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# Growth of CdS Nanoparticles to Fabricate Schottky Barrier

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***Authors' contributions***

*This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

CdS nanoparticles have been grown by a simple cost effective chemical reduction method and a Schottky barrier of gold/ nano CdS is fabricated. The grown nanoparticles are structurally characterized by transmission electron microscopy and x ray diffraction. The optical properties of nano CdS is characterized by optical absorption, photoluminescence study. The band gap of the CdS nanoparticles is increased as compared to CdS bulk form. Capacitance–voltage and current–voltage characteristics of gold / nano CdS Schottky barrier junction have been studied. It is found that these characteristics are influenced by surface or interface traps. The values of barrier height, ideality factor, donor concentration and series resistance are obtained from the reverse bias capacitance–voltage measurements.

*Keywords: CdS nanoparticles; structural properties; optical properties; Au/n-CdS schottky barrier.*

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## 1. INTRODUCTION

Semiconductor nanoparticles are promising material in electrical and optoelectronic devices. Properties of nanostructures such as structural, electrical, optical etc. are different from their bulk form due to mainly quantum confinement effect and surface to volume ratio [1-3]. Cadmium Sulphide a group II - group VI semiconductor having characteristic band gap 2.42 eV in bulk form has been used in different optoelectronic devices e.g. Solar cell, LED, Laser etc. [4-7]. CdS nanostructures based hetero junctions, Schottky barriers are important for application in such devices [8-10]. The Schottky barriers of CdS with different metals have been studied by researchers [11-13]. The electrical properties of Schottky devices are affected by metal semiconductor interface or surface properties of semiconductors [14]. Proper modification of surface states of semiconducting nanoparticles is still a challenge for researchers. In this work an effort has been made to grow CdS nanoparticles by a very cost effective and controlled way. The effect of nanoparticles surface on the formation of barrier is investigated to modify the Schottky device based on CdS nanoparticles. There are various physical and chemical methods to prepare CdS nanostructures [15-18]. We have followed a simple chemical reduction method to grow CdS nanoparticles which is cost effective also [19].

In this work CdS nanoparticles are prepared by a reliable low cost method to fabricate Schottky barrier with gold. The surface of the nanoparticles is modified by controlling the growth condition. The technique for preparation of nano CdS film on ITO coated glass is also cost effective. The structural and optical properties of synthesized CdS nanoparticles are characterized. The electrical properties of Au/n-CdS Schottky junction have been studied by current-voltage and capacitance – voltage measurements. The values of barrier height, ideality factor, and donor concentration are obtained by experiment results.

## 2. EXPERIMENTAL DETAILS

The CdS nanoparticles are synthesized by a chemical reduction method at room temperature. Cadmium chloride, sulphur powder and sodium borohydride are used to grow CdS nanoparticles. The structure of grown nanoparticles are characterized Transmission Electron Microscope JEOL JEM200 at 200 kV. Optical absorption of the grown nanoparticles is performed by Shimadzu-Pharmaspec-1700 visible and ultraviolet spectrophotometer. Photolumine-scence spectra of sample are observed by Perkin Elmer spectrophotometer. The procedure to grow CdS nanoparticles, structural, optical characterization of as prepared CdS nanoparticles is described elsewhere [19,20].

To fabricate Schottky junction a film of the CdS nanoparticles has been grown from the dispersed CdS nanoparticles on ITO coated glass. The pre-cleaned ITO coated glass substrate has been dipped in to the dispersed solution of CdS nanoparticles at least for 6 hrs. Uniformly thin film of CdS nanoparticles has been deposited on the glass substrate. Schottky junction is fabricated by evaporating gold (Au) dots of 2 mm diameter through a mask on CdS film. Fig. 1 shows the schematic diagram of fabricated Schottky barrier.

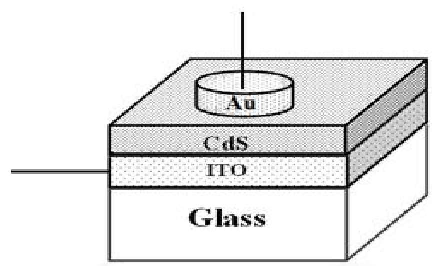


**Fig. 1. Schematic diagram of fabricated Au/nanoCdS Schottky device**

Current-voltage and capacitance-voltage measurements of Au/n-CdS Schottky junction are performed using HP4284A LCR meter and Keithley electrometer.

