INFLUENCE OF DIFFERENT TCO-SYSTEMS ON MICROSTRUCTURE AND PERFORMANCE OF CdTe-SOLAR CELLS IN SUPERSTRATE CONFIGURATION

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INTRODUCTION

Transparent electrodes are deposited as first layers in CdTe-thin film solar cells in superstrate configuration. The transparent conductive oxides (TCO) have to withstand the thermal and chemical exposure of all subsequent process steps without degradation of the film properties. TCOs are exposed to temperature of about 500°C in CdS and CdTe deposition process. Temperature exposure lasts about 5 … 30 min in the close-spaced sublimation (CSS) coating process. Strong chemical exposure results from subsequent chloride activation of the heterojunction system at atmospheric pressure and the nitric-phosphoric (NP)-etching.

Hence, for two TCO-systems - **indium tin oxide (ITO)** and **aluminum-doped zinc oxide (AZO)** - the conductivity, absorption, crystallinity and surface roughness have been investigated and compared with commercial **fluorine-doped tin oxide (FTO)** substrates.

EXPERIMENTAL

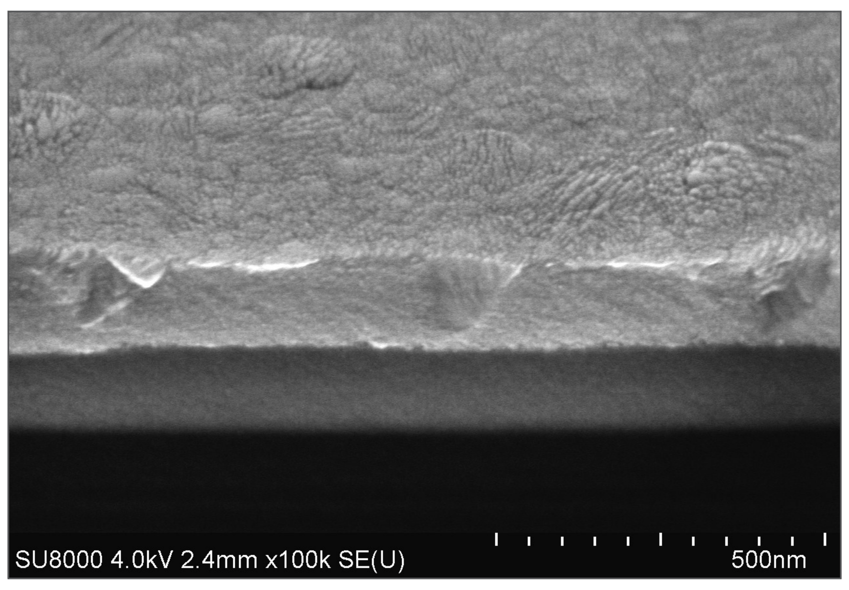
The ITO- and AZO-layers are deposited on low iron float glass substrates at room-temperature and on preheated substrates. Selected substrates have been annealed additionally. To avoid diffusion of Na from float glass into the CdS layer the float glass substrates have been coated with thin SiO_2 layer before deposition of ITO or AZO. Furthermore, a thin SnO_2 buffer layer was applied on the TCOs before deposition of CdS window layer and CdTe absorber layer. Solar cells have been completed by chloride activation process and nitric-phosphoric (NP)-etching for Te enrichment on CdTe surface before sputtering the gold back contact layer.

