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Deposition of CdS Thin Film by Thermal Evaporation

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***Abstract*—The CdS thin film is widely used for numerous applications such as in optoelectronic devices, solar cells, LEDs, photonics devices etc. The ultra-thin CdS layer is commonly used as by layer or as window layer for CdTe, CIS, CIGS, CZTS thin-film solar cells. The CdS has high bandgap of 2.42 eV and transparent after 510 nm wavelength. The excellent optoelectronics properties of CdS material are very attractive as hetero-junction partner (n-type) in thin-film solar cells. There are several fabrication techniques used to deposit thin CdS layer such as Screen Printing, Thermal Evaporation (TE), Molecular Beam Epitaxy (MBE), Chemical Vapour Deposition (CVD), Pulsed Laser Deposition (PLD), Sol-Gel, Spray Pyrolysis, Electrochemical Deposition, Close Space Sublimation (CSS), Sputtering, Chemical Bath Deposition (CBD) etc. Among them TE is low cost, faster and the complete set-up is ready to be used in the Lab. In this work, the CdS thin films were grown on borosilicate glass substrate by thermal evaporation techniques using VCM 600 V1 in a high vacuum condition at room temperature. Around 200nm CdS thin film were fabricated on BSG substrate and it took 35 minutes only. As grown CdS thin film were characterized to evaluate its properties for the possible application in CdS/CdTe thin-film solar cell. The as-deposited CdS film characterization results showed lower resistivity with higher mobility and carrier concentration which are good enough to be used in thin-film solar cells, LEDs and photonic devices.**

Keywords*—*CdS Thin Film; Thermal Evaporation; VCM 600 V1; CdS/CdTe Solar Cell; In-house Fabrication.

I. INTRODUCTION

The CdS is very potential to be used in solar cells. The present civilization of a developing country which is measured by the energy consumption for the prosperity and progression of modern society is depended on the energy. Currently, maximum power is collected from the conventional energy where 80% power generated from fossil fuel [1]. Day by day the energy consumption rate has been increased to growths of population, commercial and residential sector while it forecast that the energy consumption rate would be increased up to 30 TW in 2050 [2]. Many researchers are predicted that the fossil fuel is in the end of the stage and by next 100 years, the storage of energy will be completely consumed which is the alarming issue in present condition [3]. But the fossil fuels create the greenhouse gasses and the radioactive wastes are produced from the nuclear power station. Daily over 110 million tons of CO_2 gas is emitted in the atmosphere due to our present convenient lifestyle.

The environment pollution with energy shortage is inspired for searching a new cost-effective earth abundant energy sources that will not be polluted the atmosphere as well as to meet up the present energy demand. In this situation humanity are focused on the clean and green abundant solar energy resources that are potential to meet up the total energy demand. This solar energy is converted into electrical energy by using photovoltaic technology.

Cadmium sulfide is an inorganic yellow solid compound [4]. The CdS is promising intrinsic n-type material is used as the window layer material that is placed in the group II-VI compound semiconductors elements. The abundant CdS materials are environmentally acceptable elements. It gives the flexibility to design devices. The CdS has a direct band gap with a relatively wide range is of Eg = 2.42eV at room temperature, only a few microns of CdS are needed to absorb the incident light and the wavelength transparency range is around 510 nm and above [5]. Polycrystalline Cadmium Sulfide is a tremendous thin-film material in the compound semiconductor for easy ohmic contacts that absorption coefficient is high and also the favourable band gap energy, low resistivity, highly stable and low-cost material. To achieve the high current density in the thin film solar cells, CdS layer must be very thin to allow more photon to pass through to the absorber layer in solar cells.

The wide band gap of CdS creates its citable performance of nanostructure semiconducting materials in electronics, optoelectronics [6] and photonics [7] and many other disciplines. Nowadays, the researchers are becoming more and more dependent on synthesized nano-structured CdS for many optoelectronic applications like solar cells, thin films, electroluminescent displays, light emitting devices [8] because

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of its characteristics of tuning emissions in the visible light range. These excellent properties of CdS material which are motivated to make many hetero-junction ultra-thin solar cells such as p-type Cu_2S [9], $CulnSe_2$ [10], Cadmium telluride (CdTe) and CuIn(Ga)Se [11] solar cells, CdS use as their hetero-junction partner (n-type CdS) as a window layer where light can enter into the CdS layer and then this passes to the absorbed (p-type) layer.

