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Application of Combinatorial Tools for Solar Cell Improvement—New High Performance Transparent Conducting Oxides

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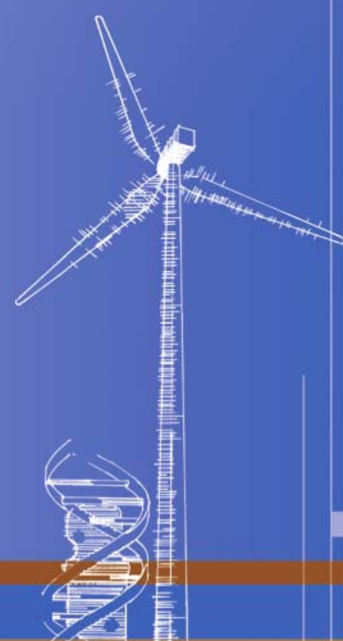

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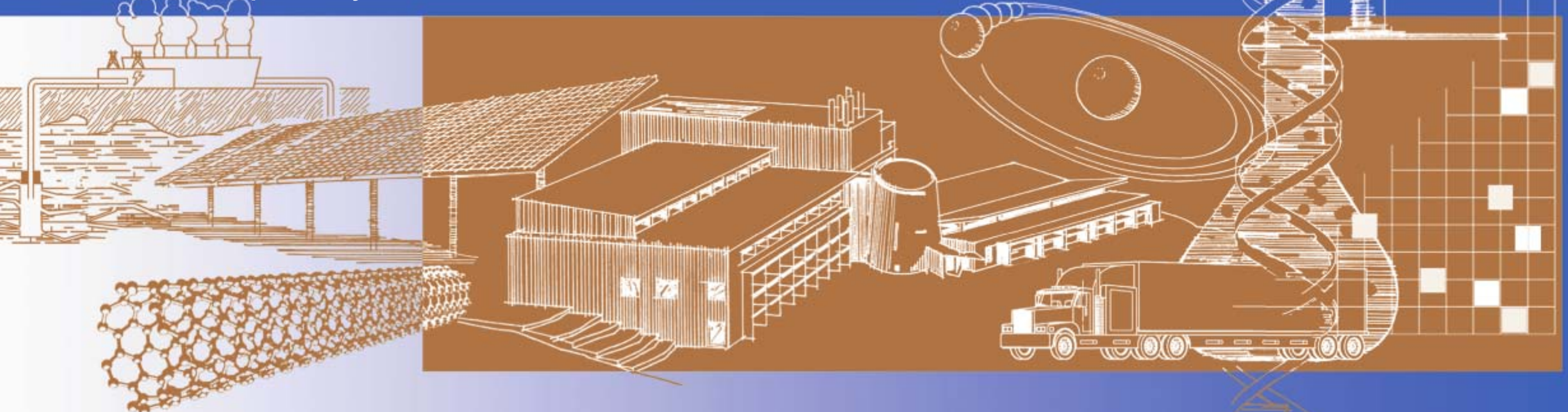

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Application of Combinatorial Tools for Solar Cell Improvement – New High Performance Transparent Conducting Oxides

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ABSTRACT

Transparent conducting oxides (TCOs) can serve a variety of important functions in thin film photovoltaics such as transparent electrical contacts, antireflection coatings and chemical barriers. Two areas of particular interest are TCOs that can be deposited at low temperatures and TCOs with high carrier mobilities. We have employed combinatorial high-throughput approaches to investigate both these areas. Conductivities of = 2500 $^{-1}$-cm^{-1} have been obtained for In-Zn-O (IZO) films deposited at 100 °C and > 5000 $^{-1}$-cm^{-1} for In-Ti-O (ITiO) and In-Mo-O (IMO) films deposited at 550 °C. The highest mobility obtained was 83 cm^2/V-sec for ITiO deposited at 550 °C.

1. Introduction

Transparent conducting oxides (TCOs) can serve a variety of important functions in thin film photovoltaics such as transparent electrical contacts, antireflection coatings and chemical barriers [1]. Two areas of particular interest are TCOs that can be deposited at low temperatures and TCOs with high carrier mobilities. We have employed combinatorial high-throughput approaches to investigate both these areas [2,3].

