Silicon Heterojunction Solar Cells with Indium-Free Stable Transparent Conducting Oxides

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Introduction

Amorphous (*a*-)SnO_2 transparent conductive oxide (TCO): A promising In_2O_3-based TCO alternative for silicon heterojunction (SHJ) solar cells.

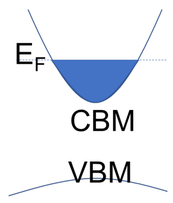
Indium-containing TCOs are commonly used in SHJ solar cells, but the limited availability and economic instability of indium have hindered their widespread use. To address this, researchers have explored In-lean and In-free window electrodes, including In_2O_3-based TCO/dielectric layers and ZnO-based TCO/dielectric layer stacks. However, these multilayered structures increase the manufacturing cost and require verification of damp-heat stability. In this study, we investigate the feasibility of using *a*-SnO_2 TCO fabricated by reactive plasma deposition (RPD) as a stable, indium-free alternative to In_2O_3-based TCO in SHJ solar cells, while maintaining compatibility with current production lines.

Aim and Approach

	crystalline	amorphous
In_2O_3-based	H-, Sn-doped	H-, Zn-doped
SnO_2-based	F-, Sb-doped	uid, Zn-doped

Good conductor ***Poor conductor***

Why?



Our approach ⇨ **Higher ionization ratio** **Less ion bombardment** **than MS**

a-SnO_2 films

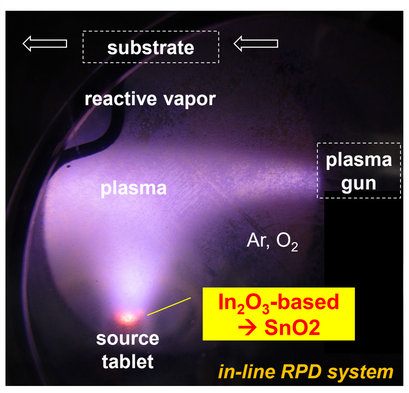
ALD (Atomic Layer Deposition)
High ρ at low $T_{depo.}$ (~200°C)
←Impurity, Density, etc.

MS (Magnetron Sputtering)
Lowest ρ: 3−5E-3 Ωcm
←Defects like O_i and Sn^{2+}?
→Still high R_{sheet} for SHJ cells
400−670 Ω/sq. @75nm-thick

RPD (Reactive Plasma Deposition)
No reports on *a*-SnO_2 films
Low impurity & High density like MS

First report on *a*-SnO_2 TCO films by RPD

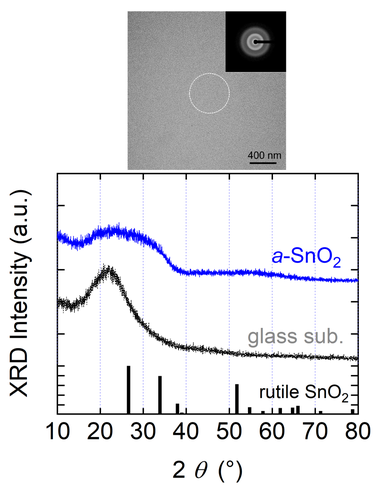
Synthesis



Tablet: SnO_2 ceramic
T_g: w/o heating
Post-annealing:
200°C, 30 min, N_2
Thickness: ~75 nm

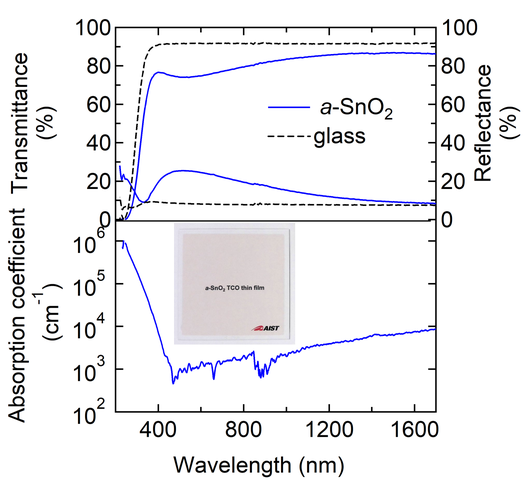
An in-line RPD system is used in current SHJ cell production line. In this experiment, we have just changed the ceramic tablet from conventional In_2O_3-based materials to SnO_2.

