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LOW-TEMPERATURE DEPOSITED CdS and CdTe THIN FILMS AND THEIR SOLAR CELL APPLICATION

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In this paper the results of novel manufacturing process for high efficiency CdS/CdTe solar cell performance are given. In the device structure CdS and CdTe thin films were deposited on SnO_2/Corning 7059 glass substrates by so-called "low-temperature vacuum deposition" method. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques were used for structural researches. It was found that the grain sizes and surface morphologies of CdTe and CdS films deposited by low-temperature processing (substrate temperature was about 218K) are nearly the same which is known to be one of the key parameters for high-efficiency CdTe/CdS solar cell performance. Using this new processing we have prepared the devices with efficiencies more than 14%. The method seems to be an attractive alternative for high efficiency CdTe–based solar cell application.

INTRODUCTION

In the photovoltaic material family, cadmium telluride is regarded as one of the most promising material for fabrication of high efficiency polycrystalline CdTe/CdS thin film solar cells [1-3] because of its near-optimum bandgap of about 1.48eV and high optical absorption coefficient in visible range. In spite of the large lattice mismatch between cubic CdTe and hexagonal CdS (nearly 9.7%) the CdTe/CdS solar cells are characterized by essentially high efficiencies caused by interdiffusion at the junction interface removing the lattice mismatch [4,5]. "$CdCl_2$ heat treatment" is considered as a key step in CdTe/CdS device processing leading to interdiffusion between CdTe and CdS.

Other important parameters that can affect the solar cell performance are the grain sizes and surface morphologies of device components. The considerable difference between these parameters for CdTe and CdS can provide high concentration of defect centers in CdTe/CdS interface resulting in decrease of device efficiency.

There are various techniques (for example, evaporation, electrodeposition, spray pyrolysis, RF sputtering, chemical bath deposition, and close-spaced sublimation) to prepare the CdTe/CdS thin film solar cells with high conversion efficiency. The conventional high efficiency CdTe-based solar cells have a superstrate configuration of glass/n-SnO_2/n-CdS/p-CdTe/back contact. The components of the structures are usually deposited by different methods, for example, CdTe films are deposited by close space sublimation (CSS) method but for the deposition of CdS films can be used chemical bath deposition (CBD), RF sputtering, physical vapour deposition (PVD), and others methods. The grain sizes and surface morphology of CdS films deposited by CBD method considerably differ from that for CdTe films obtained by other methods which can essentially limit the device performance. That's way the oxygen species are incorporated during CdTe film formation and "CdCl2 treatment" in order to decrease the grain size of CdTe films for conformity with that of CdS film.

In our previous report [6], feasibility of thin film solar cell application of CdTe films prepared at low temperatures was shown on the basis of scanning electron microscopy (SEM) and X-ray diffraction (XRD) characterizations of the films. It was shown that the method is simple and suitable for low-cost solar cell application.

In this work for CdTe/CdS thin film solar cell fabrication low-temperature processing was used for CdS and CdTe films deposition on the glass/SnO_2 conductive layers. It was motivated by the fact that the grain sizes and surface morphologies were the same for CdS and CdTe films prepared by above mentioned method.

This paper reports the first successful operation of CdTe/CdS-based solar cells prepared by low-temperature evaporation method.

EXPERIMENTAL DETAILS

In this work, thin film CdS/CdTe heterojunction devices have been prepared by low-temperature vacuum deposition method. Details of the method as well as SEM and XRD characterizations of the films can be found in our previous paper [6].

For the device fabrication CdS films of about 90nm and CdTe films of about 5.0μm thick were subsequently evaporated onto bilayer SnO_2 coated Corning 7059 glass substrates received from NREL. High purity CdS and CdTe powders were used as a source material. Temperature of the substrates was hold at 218K during the evaporation process. The growth rate was controlled by keeping the source temperature within the range of $600\div650^0$C and was about 1.5nm/s.