RESULTS

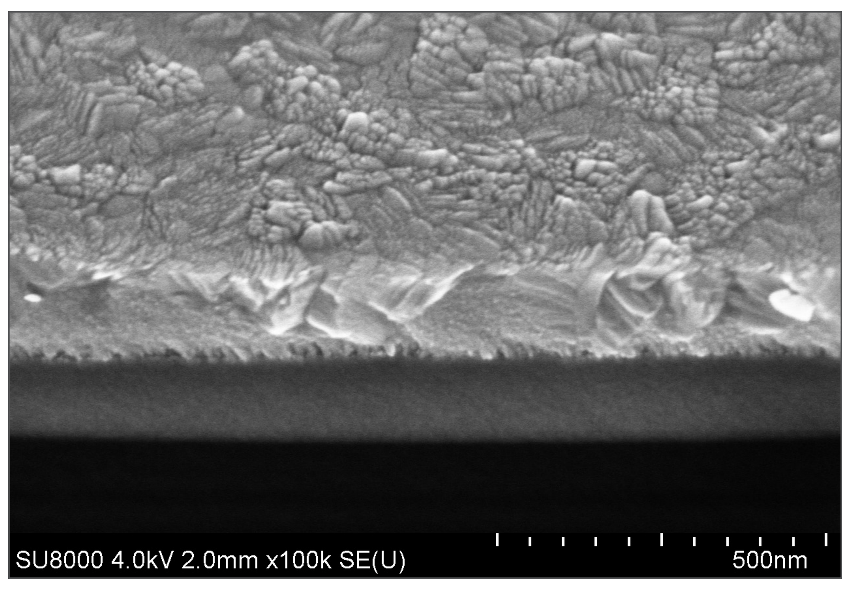
TCO SURFACE ROUGHNESS

	as deposited		annealed 500°C, 30 min	
	Ra [nm]	Rt [nm]	Ra [nm]	Rt [nm]
FTO, AGC-IS-9	13	118		
ITO @RT	1.0	15	1.1	20
SiO_2-ITO @RT	2.3	23	2.1	22
ITO @350°C	3.8	36	3.8	36
SiO_2-ITO @350°C	3.8	29	3.4	28

