COMPARISON BETWEEN RESEARCH-GRADE SnO_2 AND COMMERCIAL AVAILABLE SnO_2 FOR THIN-FILM CdTe SOLAR CELL

Xiaonan Li, Joel Pankow, Bobby To, and Timothy Gessert

National Renewable Energy Laboratory • Golden, CO 80401

ABSTRACT

A comparison between research-grade, tin-oxide (SnO_2) thin films and those available from commercial sources is performed. The research-grade SnO_2 film is fabricated at NREL by low-pressure metal-organic chemical vapor deposition. The commercial SnO_2 films are Pilkington Tec 8 and Tec 15 fabricated by atmospheric-pressure chemical vapor deposition. Optical, structural, and compositional analyses are performed. From the optical analysis, an estimation of the current losses due to the SnO_2 layer and glass is provided. Our analysis indicates that the optical properties of commercial SnO_2 could be improved for PV usage.

INTRODUCTION

Fluorine-doped SnO_2 films are used extensively as transparent electrodes for thin-film photovoltaics (PV). Obtaining high-quality SnO_2 is critical for high-efficiency thin-film PV. This is especially true for thin-film α-Si and CdTe solar cells, in which SnO_2-coated glass is used as a substrate, and the rest of the device is deposited on it.

In this study, we will compare the film properties of research-grade SnO_2 films and those available from commercial sources. We will identify the differences and what could be improved. The research-grade SnO_2 film used in this study is fabricated at NREL by low-pressure metal-organic chemical vapor deposition. The commercial SnO_2 films are Pilkington Tec 8 and Tec 15, because these SnO_2-coated glass substrates are the best fit for the PV industryÕs needs and are thus used by most PV manufacturers.

EXPERIMENTAL

The research-grade SnO_2 film is fabricated at NREL with tetramethyltin (TMT), oxygen, and bromotrifluoromethane ($CBrF_3$) as precursors [1]. The commercial SnO_2 films are Pilkington Tec 8 and Tec 15 fabricated by atmospheric -pressure chemical vapor deposition [2]. The substrate used for research-grade SnO_2 is Corning 7059, and soda-lime glass is used for commercial SnO_2.

1) Bio-Rad HL5500 Hall system.
2) The total transmittance (T) and reflectance (R) spectrum were measured by a Cary 5G spectrophotometer with an integrating - sphere detector.
3) Using the obtained optical absorption from the above characterization and AM 1.5 solar spectrum, the estimated current loss was calculated.
4) XRD, Scintag Model PTS
5) AFM, Autoprobe LS from Park Scientific Instruments with Si Cantilevers
6) XRF, PANalytical Axios wavelength dispersive X-ray fluorescence spectrometer

RESULTS AND DISCUSSIONS

Figure 2 provides a characterization that separates the effect of glass substrate and SnO_2 film. The corning 7059 glass has very small optical absorption, the calculation on the research-grade SnO_2 sample should be fairly accurate. The calculation on the commercial sample may indicate only a close estimate because of the high optical absorption of the soda -lime glass substrate. We can see that the glass substrate absorption of the commercial SnO_2 contributes a large portion in the long-wavelength range. In the short-wavelength range, the absorption due to the SnO_2 film is dominant.

OPTICAL ABSORPTION

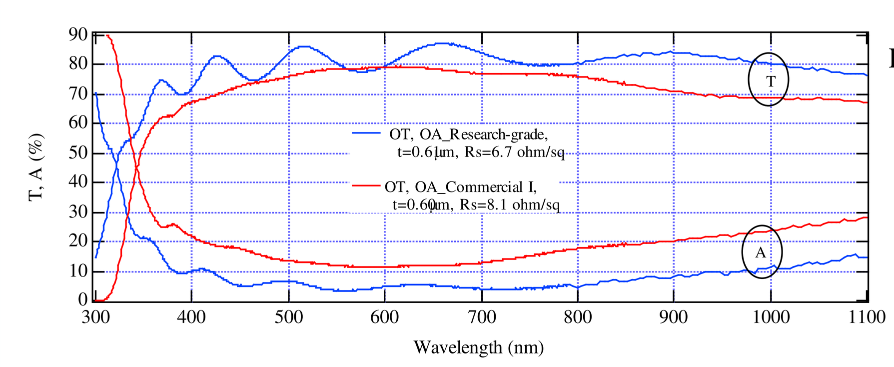


Fig. 1. Optical transmission and absorption taking from research-grade and commercial SnO_2-coated glass.