II. Deposition Techniques

There are different types of fabrication techniques used to deposit CdS films. Among them Screen Printing, Molecular Beam Epitaxy (MBE), Chemical Vapour Deposition (CVD), Thermal Evaporation (TE), Pulsed Laser Deposition (PLD), Sol-Gel, Spray Pyrolysis, Electrochemical Deposition, Close Space Sublimation (CSS), Sputtering, Chemical Bath Deposition (CBD) are mostly used. In TE evaporation techniques for evaporating materials laser evaporation, resistive heating, arc evaporation, flash evaporation, R. F. heating and electron bombard heating are used.

In 2000, A.I. Oliva et al. used two different techniques as chemical bath deposition (CBD) and close spaced sublimation (CSS) for CdS film deposition [12]. Here two new modalities such magnetic agitation on the bath solution and ultrasonic vibration was applied on the whole deposition system in CBD technique. CdS thin film deposited by CSS technique in a high vacuum of 10^6 Torr at substrate temperature range were fixed 700°C and 500°C and it took 4-60s and in CBD technique used to 5-40min. Britta and C. Ferekides demonstrated CdS/CdTe thin film solar cell deposited by CBD with CSS techniques and achieved 15.8% efficiency in 1993 [13]. Here the thickness of CdS thin film was around 0.07 to 0.10 µm. The n-type CdS film was deposited in slow deposition rates at 20 A/min using the bath temperature at 90°C then CdTe film deposited by CSS techniques where substrate temperature was maintained at 600°C and 700°C respectively.

In thermal evaporation system, the range of temperature for substrate and evaporation source were in 300°C to 600°C and 100°C to 400°C respectively for the preparation of the tin sulphide (SnS) layer that is emphasized by E. O. Ogah et al. [14]. K. Senthilet al. used vacuum evaporation techniques for deposited the CdS thin films on the glass substrates at substrate temperature of 373 K and different temperature was used during this film annealed [15]. F. Iacomi et al. investigated the morphology, optical reflectivity and film thickness depending on the dopant nature of CdS thin films. Here uniform and small reflecting doped applied on the CdS thin films that were deposited by thermal evaporation in a high vacuum 10^{-6} Pa that was influenced the film thickness, morphology and optical reflectivity [16]. Won-Jae Lee et al. observed that the heating effect at several substrate temperature ranging from 30°C to 200°C which was influence the photovoltaic properties of CdS films for the CdS/CdTe solar cell. It was prepared by using thermal evaporation. This film showed that if the deposition temperature is increases then device efficiency is degraded with decreasing open circuit voltage and fill factor [17]. In 2017, Nafiseh Memarian et al. deposited the CdS thin films using a thermal evaporation technique which were grown up on the substrate with a vacuum about 2×10^{-5} Torr. For as-deposited CdS thin films the resistivity was varied from the range between 3.11-2.2×10^4 Ω-cm subjected to the substrate temperature ranging from 25°C to 250°C [18].

Thermal evaporation method is a physical process such as physical vapour deposition method (PVD) where evaporation is done in high vacuum condition. This process is occurred by bombardment of the energy under decreasing the ambient pressure with controlling the temperature for deposited the surface material from the target to glass substrate and vacuum evaporation techniques where evaporation system is done by heated the source material drives to the substrate in precise temperature and pressure. Thermal evaporation system is a simplest system of vacuum deposition methods that is included in a classifier in Physical Vapour Deposition techniques. Thermal evaporation method is mostly used for the film fabrication in the semiconductor industry which is quite simple, easiest to less controlling factor. The evaporation systems are using a diffusion films that is involved for the beam distribution and utility passing with precise controlling of the method. In thin film deposition process the source material condensed on a glass substrate from evaporation source under in a high vacuum that is kept on at the ambient temperature or in the higher temperature where the source material is heated through the evaporation techniques so that it is forming a desired thickness of a film.