GROWING OF ITO-LAYERS

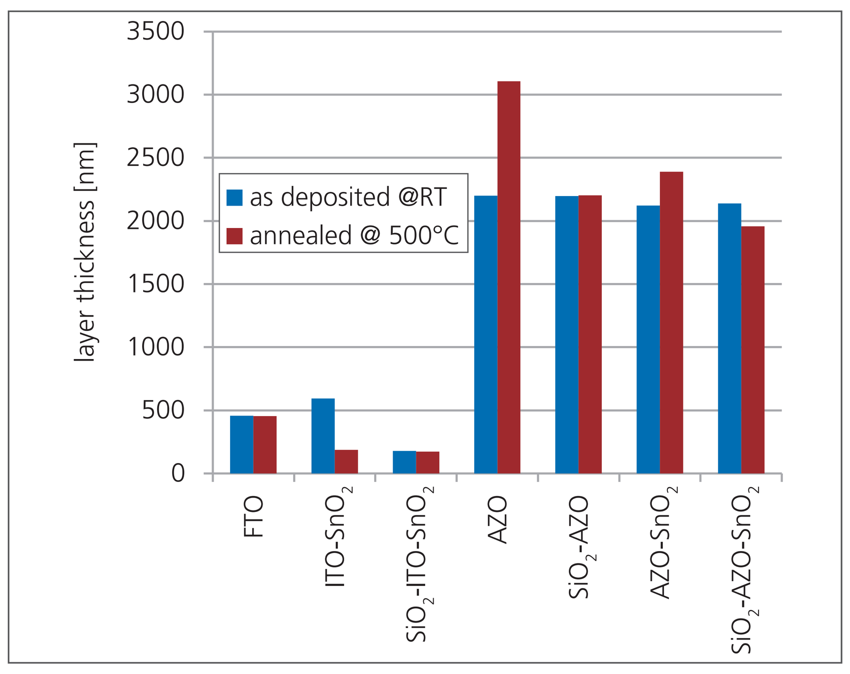


FE-SEM, ITO, 185 nm deposited on glass substrate at RT

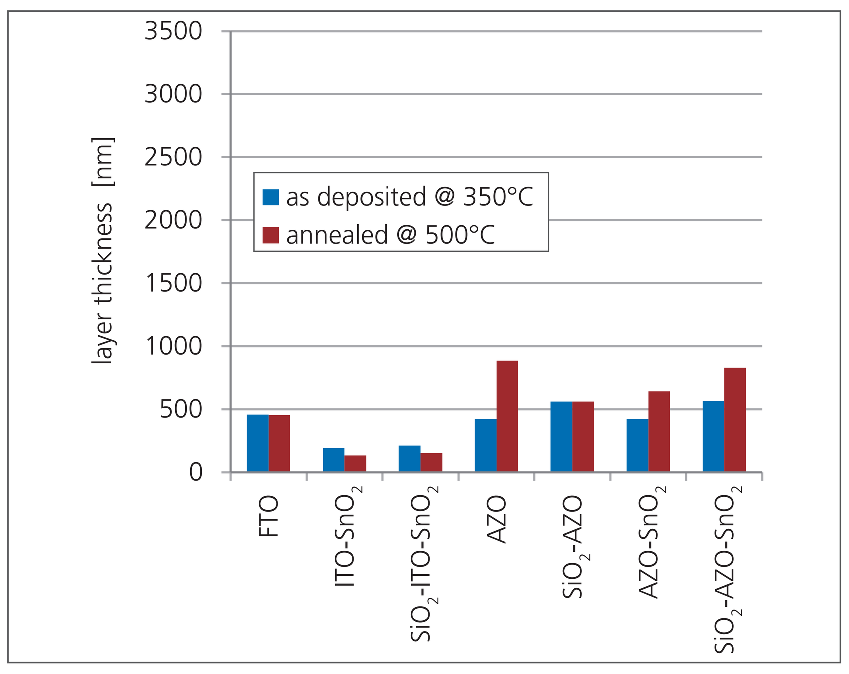


FE-SEM, ITO, 185 nm deposited on SiO_2 underlayer, 35 nm thick at RT

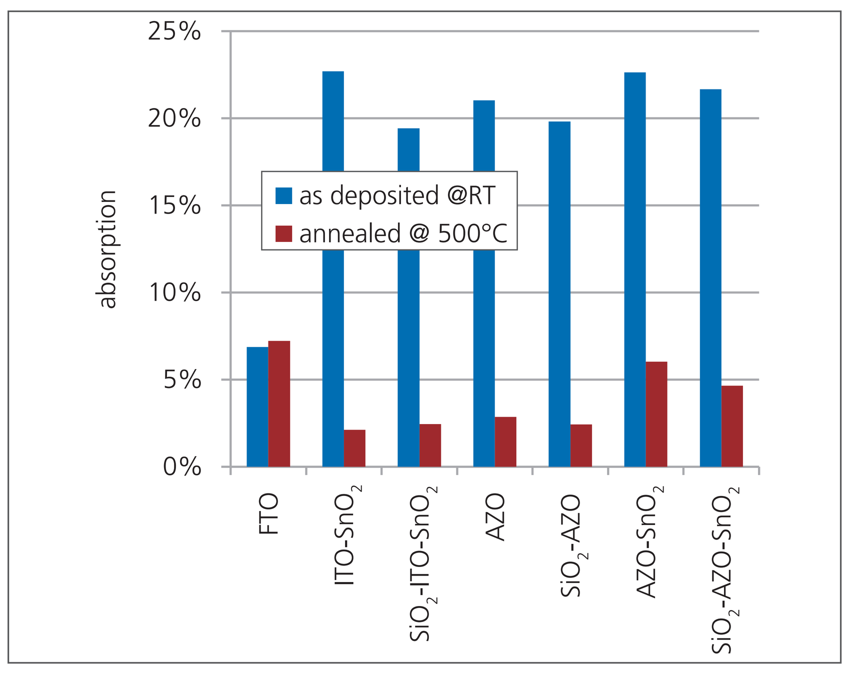
SPECIFIC RESISTANCE AND ABSORPTION



