

"Transparent conducting sol-gel ATO coatings for thin PV device applications"

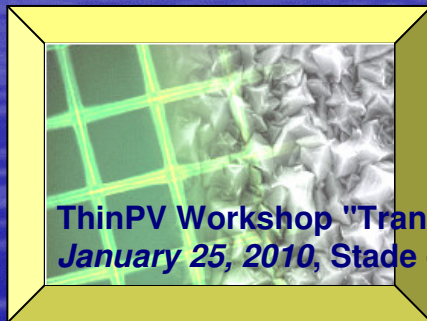
ATO coatings: liquid based deposition processes for Photovoltaic and other applications

Dr. Guillaume Guzman

Invited speaker

Materials & Thin films for emerging technologies

e-mail: guzman.box@gmail.com



ThinPV Workshop "Transparent Conducting Oxides "
January 25, 2010, Stade de Suisse, Bern, Switzerland



Content

- Background
- Properties of ATO
- Applications of ATO thin films
- Photovoltaic applications of ATO
- Wet chemical deposition processes of ATO
 - Applications
- Concluding remarks

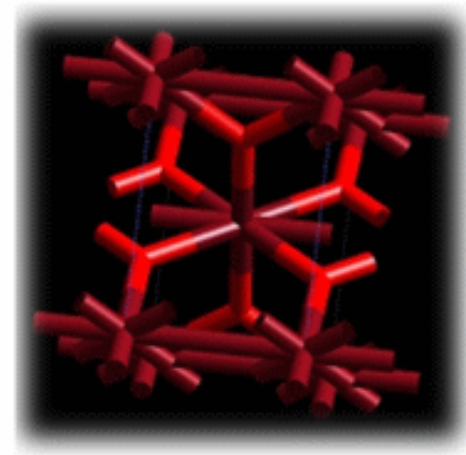
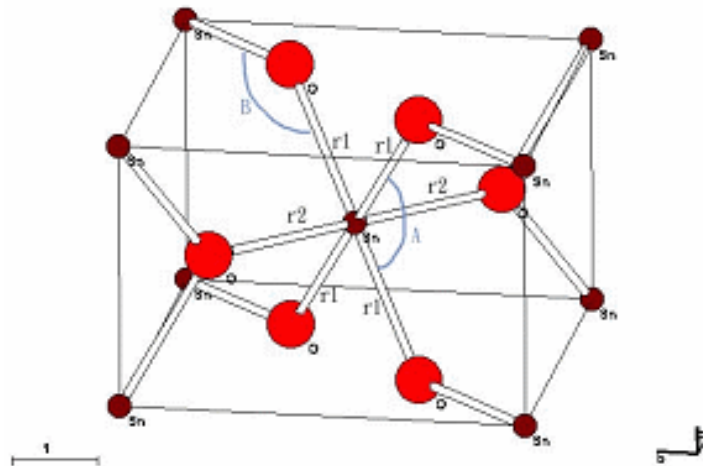


Content

- **Background**
- Properties of ATO
- Applications of ATO thin films
- Photovoltaic applications of ATO
- Wet chemical deposition processes of ATO
 - Applications
- Concluding remarks

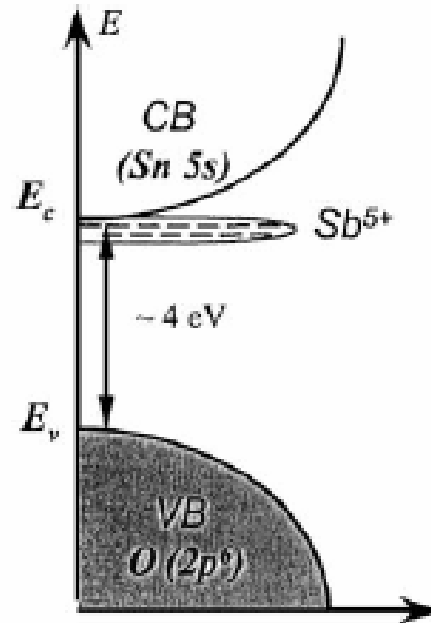
SnO₂

- Tin oxide is a very important n type semiconductor with almost wide band gap energy ($E_g=3.6$ eV) at the room temperature which is used in the fabrication of gas sensors, solar cells, Flat Panel Displays...
- Tin oxide (SnO₂) crystallize in rutile structure (tetragonal; $a=b=0.474$ nm and $c=0.319$ nm), wherein the tin atoms are 6 coordinate
- Electrically conductive when oxygen deficient
- Conductivity is better controlled by doping