$CdCl_2$ treatment was carried out using “dry” method where the samples were exposed to $CdCl_2$ vapor at 400^0C for $5\div7$min. in vacuum chamber in the presence of 100torr oxygen and 400torr helium (total pressure was 500torr). Then the samples were etched in HNO_3:H_3PO_4:H_2O mixture (NP etch) in order to convert the CdTe surface to elemental tellurium. For the back contact fabrication the special mixture of graphite paste, Cu_xTe, and HgTe was deposited and the samples were annealed at 260^0C for 25min. in the presence of inert gas. Silver paste back face electrode was next deposited and the samples were annealed at 100^0C in air to complete the devices [7].

Transmission and photoconductivity measurements were carried out by standard methods.

RESULTS AND DISCUSSIONS

Fig.1 shows XRD spectra in the $2\theta=20\div60^o$ range for thin films CdS (a,b) and CdTe (d,c) prepared at 150^0C (top) and 218K (bottom) substrate temperatures. The data shows that the CdS and CdTe films deposited at conventional 150^0C temperature (top) have hexagonal and zinc-blend cubic structures preferentially oriented along (002) and (111) directions, respectively, with certain degree of randomization. The CdS and CdTe films deposited at 218K substrate temperature (bottom) preserving hexagonal and cubic structures show strong (002) and (111) preferred orientations.

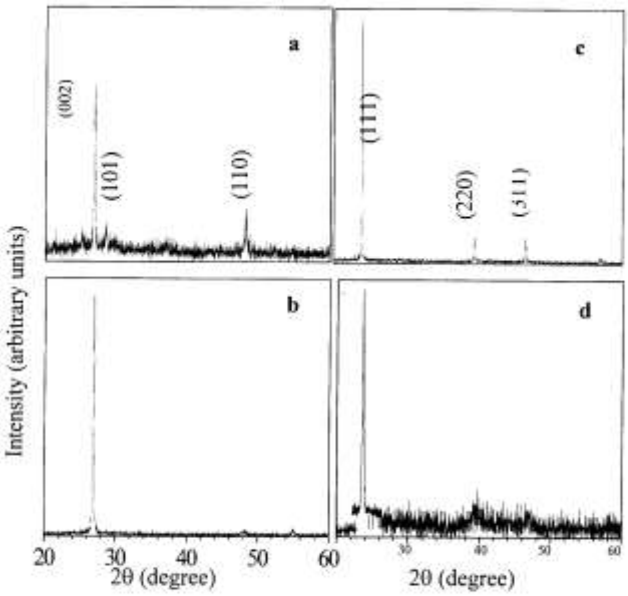

Fig.1.
XRD spectra of CdS (a,b) and CdTe (d,c) thin films deposited at 150^0C (top) and 218K(bottom) substrate temperatures

This is evidently manifested in the optical transmission spectra of the films. Fig.2 displays the transmission spectra of CdS window layers deposited at 150^0C and 218K substrate temperatures. As it is seen, the CdS film prepared at 218K shows sharper transmission edge and higher optical transparency than the film deposited at conventional temperature. Photoconductivity spectra of the CdS and CdTe films show characteristic for these materials behavior (Fig.3).

Fig.4 shows SEM photomicrographs of CdS and CdTe thin films prepared at 218K substrate temperature. As can be seen from the data, there is not much difference between the grain sizes of CdS an CdTe films. In both films about 350nm size grains can be seen, but tightly packed smaller grains are located between the large one. Both of the films have a clearly faceted surface morphology with an average grain size of about 300nm.