## 3. RESULTS AND DISCUSSION

The TEM image and corresponding selected area electron diffraction (SAD) pattern of grown CdS nanoparticles is shown in Fig. 2. The TEM image confirms that CdS nanoparticles are formed and agglomerated. The size of the as prepared nanoparticles is of the order of 11-14 nm. Patel et al prepared CdS nanoparticles of size 12 nm [14]. The SAD pattern displays the presence of diffraction rings which corresponds to the hexagonal wurtzite crystal phase of CdS.

Fig. 3 shows the x ray diffraction (XRD) pattern of the as prepared sample. The XRD pattern shows that synthesized nano CdS sample has hexagonal wurtzite structure [20].The prominent peaks shown in the XRD pattern are indexed with respective planes.

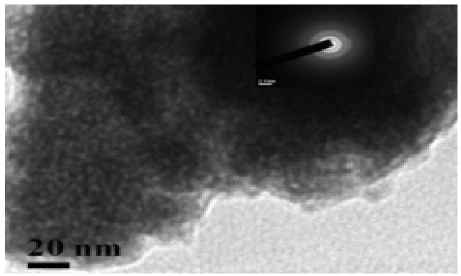


**Fig. 2. TEM image and SAD pattern (inset) of as synthesized CdS nanoparticles**

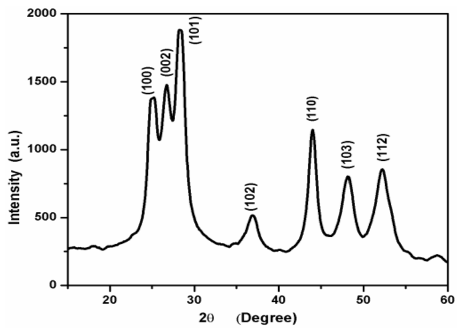


**Fig. 3. The XRD pattern of the as grown CdS nanoparticles**

The variation of optical absorbance of CdS nanoparticles with wavelength is shown in Fig. 4.

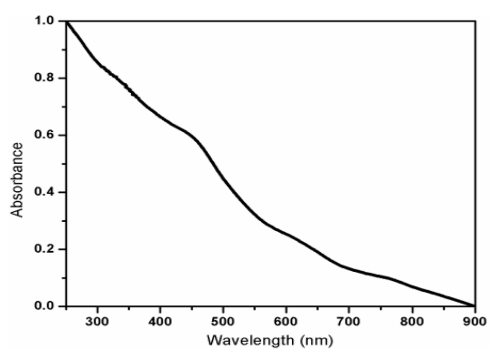


**Fig. 4. The optical absorption spectrum of as prepared sample**

The absorption spectrum is normalized. The band gap of the as-prepared nanoparticles is determined from the Tauc relation [21]

$$(\alpha h\nu)^2 = C\,(h\nu - E_g) \quad (1)$$

Where C is a constant, $E_g$ is the band gap of the semiconductor material and α is the absorption coefficient. Band gap of the CdS nanoparticles is calculated from $(\alpha h\nu)^2$ vs. $h\nu$ plot which is given in Fig. 5. The linear part of the curve is extrapolated to energy (hv) axis to determine band gap. The band gap is found to be 2.97 eV. Patidar et al. [16] obtained band gap of CdS nanoparticles on the order of 2.47-3.12 eV.

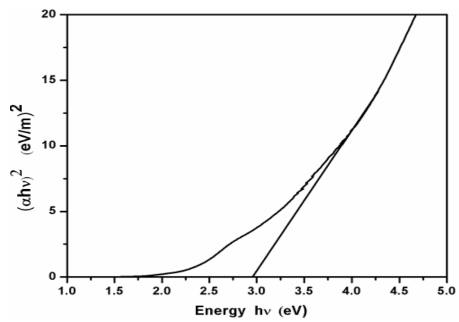


**Fig. 5. The band gap determination curve for as prepared sample**

The photoluminescence spectrum of as-prepared CdS sample is displayed in Fig. 6.

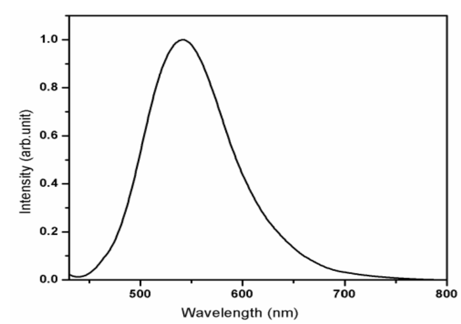


**Fig. 6. The photoluminescence spectrum of as prepared sample**

The photoluminescence intensity is normalized. Photoluminescence spectrum displays peak around 542 nm due to presence of surface states [22]. Wang et al. [19] observed photoluminescence peak of CdS nanoparticles at 560 nm.