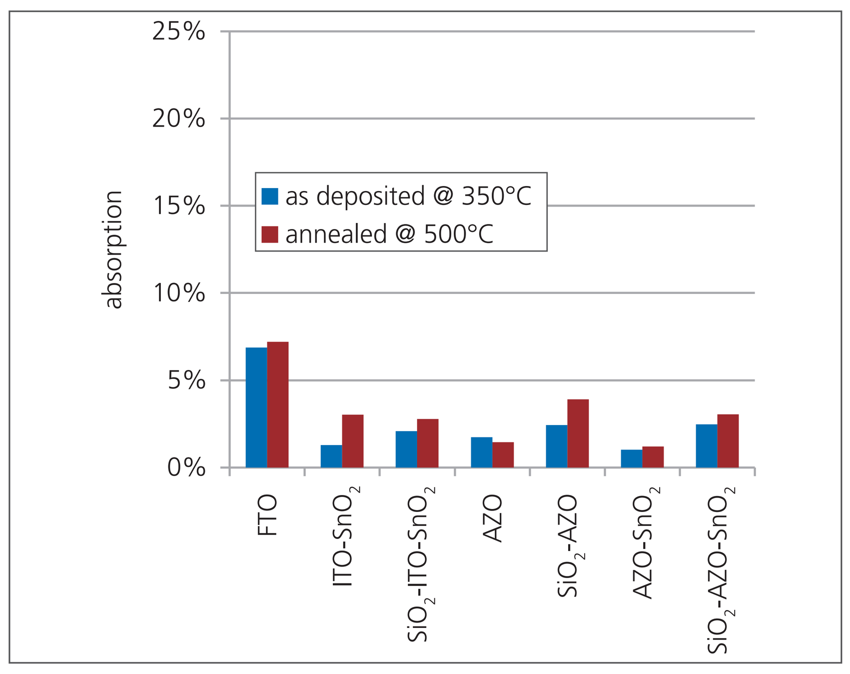
TCO-layer thickness for 10 Ω□, deposition @RT



TCO-layer thickness for 10 Ω□, deposition @350°C



Absorption of 10 Ω□ TCO-layer, deposition @RT



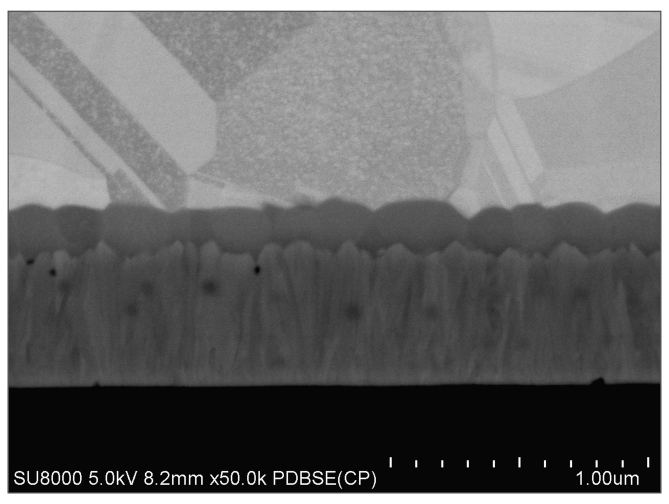
Absorption of 10 Ω□ TCO-layer, deposition @350°C