Sb doped SnO₂ (ATO)

- Is a n-type donor
- The sharp increase of electrical conductivity is due to the formation of Sb⁵⁺ energetic levels overlapping the bottom of the conduction band





Content

- Background
- **Properties of ATO**
- Applications of ATO thin films
- Photovoltaic applications of ATO
- Wet chemical deposition processes of ATO
 - Applications
- Concluding remarks



ATO Properties

- Low resistivity ($\sim 10^{-3}$ Ohm.cm)
- Optically transparent ($> 80\%$)
- Infrared reflecting
- Hardness (Mohs): 6.5
- High work function (>5 eV)
- Etchant: $Zn+HCl$ or $CrCl_2$
- Thermal stability ($>400^\circ C$)
- Relatively low cost



Content

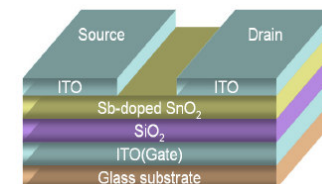
- Background
- Properties of ATO
- **Applications of ATO thin films**
- Photovoltaic applications of ATO
- Wet chemical deposition processes of ATO
 - Applications
- Concluding remarks

Applications of SnO₂:Sb

SnO₂:Sb is used extensively in (similar for other TCOs):

- **Heat shields for protection** against long wavelength ir radiation
Solar Cells (light trap, electrode, protecting layer) – Low E glass
- **Solar energy collectors**
- **Defrosting Windows** preventing the formation of ice
- **Oven Windows**
- **Static Dissipation** (antistatic coating on glass)
 - airplane windows, optical instruments, electrical meters, ...
- **Electrochromic Mirrors and Windows**
- **Flat-Panel Displays**
- **Touch-Panel Controls**
- **Invisible Security Circuits**
- **Improving the Durability of Glass**
- electrodes for nuclear detectors

- Potential for transparent electronics on glass ¹



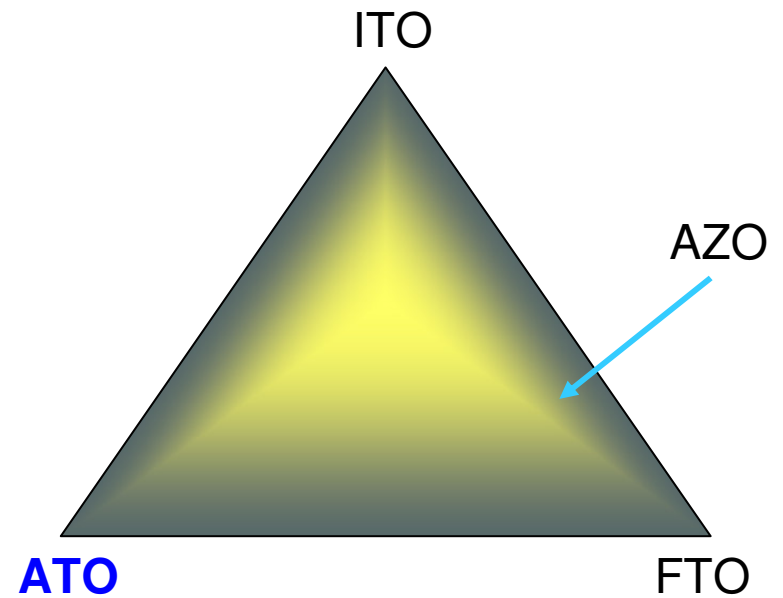
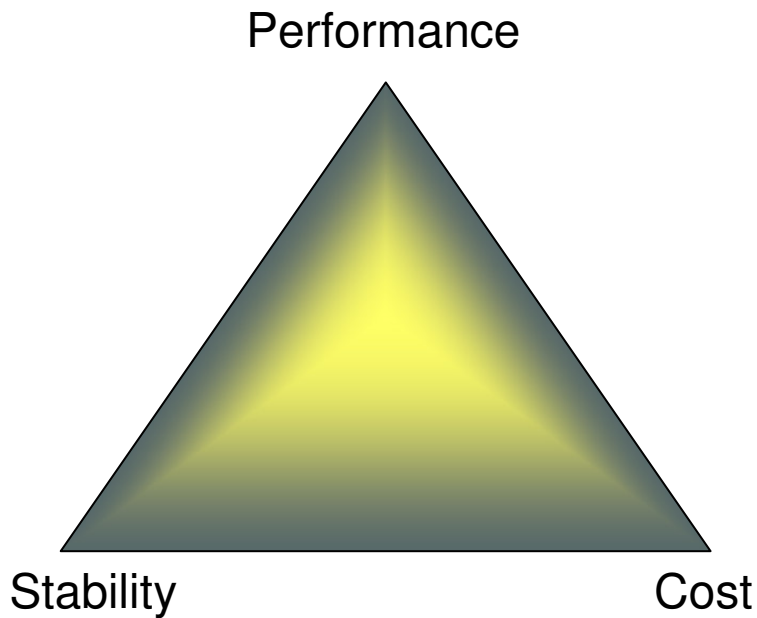


