INFLUENCE OF EVAPORATION RATE, SUBSTRATE TEMPERATURE AND PROCESS CHAMBER PRESSURE ON THE MICROSTRUCTURE OF CDTE LAYERS

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ABSTRACT

The growth of CdTe thin film solar cell devices by close spaced sublimation (CSS) was systematically investigated. CdTe thin films were deposited onto CdS coated FTO (fluorine-doped tin oxide) substrates with varying substrate temperature (260 … 475°C) under various pressures of nitrogen (1.8×10^{-3} mbar, 6.7×10^{-2} mbar, 2.0×10^{-1} mbar). The microstructure of the films were examined before and after activation treatment with a high-resolution field emission scanning electron microscope (FE-SEM) on ion beam prepared cross sections. The grain size and grain morphology can be strongly influenced by the substrate temperature. The substrate temperature was continuously measured during the CdTe deposition. Therefore it is possible to define a temperature region in which compact CdTe layers could be deposited. In contrast, little influence of the chamber pressure on the grain size could be observed.

EXPERIMENTAL

A series of CdTe thin film solar cell devices with following device structure CdTe/CdS/FTO were grown onto CdS/FTO substrates at different substrate temperatures under various pressures of nitrogen (see Fig. 1). As front contact commercially available FTO coated glass (AGC, IS9) was used. CdS and CdTe were deposited by close space sublimation. Prior to CdTe deposition the samples were connected with a thermocouple for continuous measurement of the substrate temperature during the whole deposition process. Substrates were heated up prior to deposition to different temperatures in the range from 260 … 475°C and then transferred above the evaporation source. For low substrate temperatures an increase of temperature up to 100 K during CdTe deposition is observed (see Tab. 1). Table 1 gives an overview of the varied deposition parameters including measured substrate temperatures during deposition. Deposition of CdTe was carried out under different pressures of nitrogen (1.8×10^{-3} mbar, 6.7×10^{-2} mbar, 2.0×10^{-1} mbar). The growth rate of CdTe was constant (~ 5 µm/ min) for all depositions that means the sublimation temperature of the CdTe source had to be adjusted to compensate the loss in growth rate by increasing chamber pressures. Following CdTe deposition the activation treatment was performed by wetting the samples with drops of $CdCl_2$ dissolved in methanol and annealing in air at 410°C for 25 min in a muffle furnace. All devices were etched for 15 s in nitric-phosphoric (NP) acid etch. The activation treatment was not optimized for the specific as deposited CdTe microstructure. Immediately after etching the samples were transferred to a sputter chamber and an approximately 150 nm thick gold back contact was deposited by DC-magnetron sputtering.

The microstructure of all samples was characterized by SEM investigation of the cross section before and after the activation treatment. A high-resolution field emission scanning electron microscope SU8000 by Hitachi (FE-SEM) was used to examine the microstructural changes by activation treatment. Cross sections of the CdTe thin film solar cell devices were prepared by ion beam polishing.

T_m [°C] / p [mbar]	310°C	400°C	500°C
1.8×10^{-3}	264 … 360	362 … 431	478 … 513
6.7×10^{-2}	275 … 371	366 … 444	476 … 515
2.0×10^{-1}	279 … 389	349 … 448	476 … 532