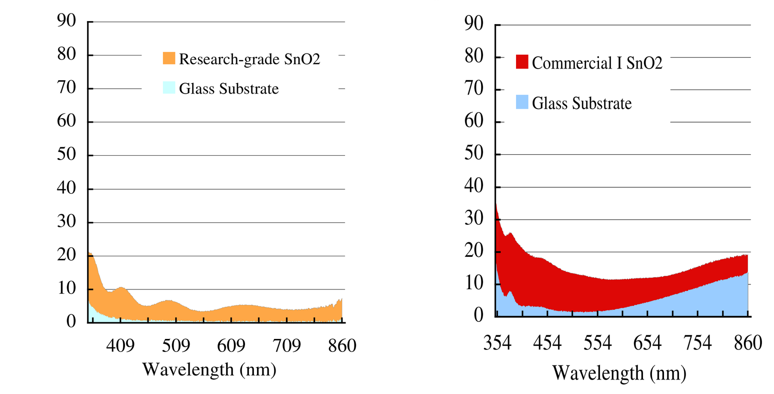


Fig. 2. Optical absorptance from research-grade and commercial SnO_2-coated glass (same samples as Figure 1 used). The color indicates the absorption due to different parts of the structure.

IMPURITIES

The SnO_2 film quality (e.g., structural defects and impurity levels) could cause the high optical absorption in the short wavelength, and the free-carrier scattering may account for the long-wavelength absorption. First, the optical absorption in the short-wavelength range could be due to the presence of reduced species such as Sn or SnO. In previous experiments, we found, by grazing-incidence X-ray diffraction, that annealing SnO_2 in H_2 gas will form the species Sn or SnO. Meanwhile, the optical absorption at the short-wavelength range increased significantly [3]. Second, regarding the impurities issues, fluorine doping produces free carriers that must be considered. Figure 3 shows that for similar film thickness, the doped SnO_2 film has higher optical absorption than the undoped film.

$$\alpha_f = \frac{Nq^2\lambda^2}{m^* 8\pi^2 nc^3 \tau}$$

X-RAY FLUORESCENCE SPECTROMETER

By XRF, all elements in Corning 7059 borosilicate glass as well as soda lime glass were detected and well resolved. For the soda lime glass substrates, sodium and magnesium were detected on the tin oxide coated side of the glass. Their origin is predominantly from the glass substrate and their attenuated signal compared to their signal from the uncoated side is consistent with a tin oxide overlayer. In addition to alkali metals and other elements associated with the soda lime or borosilicate glass substrates, tin and oxygen were also detected on the tin oxide coated sides as well as varying levels of Impurities. For research-grade SnO_2, we found fluorine, carbon and commercial SnO_2, we found chlorine, fluorine, sulfur, carbon.

SnO_2 FIGURE OF MERIT

A figure of merit, $(\Phi_{TC})=T^{10}/R_s$, that can reflect both electrical and optical properties of the film is used as a comprehensive index to characterize the quality of the transparent conducting oxide (TCO) substrate.

The optical data were taken with the glass substrate. The transmittance used for calculation Φ_{TC} is an average between the wavelength regions from 350 to 860 nm and taken with glass substrates. From Table 1, we can see that the research-grade SnO_2-coated substrate is superior to the commercial SnO_2-coated substrate.

Table 1 SnO_2 electric and optical properties

Sample ID	R_{sq} (Ω/sq)	*Average Transmittance (T %) (350-860 nm)	Figure of Merit ($\Phi_{TC}=T^{10}/R$) ($x10^{-2}$)
research-grade SnO_2:F	6.7	80.17	1.636
Commercial SnO_2:F I	8.1	74.80	0.678
commercial SnO_2:F II	14.6	79.38	0.680

*The values of average transmittance list here are taken from film/glass structure.