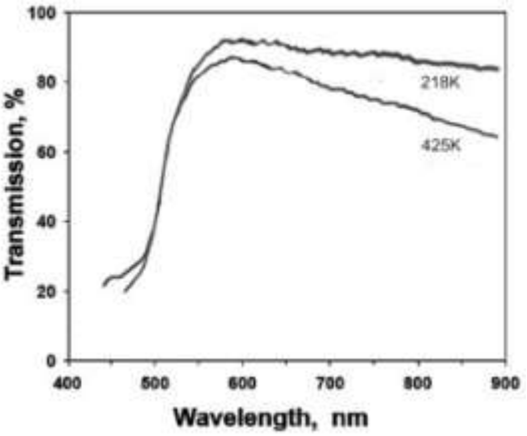

Fig.2.
Transmission spectra of CdS window layers deposited at 150^0C and 218K substrate temperatures.

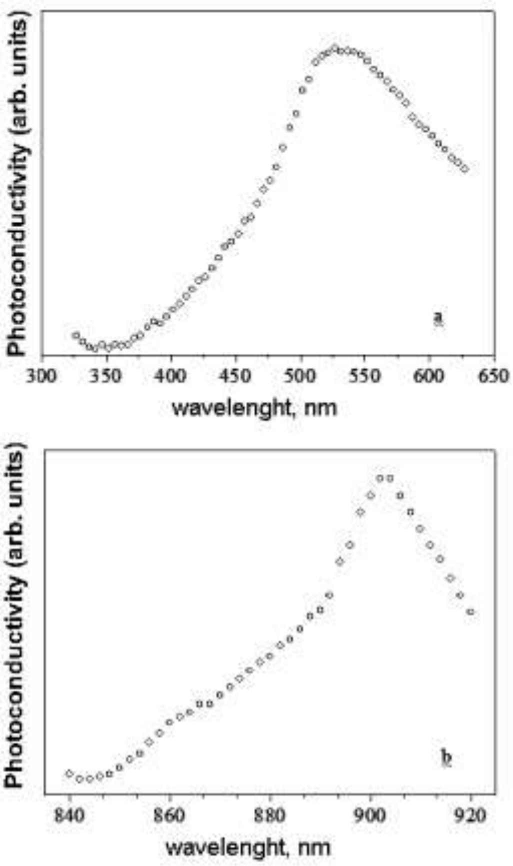

Fig.3.
Photconductivity spectra of CdS (a) and CdTe (b) films deposited at 218K substrate temperatures.

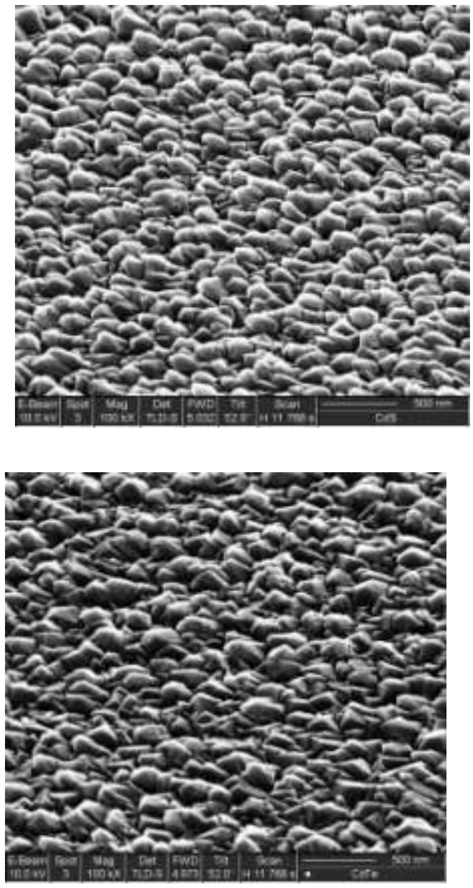

Fig.4.
SEM photomicrographs of CdS and CdTe thin films prepared at 218K substrate temperature.

We prepared a number of glass/n-SnO_2/n-CdS/p-CdTe/ back contact device structures for solar cell application. The n-CdS/p-CdTe structures were prepared on 4x4cm^2 square glass/n-SnO_2 substrates. After “CdCl2 treatment” the substrates were cut into individual 1cm^2 square pieces and Cu_xTe-HgTe back contacts to the structures were fabricated. I-V parameters of the typical devices with an area of about 0.6cm^2 are listed in Table 1.