Tab. 1: Varied deposition parameters

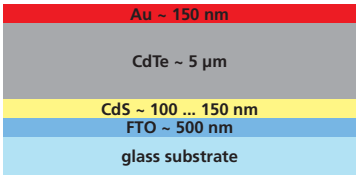

Fig. 1: scheme of a CdTe thin film solar cell

Fig. 2: CSS equipment for CdTe deposition

RESULTS

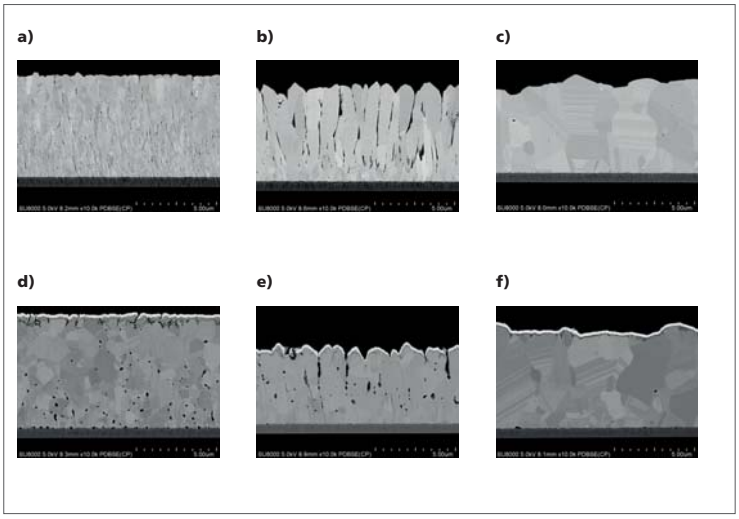

Fig. 3: SEM images of CdTe thin films, chamber pressure 1.8×10^{-3} mbar, varying substrate temperature; as deposited (a) 264-360°C; (b) 362-431°C; (c) 478-513°C; after activation treatment (d) 264-360°C; (e) 362-431°C; (f) 478-513°C

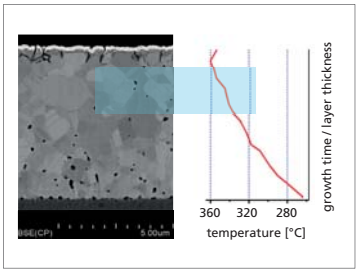

Fig. 4: CdTe layer thickness in correlation with substrate temperature (chamber pressure 1.8×10^{-3} mbar; 264 … 360°C)

SUBSTRATE TEMPERATURE

The SEM cross section show an area with almost no porosity which can be correlated with the substrate temperature. The deposition of compact CdTe layers could be possible around 320 … 360°C

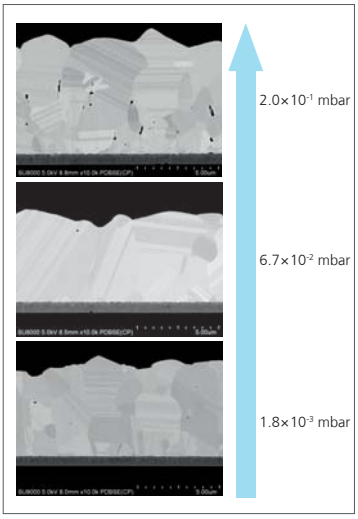

Fig. 5: SEM images of CdTe layers deposited at different chamber pressures at substrate temperature 500°C

EFFECT OF SUBSTRATE TEMPERATURE ON MICROSTRUCTURE

Fig. 3 (a), (b), (c) **as deposited** CdTe thin films:
- increasing grain size with increasing substrate temperature (200 nm at T_{sub} = 264 … 360°C to 1.6 µm at T_{sub} = 478 … 513°C)
- columnar grain morphology at low substrate temperatures
- high degree of porosity located at the grain boundaries in CdTe thin films deposited at lower substrate temperatures

Fig. 3 (d), (e), (f) **activated** CdTe thin films
- redistribution of porosity after activation treatment
- grain growth is more pronounced in low temperature deposited CdTe layers, but did not achieve the grain sizes of high temperature CdTe layers in the as deposited state
- maybe insufficient activation treatment for low temperature CdTe layers
- maybe limited grain growth by pores which act as pinning centers for grain boundaries

EFFECT OF CHAMBER PRESSURE ON MICROSTRUCTURE

Increasing chamber pressure does not change grain size and morphology significantly, but a higher degree of porosity at given substrate temperature could be observed.

SUMMARY

The deposition parameters of closed space sublimation CdTe thin films were systematically varied and the resulting microstructure was studied on ion beam polished cross sections. Strong influence of the substrate temperature on the grain size and morphology could be observed. Deposition at low substrate temperatures result in small sized columnar grain morphologies. An increase in substrate temperature increases the diameter of the columnar grains until a certain substrate temperature there the columnar growth morphology is lost and lateral grain sizes of 1.5 µm could be achieved.

CdTe thin films deposited at lower substrate temperature show a high degree of porosity between the columnar grains which is still present after activation treatment. Rising the chamber pressure leads to an increase in porosity also in films deposited at high substrate temperatures around 500°C. Anyway the continuous temperature measurement during the CdTe deposition indicates a temperature region around 320 … 360°C visible in the SEM cross sections where the CdTe thin films show almost no porosity and good solar cell efficiencies could be expected.

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