2. Experimental Approach

Compositionally graded samples ("libraries") are deposited by co-sputtering onto 2"x2" glass substrates. Three to five libraries are generally required to cover the full composition range for a binary tie-line, such as from In_2O_3 to ZnO. In this study, we report on new high performance In_2O_3 based materials substituted separately with Zn, Mo, and Ti [3-6]. After deposition and, in some cases, additional controlled atmosphere annealing, the libraries are characterized by a variety of automated combinatorial mapping tools. At present these include EPMA for metals stoichiometry, 4-pt. probe for sheet resistance, UV/VIS/NIR (200-2000nm) reflection and transmission, FTIR optical reflection and transmission (1.8 – 25 m) and x-ray diffraction (XRD) using a large area 2D detector. For selected libraries, smaller samples are cut out for Hall effect measurements to determine the carrier concentration and mobility.

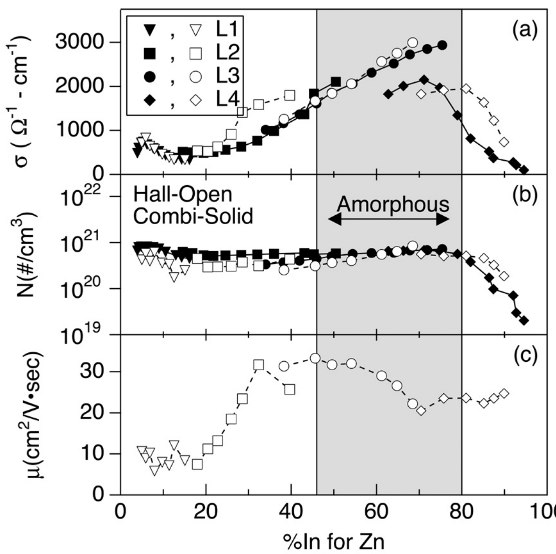

Fig. 1. Electrical conductivity (a), carrier concentration (b) and mobility (c) for In-Zn-O (IZO) deposited at 100 °C.

3. Results and Accomplishments

3.1 In-Zn-O (IZO)

For In-Zn-O (IZO) libraries deposited from ceramic oxide targets at 100 °C in Ar with no post-deposition annealing, a broad maximum in the conductivity with ≈ 2500 $^{-1}$-cm^{-1} is found for x ~ 0.55 to 0.75 in $Zn_{1-x}In_xO_y$ (Fig. 1a). This roughly correlates with the composition range found to be amorphous by the XRD mapping. For higher In content, the carrier concentration decreases (Fig 1b) and for lower In content, the mobility decreases (Fig 1c). For samples with a composition in the amorphous region, the conductivity is unchanged by annealing for one hour in air at 200 °C. Figure 2 shows the optical reflectivity from 0.3 to 25 m for an IZO library compositionally centered on the conductivity maximum. These samples are transparent in the visible region as evident from the spectra shown in the top panel and, in both panels, the solid black circles show the approximate plasma wavelength ($_p$).

3.2 In-Mo-O (IMO)

For In-Mo-O (IMO) libraries deposited at 350 °C, a maximum in the conductivity with ≈ 1000 $^{-1}$-cm^{-1} is found for ~ 6% Mo in place of In (Fig. 3a). Increasing the deposition temperature to 550 °C results in a five fold increase in the maximum conductivity to ≈ 5000 $^{-1}$-cm^{-1}.

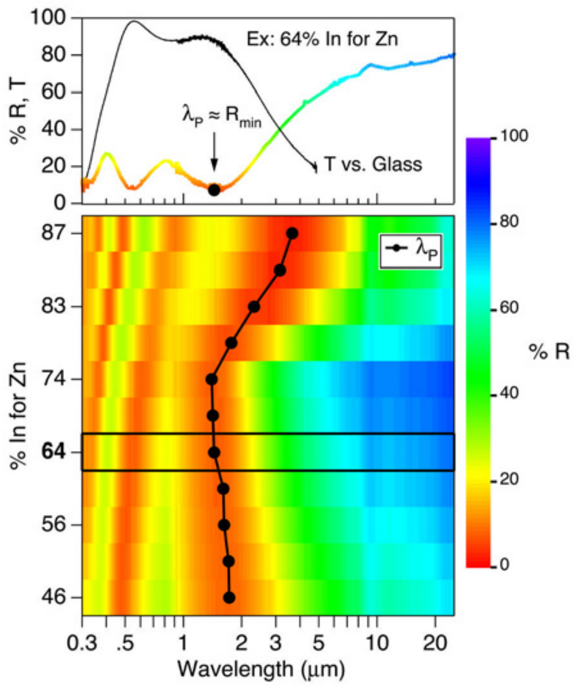

Fig. 2. Optical reflectance spectra for In-Zn-O (IZO) deposited at 100 °C.