Table 1.

Glass/n-SnO_2/n-CdS/p-CdTe solar cells.

Cells No	V_{oc}, mV	J_{sc}, mA/cm^2	Fill factor, %	Efficiency, %
Sample 1	835	23.67	69.1	13.66
Sample 2	845	23.62	70.3	14.03
Sample 3	850	23.78	69.8	14.10
Sample 4	638	21.34	59.0	8.86
Sample 5	670	22.42	57.0	7.76

Our best cell I-V parameters measured under 100mV/cm^2 solar simulator are Voc=850V, Jsc=23.78mA/cm^2 and FF=69.8% corresponding to a total area conversion efficiency of 14.1%. As it is seen from the Table 1, two devices (samples 4 and 5) exhibit essentially lower efficiencies as compared with other one. These devices were fabricated on the pieces cut from edge part of the substrates. In our opinion the most obvious reason for markedly low efficiencies of the devices fabricated on the edge part of the substrate is high density of pinholes caused by decrease of CdS film thickness in this part. Low values of Voc and FF indicates the essential low shunting resistance of these devices.

CONCLUSIONS

Low-temperature evaporation method of CdS and CdTe thin films was found to be one of the successful ways for high efficiency solar cell application. Nearly the same grain sizes and surface morphologies as well as high density of the films provide an optimum intermixing of the components favoring the formation of junction with low concentration of interface states. As a result the high efficiency solar cells with conversion efficiency more than 14 % were fabricated. Our preliminary studies show the possibility of further optimization of the manufacturing technology of CdS/CdTe thin film solar cells by varying physical properties of the device components to achieve maximum efficiency and the researches are in progress.

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AŞAĞI TEMPERATURDA TOZLANDIRILMIŞ CdS və CdTe NAZIK TƏBƏQƏLƏRI VƏ ONLARIN GÜNƏŞ ELEMENTLƏRIDƏ TƏTBIQI

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Məqalədə yüksək effektivlikli CdS/CdTe günəş elementlərinin yeni hazırlanma prosesinin nəticələri verilmişdir. Göstərilən cihaz strukturunda CdS və CdTe nazik təbəqələri SnO_2/Corning 7059 altlıq üzərinə “aşağı temperaturlu tozlandırma“ üsulu ilə çəkilmişdir. Struktur tədqiqi üçün elektron mikroskopu (SEM) və Rentgen difraksiyası (XRD) metodları istifadə olunmuşdur. Müəyyən olunmuşdur ki, alınan təbəqələrin danələrinin ölçüsü və səth morfologiyası təqribən eynidir ki, bu da yüksək effektivlikli CdS/CdTe günəş elementlərinin alınmasında həlledici parametrlərdəndir. Bu prosesdən istifadə edərək effektivliyi 14%-dən yuxarı olan günəş elementləri hazırlanmışdır.

ТОНКИЕ ПЛЕНКИ CdS и CDTE ПОЛУЧЕННЫЕ НИЗКО-ТЕМПЕРАТУРНЫМ НАПЫЛЕНИЕМ И ИХ ПРИМЕНЕНИЕ В СОЛНЕЧНЫХ ЭЛЕМЕНТАХ

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В работе приводятся результаты процесса создания эффективных CdS/CdTe солнечных элементов. В данной приборной структуре тонкие пленки CdS и CdTe были нанесены на SnO_2/Corning 7059 подложки низко-температурным вакуумным напылением. Для структурных исследований были использованы сканирующий электронный микроскоп (SEM) и метод рентгеновской диффракции(XRD). Было показано, что размеры зерен и поверхностная морфология пленок CdS и CdTe, полученных низко-температурным напылением (температура подложки 218К), одинаковы, что является одним из ключевых параметров для создания эффективных CdS/CdTe солнечных элементов. Вышеуказанным методом получены солнечные элементы с К.п.д. выше 14%.

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