Structure



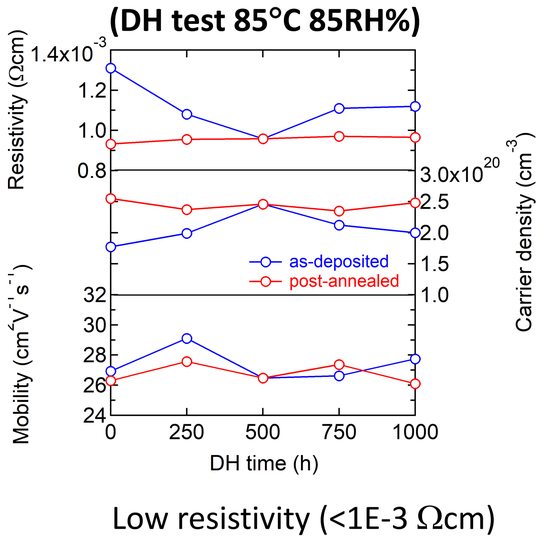
Amorphous structure
(no nano-crystalline)

Optical property



Transparent (1E3 cm-1)
E_g^{opt}: 2.95 eV (Tauc gap)

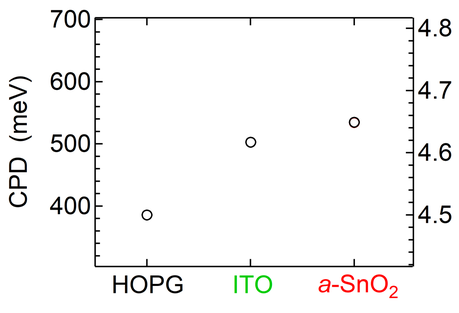
Electrical property (DH test 85°C 85RH%)



Low resistivity (<1E-3 Ωcm)
Stable under DH test

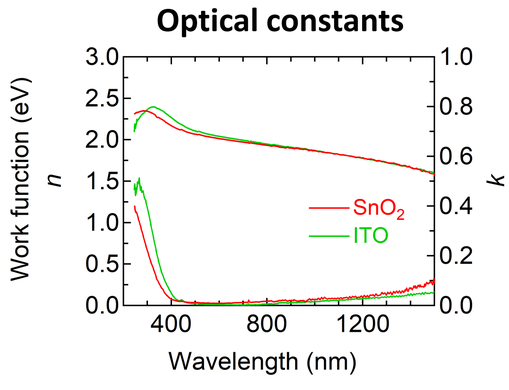
ITO and *a*-SnO_2 films

Work function probed by KP



Similar to ITO

Optical constants



Larger E_g^{opt} than ITO

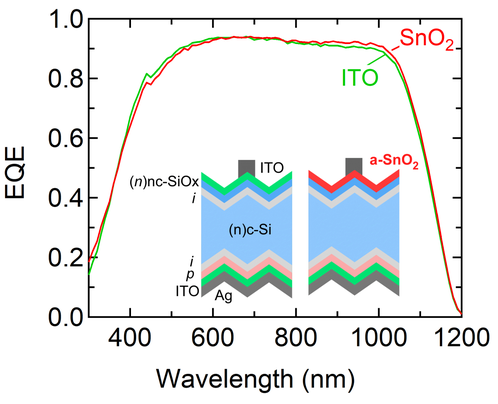
Comparison of SHJ solar cells with ITO and *a*-SnO_2 layers

Process flow of SHJ cell

c-Si wafer
(n-type, 2-3 Ωcm, 280 μm)
↓
Texturing
(KOH-based solution)
↓
Cleaning
↓
PECVD (rf)
↓
TCO deposition
MS-ITO* or **RPD-SnO_2**
(w/o heating, 105 nm thick)
↓
Anneal@160°C
↓
Metallization
↓
Evaluation

