UV-Visible absorption spectra. I-V characteristics of the CdTe nano-rods showed a linear symmetrical variation at room temperature. This was due to the high crystallinity and homogeneous powder sample of CdTe nano-rods. The higher value of mobility of the order of 1.1264 X 10^3 cm²/V-s of the as synthesized CdTe nano-rods reveals moderate grain boundaries and less structural defects. Hence compared to bulk CdTe, nano-structured CdTe materials are more ordered in structure and hence improved crystallinity. Room temperature Hall measurement employing Van Der Pauw method indicates high resistivity of the order of 10^7 Ω cm and the as synthesized nano-rods are of p-type material.

1. Introduction

Research interest in the low dimensional semiconducting materials has increased enormously due to their interesting physical and chemical properties and hence their behavior in different ambient conditions. One such novel invention in the past two decades in the field of nanomaterials has set a landmark to the looming smart nano devices [1]. Progressively researchers started working on semiconductor nanoparticles. Semiconductor nano-crystals whose radii are smaller than the bulk exciton Bohr radius constitute a class of materials intermediate between molecular and bulk forms of matter [2]. Due to quantum confinement [3] these materials possess fascinating properties such as size dependent tunable emission, narrow emission band width, broad excitation, strong absorption abilities and good photo stability [4]. CdTe is one of such materials which has special technological importance because it is the known II-VI compound semiconductor that can form conventional p-n junctions [5]. CdTe is successful contender to Si due to its vital material properties such as long term efficient performance, good absorbance property and direct band gap [6]. CdTe offers possibility of studying quantum confinement in higher cluster size regimes [7]. Among the colloidal nano-crystals CdTe is studied because of the efficiency of synthesis, high quality resulting samples and the fact that the optical band gap lies in the visible range [8]. The direct band gap of 1.44 eV (bulk) at room temperature and high optical absorption coefficient in the visible spectrum makes CdTe an ideal material for photovoltaic applications [9]. CdTe nanoparticles can find applications in solid state lighting, displays, optical communication sensors as well as in biological imaging and detection [10]. CdTe when alloyed with Zn in suitable proportion, Cd_{1-x}ZnxTe...
ternary compound provides exciting research opportunities in the field of x-ray, gamma ray detectors, electro-optic modulators and laser windows [11].

A broad study [12] of a simple, but versatile solution-based method for synthesizing different shapes and morphologies of high-quality CdTe nano-crystals has been studied by researchers. Thus, quasi-spherical particles, nano-rods, and nanowires were obtained by changing the solvent composition, while keeping the principal reagents and reaction conditions otherwise fixed [12]. For the applications such as glucose sensor, detection of Cd$^{2+}$ ion in solutions, biological labels CdTe nano-structures have been widely studied and appreciated [13-15]. Wang Meiping et.al. have synthesized TGA capped CdTe nano-crystals and studied effects of reaction time, pH values and precursor concentration on the photoluminescence (PL) properties [15]. Thus it is comprehended from the literature that electrical properties of the CdTe nano-structures is less focused. Furthermore to study the application of CdTe nano-structures as an electronic device, study of electrical parameters which is an essential for device fabrication, still lags behind. In that direction the present work emphases on the study of I-V characteristics of CdTe nano-rods and calculation of electrical parameters of CdTe nano-rods using Hall measurement.

2. Experimental Details

2.1. Synthesis of CdTe Nano-rods by Hydrothermal method

Cadmium Chloride (CdCl$_2$, 0.04M/4mL), Sodium Tellurite (Na$_2$TeO$_3$, 0.01M/4mL), Sodium Borohydride (NaBH$_4$, 50mg), Trisodium Citrate Dihydrate (100mg) and TGA (0.01M) were used as starting materials for the synthesis of CdTe nano-rods by Hydrothermal method as published elsewhere [16]. All materials were of analytical grade and purchased from Sigma Aldrich. During the synthesis the molar ratio of Cd:Te is maintained to be 1:0.25. Initially, 4 mL of 0.04M CdCl$_2$ is added to 36 mL of dI water. This is kept under magnetic stirring at RT. Then 4 mL of 0.01 M Na$_2$TeO$_3$ is added to solution under stirring, followed by addition of 100 mg of Trisodium Citrate Dihydrate and 50 mg of Sodium Borohydride (NaBH$_4$) and 33 µl of TGA. Then the entire precursor solution of CdTe is prepared. This CdTe precursor is continued to stir magnetically for 30 mins at room temperature. After 30 minutes the precursor solution is transferred into a Teflon coated 50 ml autoclave. Later the autoclave is kept in a muffle furnace at 180$^\circ$C for 90 minutes. After 90 minutes the furnace is turned off and the autoclave is left in the furnace to cool to room temperature. The solution containing CdTe nano-rods is then washed with methanol and dI water several times and centrifuged at 3000 rpm. Afterwards the solution is dried in hot air oven at 60$^\circ$C for 1 hr. Finally black precipitates of CdTe nano-rods are obtained.