### 3.1 Capacitance(C) –Voltage (V) Measurement

The C-V measurement of Au/n-CdS Schottky junction with reverse and forward biasing voltages at temperature 303 K is shown in Fig. 7.

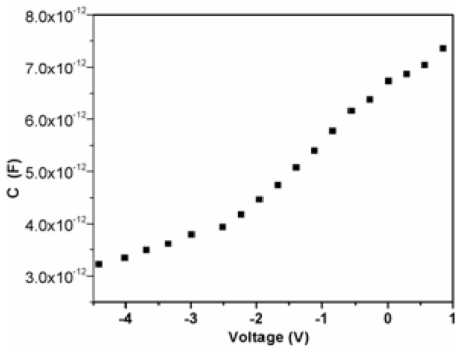


**Fig. 7. The C-V characteristics of Au /nano CdS Schottky junction**

The $1/C^2$ vs. V plot is given in Fig. 8. The carrier concentration, built-in-voltage is determined from the slope [23] and the intercept on the V axis of $1/C^2$ vs. V plot using the Mott-Schottky relation (2)

$$C^{-2} = \frac{2(V_b + V)}{q\varepsilon\varepsilon_\circ A^2 N_d} \quad (2)$$

where $N_d$ is the donor concentration, $V_b$ is the built-in potential, q is the electronic charge, $\varepsilon_0$ is the permittivity of free space, ε is the dielectric constant of the semiconductor. W is the width of the depletion region. A is the area of the device. In Mott-Schottky relation it is assumed that surface or interface traps are absent, no interfacial layer is present between metal and semiconductor [14].

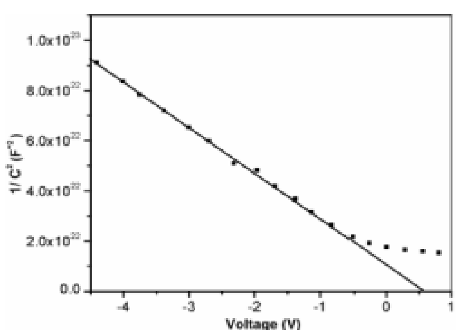


**Fig. 8. Reverse bias $1/C^2$vs V characteristics of Au/n-CdS Schottky barrier**

The obtained values of $N_d$ and $V_b$ are given in Table 1. The value of barrier height $\varphi_b$ is calculated by the following relation

$$\Phi_b = V_b \ \ + V_p \quad (3)$$

Where $V_p$ is the potential difference between the Fermi level and the top of the valance band in CdS. $V_p$ is calculated by knowing the donar concentration $N_d$ and value of $N_d$ is obtained from the following relation

$$V_p = KT\ ln\ (N_c / N_d) \quad (4)$$

**Table 1. Different parameters of Au/n-CdS Schottky junction at temperature 303K**

| $V_b$ (V) | $N_d$ ($cm^{-3}$) | Φ (eV) | η |
|---|---|---|---|
| **0.56** | $5.41 \times 10^{15}$ | 0.80 | 2.19 |

Where $N_c$= $1.5X10^{20}$ $cm^{-3}$ is the density of states in the conduction band for CdS [13]. The calculated barrier height value for the Au/n-CdS Schottky junction is given in Table 1. Farag et al. [13] obtained barrier height 0.76-0.86 eV. Patel et al. [14] obtained barrier height of 0.82 eV. It is seen from the result that C-V characteristics of Au/n-CdS Schottky junction is influenced by surface traps [24,25].

## 3.2 Current (I)–voltage (V) Characteristics

The I-V characteristics of the Au/n-CdS device under forward and reverse biasing conditions at 303K is shown in Fig. 9.