THEORETICAL SOLAR CELLS EFFICIENCY

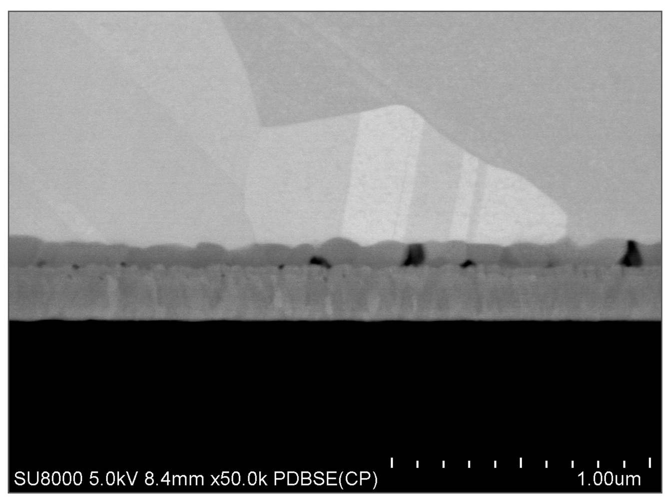
derived from ideal solar cell with TCO without absorption and without electrical resistance (efficiency: 15.9%). Thickness optimized for FTO, ITO and AZO.

	efficiency [%]	layer thickness [nm]	sheet resistance [Ω□]
FTO	13.1	600	7.6
SiO_2-ITO-SnO_2	14.1	340	4.5
SiO_2-AZO-SnO_2	14.0	1700	4.9

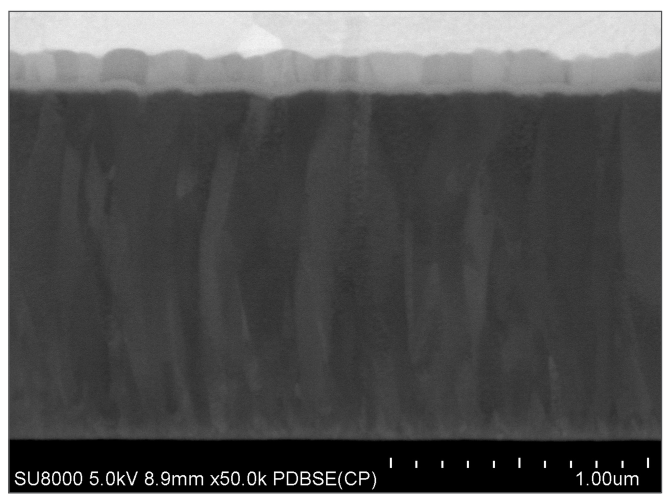
COMPLETED SOLAR CELLS



FE-SEM of interfaces between FTO, CdS and CdTe



FE-SEM of interfaces between ITO, CdS and CdTe



FE-SEM of interfaces between AZO, CdS and CdTe

The sputtered TCOs show distinctive lower surface roughness than FTO layer. Therefore less thick CdS layers with reduced absorption can be applied. On **selected AZO** based cells the gold-, CdTe- and CdS-layers have been removed by etching afterwards to investigate the TCO. No significant changes could be seen in AZO resistance after the CSS coating process and chemical treatment.

CONCLUSIONS

The performance of TCO layers in CdTe based solar cell has strong influence on the resulting efficiency of solar cells. Commercially available FTO are preferred solution in production process by economic reasons. Using of sputtered TCOs needs additional investment in sputter equipment for production line. ITO is long term proven in production process as well. However, the indium material price has increased steeply in last years due to limited supply and growing use for display applications. The sputter target price is about four times higher for ITO targets compared to AZO targets.

The necessary layer thickness for AZO is comparably thicker by about the same factor. From today's economic point of view ITO and AZO can regarded equivalent in solar cell mass production. In contrast to ITO the materials used for AZO do not suffer shortage and will be available in future for reasonable price. The investigations have verified AZO as a candidate which can perform similar good as ITO in solar cell.

Electronic properties of AZO match to CdTe based solar cells. Absorption and conductivity allow similar performance as ITO. Investigations above have demonstrated sufficient stability of AZO layers against thermal and chemical exposure in subsequent cell preparation process. Reasonable efficiency could be demonstrated with first cells.

The optimization of complete AZO based CdTe cells and the long term stability of cells are requirements for qualification proof in solar cell mass production.

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