2.2. Characterizations

CdTe nano-rods synthesized by hydrothermal method are sequentially subjected to different characterization techniques. The Powder X-ray Diffractometer (P-XRD) characterization was done on Rigaku with X-rays of energy 40kV and 30mA. The continuous scan rate was 3$^\circ$/ minute for the entire X-ray scanning running through 10$^\circ$ to 80$^\circ$ scan range. CdTe nano-rods are subjected to Scanning Electron Microscope (SEM) characterization to study structural and morphological aspects. Energy Dispersive X-ray Analysis (EDAX) is run through the samples for compositional study of the as synthesized nano-rods. The Varian Cary Eclipse Fluorescence Spectrophotometer with UV-Visible spectral range and Xenon flash lamp technology with room light immunity and high sensitivity was used for Fourier Transform Infar-Red (FTIR) Spectroscopic analysis to confirm the successful capping of TGA on CdTe nano-rods. The spectra was recorded over 400-4000 cm$^{-1}$ range with a resolution of 4 cm$^{-1}$. Band gap is determined using Perkin Elemer UV-Visible Spectrometer by recording the absorption data from 200 nm to 800 nm wavelength range. Electrical characterization is performed to study I-V characteristics of the as synthesized nano-rods using DC probe station PM5, Agilent Device Analyzer B 1500 A. The
measurement was carried out at 0.1 fA / 0.5 microvolts resolution. Van Der Pauw (VDP) Hall measurement at room temperature (RT) is also used as electrical characterization for the CdTe nano-rods to calculate basic electrical parameters. Four probe method is used for the Hall measurement.

3. Results and Discussions

3.1 P-XRD Study:

The P-XRD pattern shown in figure 1. is obtained for the CdTe nano-rods. The obtained data is compared with JCPDS 75-2086 data card. The average diameter of nano-rods is calculated to be 35.04 nm using relation (1) Scherer formula [17] as below.

\[ D = \frac{K \lambda}{\beta \cos(\theta)} \]  

where \( \beta \) is full width at half maximum, \( \lambda \) is the wavelength of X-rays, \( \theta \) is the angle of diffraction and \( K \) is the Scherrer constant of the order of unity. The CdTe nano-rods are crystallized in to cubic zinc blende structure [18]. The sharp and well defined peaks shows that the CdTe nano-rods are highly crystalline.

![Figure1. P-XRD pattern for CdTe Nano-rods](image)

Lattice constant ‘a’ is calculated using the relation (2) and it is observed in table 1 that ‘a’ is almost constant for all the indexed peaks.

\[ a = d \sqrt{h^2 + k^2 + l^2} \]  

The peaks corresponding to 2θ equal to 38.253 and 40.4087 are akin to Te (102) and Te (110) phases respectively. These may be due to unreacted Te precipitate in the sample.
Table. 1 d and a values for the indexed (hkl) values of CdTe Nano-rods calculated from XRD data

| Position of peak (2θ) | Interplanar Spacing d (Å) | Miller Indices (hkl) | Lattice Constant (a) in Å |
|-----------------------|---------------------------|----------------------|---------------------------|
| 27.547                | 3.2352                    | 200                  | 6.47                      |
| 46.955                | 1.9334                    | 311                  | 6.41                      |
| 56.878                | 1.6174                    | 400                  | 6.46                      |
| 62.793                | 1.4785                    | 331                  | 6.44                      |

3.2. SEM with EDAX study

The morphology of the CdTe nano-rods is studied with SEM characterization shown in figure 2. It can be seen from the SEM image that CdTe possess rod shaped morphology whose diameter is calculated using XRD data. The compositional data is collected with EDAX spectra shown in figure 3. In the EDAX spectra along with Cd and Te, Sulphur is included. This arose due to organic ligand TGA on the surface of the CdTe nano-rods [19]. Table 2 provides the % composition of the elements Cd, Te and S present in the CdTe nano-rods.