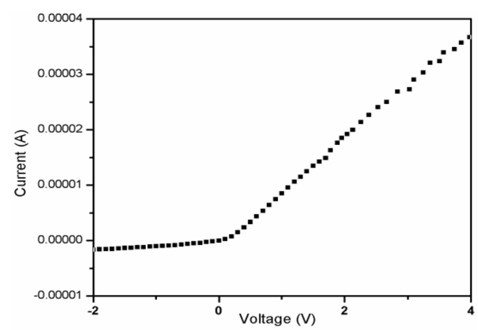


**Fig. 9. The I-V characteristics of the Au/n-CdS device in forward and reverse biasing condition**

The electron affinity of n-type CdS is 4.8 eV [26] while the work function of gold (Au) is about 5.25 eV [27]. So a Schottky barrier should be formed at the contact interfaces of Au/n-CdS. For a metal semiconductor Schottky barrier diode assuming thermionic emission to be the dominant transport mechanism the relationship between current and voltage is given by

$$I=I_s\ [exp(qV/\eta kT)-1] \quad (5)$$

Where $I_s$ is saturation current, $V$ is applied voltage, $\eta$ is the ideality factor, $k$ is the Boltzmann constant, $T$ is the absolute temperature in Kelvin. $I_s$ is described as

$$I_s=AA^*T^2 exp(-q\Phi/kT) \quad (6)$$

Where A is the area of device, A* is the modified Richardson constant and Φ is the effective barrier height from metal to semiconductor.

The saturation current is determined from a plot of ln(I) vs voltage (V), where $I_s$ is obtained as the intercept of the linear region of the ln(I) vs V curve extrapolated to zero voltage. Fig. 10 shows the current voltage characteristics ln(I) vs V plot. The saturation current is evaluated $1.42\times10^{-7}$A.

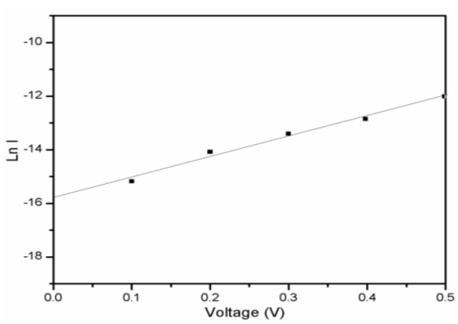


**Fig. 10. Current-voltage characteristics of the Au/nano-CdS Schottky barrier plotted as ln (I) – V**

Taking into consideration of series resistance $R_s$ the equation can be expressed as

$$I=I_s[exp(q(V-IR_s)/\eta kT)-1] \quad (7)$$

The equation can be differentiated as [28]

$$dV/d(lnI)= IR_s +\eta kT/q \quad (8)$$

The plot associated with Eq. (8) *dV/d(lnI)* vs I is given in Fig. 11.

The series resistance $R_s$ is calculated from the slope of *dV/d(ln I)* versus *I* characteristic according to equation (7) [29]. The series resistance $R_s$ here includes the contact resistance. While $\eta$ is evaluated from the *dV/d(lnI)* axis intercept of the line fit shown in Fig. 9. The series resistance is found to be 8.27 kΩ. The ideality factor in the room temperature is listed in Table 1.

The obtained high series resistance of the Au/n-CdS Schottky device may be attributed to the high resistance of the starting CdS material or to the interfacial layer created between the metal and CdS [4]. The ideality factor is determined to be 2.19. Which is greater than typical value between1 to 2 [30]. But the value of ideality factor greater than 2 is also possible [31]. Patel et al found ideality factor of Au/n CdS Schottky barrier 1.8, 6.0 [14]. Ideality factor greater than 2 has been obtained with Schottky devices made of nanostructures. An oxide layer may be present between semiconductor and metal [32]. The high value of η may be due to large recombination within the interfacial layer [15,33] which exists mainly in the semiconductor side.

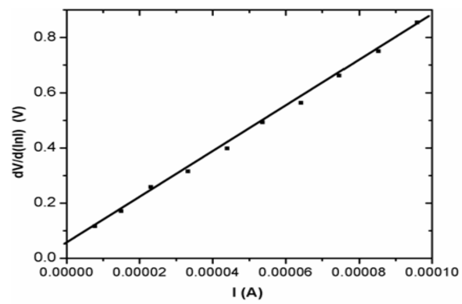


**Fig. 11. dV/d (lnI) versus I plot for Au/n-CdS device**

## 4. CONCLUSION

CdS nanoparticles are synthesized by a cost effective chemical method. The structural and optical characterizations of the synthesized CdS nanoparticles have been performed. We have also fabricated Au/ n- CdS Schottky junction with the grown CdS nanoparticles. The C-V and I-V characteristics of the Au/n-CdS Schottky junction have been studied. The values of built in potential, saturation current, barrier height, ideality factor, series resistance, the density of interface states have been calculated. It is found that the I-V and C-V characteristics of the Au/n-CdS Schottky junction are influenced by the surface states or interface traps.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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