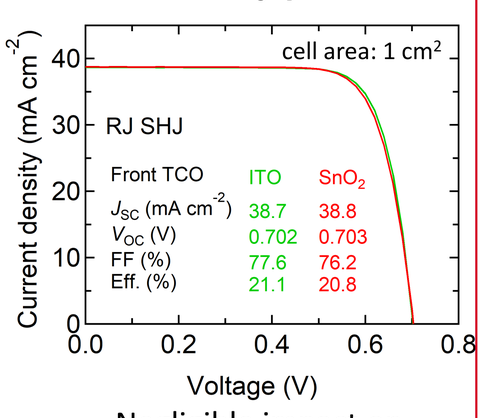
*ITO(90 wt.% In_2O_3- 10 wt.% SnO_2)

EQE



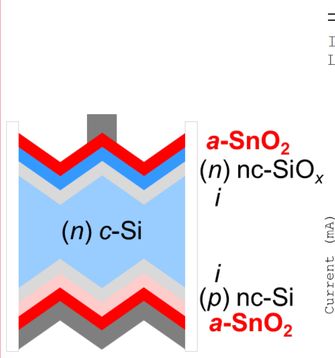
No substantial difference
(The slight difference is simply attributed to the variation in TCO thickness.)

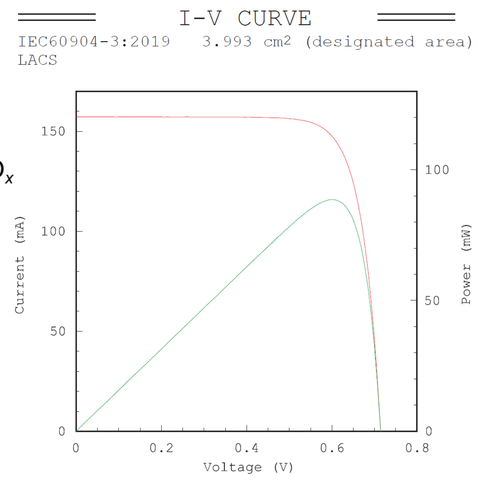
J-V



Negligible impact on
V_{OC}, FF ,and J_{SC}
R_{sheet} of TCOs on textured p/i/c-Si
a-SnO_2: 160 Ω/sq. ITO: 60 Ω/sq.

In-free SHJ solar cells with DH stable *a*-SnO_2 TCOs



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Date : 15 Nov 2022
Data No :D221028-3-1-1
Sample No :D221028-3-1
Repeat Times : 5

Isc      157.2   mA
Voc        0.714  V
Pmax      88.6   mW
Ipmax    147.3   mA
Vpmax      0.601  V
F.F.      78.9    %
Eff(da)   22.18   %
DTemp.    25.0    ℃
MTemp.    25.0    ℃
DIrr.    100.0   mW/cm2
MIrr.     99.9   mW/cm2

Ref. Device No
 J-SY22
Cal. Val. of Ref.
 130.10 [mA at 100 mW/cm2]

Scan Mode
  Isc to Voc
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Summary

- *a*-SnO_2 TCO thin films fabricated by RPD exhibit good electrical conductivity (> 1 × 10^3 Scm^{-1}) and high DH stability.
- The *a*-SnO_2 films exhibit a larger optical band gap compared to *a*-In_2O_3-based TCOs like *a*-IZO and *a*-ITO.
- Incorporation of *a*-SnO_2 in SHJ solar cells shows minimal negative impact on FF, V_{OC}, and J_{SC} compared to solar cells with ITO layers.
- Rear junction SHJ solar cells with *a*-SnO_2 exhibited an efficiency of 22.2%, highlighting the potential of *a*-SnO_2 as a cost-effective and sustainable alternative to conventional In_2O_3-based TCOs in solar cells and other applications.

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