![Figure 2. SEM image of CdTe Nano-rods](image2.png)

![Figure 3. EDAX spectra of CdTe Nano-rods](image3.png)

Table 2. EDAX analysis of compositional data of CdTe Nano-rods

| Element | Weight % | Atomic % | Net Int. | Error % | Kratio |
|---------|----------|----------|----------|---------|--------|
| S K     | 16.55    | 42.15    | 199.99   | 6.39    | 0.1342 |
| CdL     | 51.24    | 37.23    | 292.25   | 4.45    | 0.4641 |
| TeL     | 32.21    | 20.62    | 105.82   | 11.66   | 0.2209 |

3.3. FTIR Analysis

FTIR spectra for CdTe nano-rods is shown in figure 4. The absence of peak near 2400 cm⁻¹ confirms the covalent bonding between TGA and CdTe nano-rods. The dominant peak at 3318.75 cm⁻¹ is
assigned to -OH stretching of carboxylic group. Another major peak at 1632.45 cm$^{-1}$ indicates stretching vibration of CH$_2$. All other peaks between 500-400 cm$^{-1}$ indicates COOH group [20]. So it is concluded that TGA has been effectively capped on the surface of CdTe nano-rods.

![Figure 4. FTIR spectra of CdTe Nano-rods](image)

### 3.4. UV-Visible Spectra for Band Gap (BG) Determination

From the UV-Visible spectra in figure 5, it is observed that absorption peak occurs at 308 nm.

![Figure 5. UV-Visible absorption spectra of CdTe Nano-rods](image)
The plot (figure 6.) of \((\alpha h^\frac{1}{2}) \text{Vs} \ (h\sqrt{\text{v}})\) is used to determine BG of the CdTe nano-rods. Bulk CdTe semiconductor has band gap of 1.44 eV. Since it is a direct BG semiconductor, for nano structures the band gap is determined by extrapolation on the ‘h\sqrt{\text{v}}’ axis and it is found to be 1.65 eV. Hence this indicates the light harvesting property of the as synthesized CdTe nano-rods in solar cell applications [18].

![Figure 6. Band gap determination of CdTe Nano-rods](image)

3.5. Room Temperature I-V Characteristics of CdTe Nano-rods

From the analysis of UV absorption spectra it depicts that the BG of CdTe nano-rods is about 1.65 eV, which is wide BG and it moves towards the semi-insulating behavior at RT compared to bulk CdTe. This makes it difficult to establish the ohmic contact to the wide band gap semiconducting materials. However the ohmic contact has been established using silver paste by making four point contacts as it was a four probe measurement system. For this purpose the powder sample was made in to pellet of thickness 0.07 cm and 0.7 cm² area. The room temperature I-V characteristics is plotted in figure 7.
The applied DC voltage is varied from 0V to 1V in a step of 0.01V. The variation of current is almost linear with respect to applied voltage, which is behavior of forward biased semiconducting material at room temperature similar to bulk material. However the magnitude of current is very small which can be increased by suitable metal doping. Here it is remarkable to mention that the earlier studies on electrical measurements are sparse because of difficulty in establishing the ohmic contact [21]. However this work demonstrates establishing the ohmic contact to make room temperature electrical measurements.

### 3.6. Hall Measurement Using Van Der Pauw method

For any device fabrication it is important to diagnose the basic material parameters. One such material parameter is electrical parameter. To study the electrical parameters, Hall measurement using Van Der Pauw method is one of the best tools that one can apply. The VDP method can be used to measure samples of arbitrary shape, provided the material is homogeneous and the material for which small point contacts at the edge of the sample can be made [22]. Till today it has been emphasized on VDP method only for bulk materials and thin films. This report is the first of its kind to discuss about the Hall measurement of CdTe nano-rods. Using VDP some basic electrical parameters of CdTe nano-rods at room temperature have been calculated. The electrical parameters under study include resistivity, conductivity, sheet resistance, mobility and carrier concentration of CdTe nano-rods. Also room temperature Hall measurement is done for the pure CdTe nanoparticles.