This is due to increases in both the carrier concentration and the mobility (Fig. 3b). In particular, for IMO samples grown at 550 °C, the maximum mobility obtained is 65 cm^2/V-sec at ~ 4% Mo and the maximum carrier concentration is 6.6 x $10^{20}/cm^3$ at ~ 8.5% Mo.

3.3 In-Ti-O (ITiO)

For ITiO libraries deposited at T_S = 550 °C, . ≈ 5000 $^{-1}$-cm^{-1} for ~ 3 to 4 % Ti in place of In with a maximum mobility of 83 cm^2/V-sec at ~ 2 % Ti. For the sputtered ITiO samples, there is a linear increase in the carrier concentration of 3.4 x $10^{20}/cm^3$ per %Ti from ~ 1.5 to 3 %

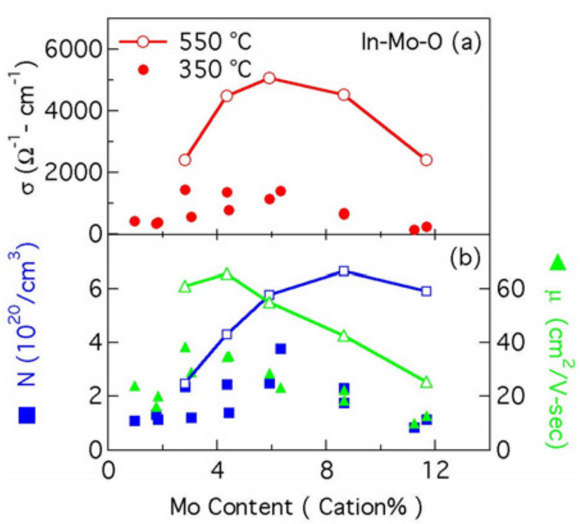

Fig. 3: Electrical conductivity (a), carrier concentration (b, left) and mobility (b, right) for In-Mo-O (IMO) for samples deposited at 350 °C and 550 °C.

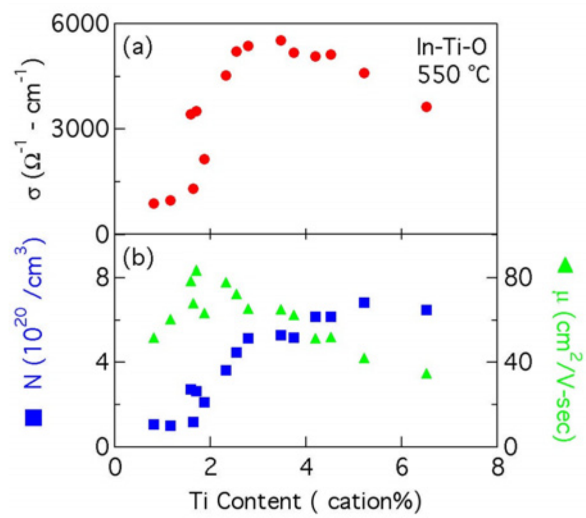

Fig. 4. Electrical conductivity (a), carrier concentration (b, left) and mobility (b, right) for In-Ti-O (ITiO) samples deposited at 550 °C.

Ti. This corresponds to 1.06 electrons / Ti indicating that for these growth conditions, Ti is a very effective dopant for In_2O_3 contributing the expected 1 electron per dopant atom for Ti doping of In_2O_3.

4. Conclusions

We have employed combinatorial high-throughput approaches to investigate both these areas. Conductivities of = 2500 $^{-1}$-cm^{-1} have been obtained for In-Zn-O (IZO) films deposited at 100 °C and > 5000 $^{-1}$-cm^{-1} for In-Ti-O (ITiO) and In-Mo-O (IMO) films deposited at 550 °C. The highest mobility obtained was 83 cm^2/V-sec for ITiO deposited at 550 °C.

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15. SUBJECT TERMS
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