Many researchers were investigated the higher performance and the better purity thin film where a uniform film could be deposited under evaporation technique. This technique was mostly used for depositing many kinds of compound as metal, alloys. Compound materials where have metal oxide types of material or sulphide types of materials that are mostly deposited through these evaporation techniques. Thermal evaporation system is very efficient in the sector of nano structured CdS synthesis film and has many advantages such as it will be reduced the amount of impurities and it reduces the propensity of oxides formation in the growing layer as well as during the evaporation the material propagation must be happen in uniformly with high integrity under variant conditions from evaporation source into substrate. The thermal evaporation techniques are simple and easy to control in VCM 600 V1 and it is very economic as well as for this system there is no needed to use argon (Ar) and nitrogen gas (N_2) during the system processing. In this work, the CdS thin film as window layer for the CdS/CdTe solar cell application was deposited by utilizing VCM 600 V1 in the laboratory.

III. EXPERIMENTAL TECHNIQUES

The commercially available borosilicate glass (BSG) substrate was used for the CdS thin film deposition by thermal evaporation technique. Before the cleaning process, the substrate was scratching using the right mark symbol through the pen cutter that is indicated the film is deposited in the opposite site as shown in Fig. 1.

Fig. 1. Image of scratched BSG substrate

At first, the borosilicate glass substrate was mechanically scrubbed by using the soap solution with washing by normal water and then washing substrate are kept on the distilled water then these glasses were cleaned by MAMD process that means the glasses degreased in Methanol, Acetone, Methanol solutions and Di-water process for 10 minutes respectively in an ultrasonic bath. After then this clean substrate is dried by using Industrial Nitrogen gas (N_2) until the water is removed from the glass and finally drying by Hotplate that was used for heating purposes of the substrate at a temperature of 80^0C to 100^0C about 5 minutes. After that CdS thin film were deposited on clean BSG substrate by VCM 600 V1 Thermal Evaporator (TE) as shown in Fig. 2.

This system consists mainly of two parts. The first part is ultra-high properties Borosilicate Glass Bell Jar with source and substrate holder. In this work, the VCM 600 V1 was operated around 35 minutes for the deposition of 200 nm thick CdS thin film. To achieve this goal a 0.47gm of 99.999% purity CdS powders were purred in the Molybdenum (Mo) evaporation boat. After that, the Mo boat was placed and the clean BSG substrate was mounted on the substrate holder inside the glass bell Jar and the distance between them was kept 10 cm as illustrated in Fig. 3.

The second part of VCM 600 V1 TE is a metal base unit which comprises a power supply, rough pump, and high vacuum turbo molecular pump. The backing pump operated initially for vacuum chamber over 10^{-1}hPa, after that turbo molecular pump was used to evacuate the chamber to 10^{-6} hPa level. Cold plasma penning systems in Pirani gauge were used to monitor the chamber pressure in the deposition time.