Magnetic field of 0.25 T and an electric current of 30µA was fixed through the sample throughout the experiment. By applying the theory behind VDP method [23] below shown table 3, gives the calculated values of some electrical parameters.
Table 3. Calculated values of electrical parameters using VDP Method

| Electrical Parameter     | Calculated Value          |
|-------------------------|---------------------------|
| Sheet Resistance        | 24.907 KΩ                |
| Sheet Carrier Density   | 2.227 X 10^9 / cm^3       |
| Carrier Concentration   | 3.1824 X 10^{10} / cm^3  |
| Resistivity             | 1.7444 X 10^7 Ω-cm       |
| Conductivity            | 5.7324 X 10^{-6} Ω-cm    |
| Hall Coefficient        | 1.965 X 10^{10} cm^2/V-C |
| Mobility                | 1.1264 X 10^3 cm^2/V-s   |

From the above tabulated value of conductivity it is clear that the CdTe nano-rods have less conductivity at room temperature which is the characteristics of the wide band gap semiconducting materials. The synthesized nano-rods have high resistivity of the order of 10^7 Ω cm as it can be seen in CdTe thin films [10^4 to 10^6 Ω cm]. The higher value of resistivity can be ascribed to higher crystallinity of the as synthesized CdTe nano-rods [9]. This crystallinity can be underlined in I-V characteristics of CdTe nano-rods, which portrays that the prepared powder sample is homogeneous as well. For CdTe thin films of thickness 0.6 µm [24] the mobility obtained is about 1.507 X 10^2 cm^2/V-s which possessed spherical morphology and 200 nm 300 nm grain size. Whereas in the present work the mobility is 1.1264 X 10^3 cm^2/V-s for CdTe nano-rods of diameter 35.04 nm. Hence at this point it can be noticed that along with the size or thickness of the material, it is the morphology of the nano structures which influences the mobility of charge carriers. Higher mobility of CdTe nano-rods can be attributed to reduced grain boundaries and less structural defects thus avoiding or minimizing scattering of charge carriers [25]. At the same time presence of moderate grain boundaries and less structural defects can be noticed in the smaller value of carrier density of the order of 10^9/cm^3. Here it is worth to mention that the hydrothermal synthesis of CdTe nano-rods is very effective to reduce of grain boundaries and structural defects. This brings to the conclusion that compared to bulk CdTe, nano-structured CdTe materials are more ordered in structure and hence improved crystallinity. From the polarity of Hall coefficient it is also concluded that the synthesized CdTe nano-rods are of p-type. The higher resistivity and p-type material of as synthesized CdTe nano-rods makes them suitable for x-ray and gamma ray detectors if suitable contacts are established [26].

4. Conclusion

The process for the synthesis of CdTe nano-rods employed was simple, low cost and less toxic, hydrothermal method. XRD pattern showed the well-defined peaks which enlightens the higher crystallinity of CdTe nano-rods. The optical band gap of about 1.65 eV of CdTe nano-rods makes them to exhibit semi-insulating behavior at room temperature. Four point ohmic contact has been established on the pellets of the CdTe nano-rods for these electrical characterizations at room temperature. The I-V characteristics of the CdTe nano-rods indicated a linear symmetrical variation at room temperature. This was due to the highly crystalline and homogeneous nature of powder sample of CdTe nano-rods which is well observed by the XRD pattern. The magnitude of current through the CdTe nano-rods can be enhanced with suitable metal doping. This fascinating electrical property makes these materials suitable for device applications such as diode. The study of mobility emphasises that not only size of the particles but also it is the morphology of the particles which influence the carrier mobility in CdTe nano structures. The synthesized CdTe nano-rods have moderate grain boundaries and less structural defects which is witnessed
by the higher mobility value calculated. The resistivity calculated, illustrates the high crystallinity of the CdTe nano-rods which supports the semi-insulating behavior at room temperature. The Hall coefficient shows that the synthesized CdTe nano-rods are of p-type material. This property makes these materials suitable for x-ray and gamma ray detectors.

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