SURFACE ROUGHNESS

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Research-grade SnO_2 Commercial SnO_2 I Commercial SnO_2 II

Table 3. Atomic Force Microscopy Data

Sample ID	Deposition temperature (¡C)	Film Thickness (μm)	Rms (nm)
Research-grade			
SnO_2:F-144	500	0.61	8.2
SnO_2:F-2374A	600	0.68	15
Commercial			
SnO_2/G sample I		0.6	34.8
SnO_2/G sample II		0.3	12.5

The smooth SnO_2 surface and addition of a high-resistance buffer layer between SnO_2 and CdS will make thinner CdS possible.

CDS THICKNESS EFFECT

Table 2 Possible current loss due to the optical absorption calculated with AM1.5 solar spectrum

Materials	Current Loss (mA/cm^2) 350-860 nm	Current Loss (mA/cm^2) 350-1200 nm
Research-grade SnO_2/G	1.64	3.47
1.1 nm 7059 Corning glass substrate	0.19	0.31
Commercial I SnO_2/G	4.50	8.19
Commercial II SnO_2/G	2.70	6.12
3.2 mm Soda-lime glass substrate	1.70	4.17

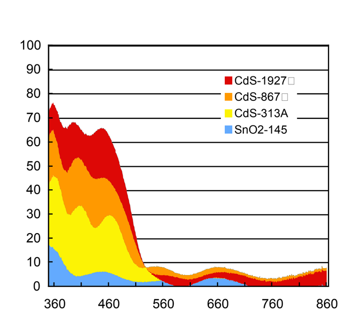
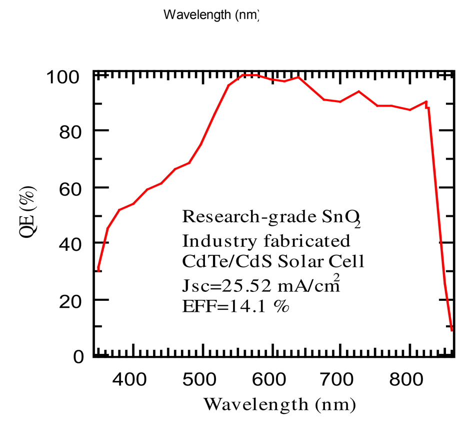


Fig. 4. Optical absorptions for three CdS samples that have different film thickness. We can see that the optical absorptions in the wavelength range of 350Ð650 nm are closely related to the CdS film thickness.

If smooth SnO_2 and i-SnO_2 buffer layers are used, the CdS layer thickness could be reduced considerably.



CONCLUSIONS

- The research-grade SnO_2 has higher optical transmittance and higher electron mobility.
- The high optical absorption of the commercial SnO_2 substrate is due partially to the glass substrate and partially to the SnO_2 film quality.
- The high impurity level could contribute to the high optical absorption of commercial SnO_2.
- The smooth SnO_2 surface and i-SnO_2 buffer layer will make the thin CdS layer possible.
- With this characterization, a gain in J_{sc} by as many as 3 mA/cm^2 is possible by improving the SnO_2-coated substrate.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-99GO10337 with the National Renewable Energy Laboratory.

REFERENCES

[1] X. Li, R. Ribelin, Y. Mahathongdy, D. Albin, R. Dhere, D. Rose, S. Asher, H. Moutinho, and P. Sheldon, ÒThe Effect of High-Resistance SnO_2 on CdS/CdTe Device Performance,Ó *AIP Conference Proceedings* **462**, p 230. 1999.

[2]United States Patent, patent Number: 5,698,262, Date of patent: Dec. 16, 1997.

[3] D. Albin, D. Rose, R. Dhere, D. Niles, A. Swartzlander, A. Mason, D. Levi, H. Moutinho, and P. Sheldon, edited by C. Edwin Witt, M. Al-Jassim, and J. M. Gee. CP394, *NREL/SNL Photovoltaics Program Review*, AIP Press **394**, New York 1997 pp. 665-681.

[4] *Optical Processes in Semiconductors*, J.I. Pankove, Dover Publication, Inc., New York, p. 75 (1971).

[5] R.G. Dhere, K. Ramanathan and T.J. Coutts, *Proc. 22nd IEEE Photovolatics Specialists Conf.*, Las Vegas, NV, Oct 7-11, 1991, pp1077.

2008 33rd IEEE Photovoltaic Specialists Conference • San Diego, CA • May 11–16, 2008 • NREL/PO-520-43296