Fig. 2. Full set up of VCM 600 V1 Vacuum Evaporator

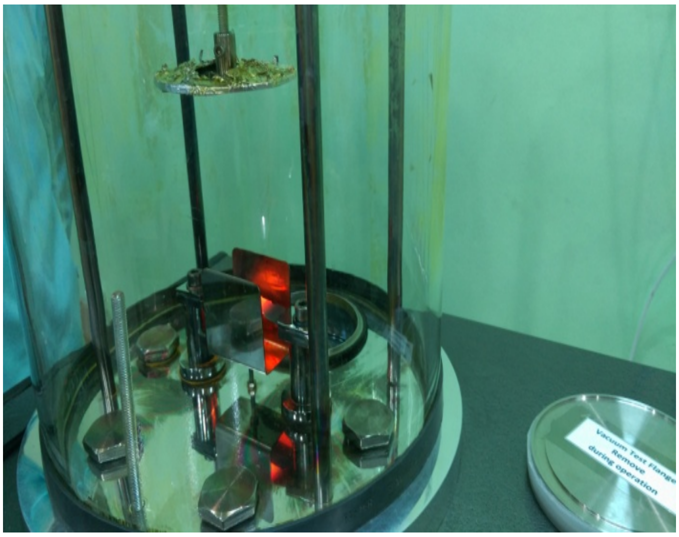

Fig. 3. Deposition of CdS film in VCM 600 V1

At high vacuum, 160A of AC current was passed between the electrodes through Mo boat to initiate evaporation of CdS source material to BSG substrate. These AC current resistively heated Mo boat and the heating intensity was controlled by the rate of current flow through it. When the temperature of Mo boat reaches above the melting point of CdS powder then the evaporation started and then deposition time was count 35 minutes. After the completion of the evaporation, the current was gradually minimized from 150 A to 0 A, and allowed Mo boat to cool naturally. After that switched off the turbo molecular pump for venting the chamber and sequentially switched off rough pump, main power. After forty five minutes the chamber was opened and removed the deposited sample. The deposited CdS thin film samples were stored properly for characterization. The deposited CdS thin film with VCM 600 V1 was done in one shot which is shown in Fig. 4.

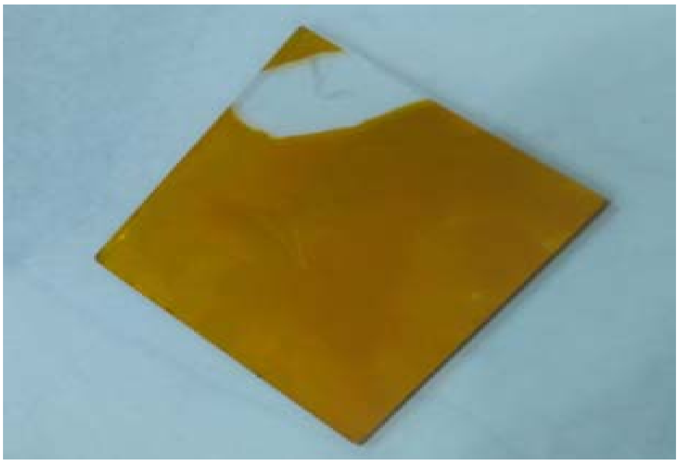

Fig. 4. The as-deposited CdS thin film on BSG

IV. RESULTS AND DISCUSSIONS

The as deposited 200 nm CdS thin film was investigated by high resolution optical microscope primarily for observing surface uniformity and pinholes. It was found that the as deposited CdS film was deposited uniformly on the BSG substrate and no pinhole observed. After that the final sample was sent for measuring its electrical properties by Hall Effect measuring system and thickness by dektak profile meter. The thickness of the as-deposited CdS films was found 204 nm. The measured Hall coefficient, bulk concentration (N), resistivity (ρ) and mobility (μ) parameters of the sample are shown in Table I. The rate of the current source were 36 nA during measurements for 1st and 2nd observation where in third observation it was 38 nA and the value for magnetic field was 0.5 T in all observations.

TABLE I PROPERTIES OF AS-DEPOSITED CDS THIN FILM

Parameters	**Sample Observations**		
	No. 1	**No. 2**	**No. 3**
Bulk Concentration ($\times10^{12}$)(/cm^3)	22.8	7.68	6.77
Mobility (cm^2/Vs)	22.7	55.8	71.6
Resistivity ($\times10^4$) (Ω-cm)	0.977	1.46	1.29
Average Hall Coefficient ($\times10^5$) (cm^3/C)	2.22	8.12	9.22

From the Table I, it is clear that the average value of bulk concentration is 12.4×10^{12} cm^{-3}, mobility is 50 cm^2/Vs, resistivity is 1.24×10^4 Ω.cm and average Hall coefficient is 6.52×10^5 cm^3/C. It was found that the as deposited CdS thin film possesses higher carrier concentration, hall coefficient and mobility but the resistivity is relatively low. It is well known that the higher mobility and carrier concentration with lower resistivity are suitable for better CdS/CdTe solar cell characteristics. The characterization results of CdS thin film showed good agreement to the related published work [17].

V. CONCLUSION

Pin hole free thin CdS film was fabricated in-house to explore the possibility of applications in CdS/CdTe solar cell. The CdS thin film was deposited on BSG at high pressure and low temperature using the thermal evaporation techniques by VCM 600 V1. Around 204 nm thickness was achieved in 35 minutes only. It was found that the as-deposited CdS film shows lower resistivity with higher mobility and carrier concentration that confirms good electrical properties to be used in solar cells, LEDs and photonic devices. The fabricated CdS thin film's characteristics encourage us towards the complete solar cell in- house fabrication.

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