Content

- Background
- Properties of ATO
- Applications of ATO thin films
- **Photovoltaic applications of ATO**
- Wet chemical deposition processes of ATO
 - Applications
- Concluding remarks

ATO is an alternative for Photovoltaics

- Product attributes balance



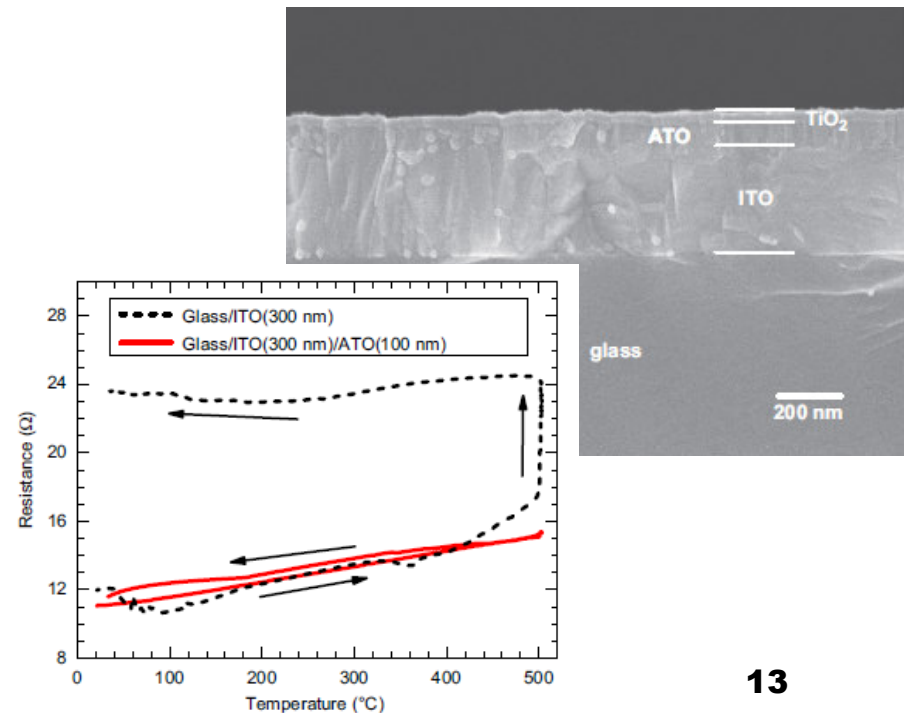
ATO for photovoltaics

- High work function (5.2 eV) good contact to p -Si ⁽³⁾
- For undoped tin oxide the absorption edge lies at 3.65 eV and for FTO and ATO it lies in the range 3.9 - 4.14 eV and 3.82 - 4.1 eV respectively. This shift in shorter wavelength region is an advantage for solar cell applications since it improves the short wavelength response of the cell ⁽¹⁾
- Cadmium telluride and some amorphous-silicon solar cells can be grown on a SnO₂ doped-covered glass substrate⁽³⁾
- ATO layers improve thermal stability of ITO in DSCs⁽²⁾ and in CdTe solar cells⁽⁴⁾

ATO in Dye sensitized Cells

- The sheet resistance of ITO significantly increased during the annealing process
- ATO layer on ITO delayed significantly the increase in sheet resistance of ITO substrate from the thermal oxidation at high temperature (500 °C).
- The double-layered ITO/ATO/TiO₂ in dye-sensitized solar cells improved efficiency and photovoltaic properties of the DSCs

Substrate	Substrate sheet resistance (500 °C, 1h; Ohm/square)	Jsc (mA/cm ²)	Voc (V)	η (%)
ITO	29.4	14.1	0.681	4.5
ITO/ATO	6.7 – 9.8	13.8	0.684	4.57-6.2
ITO/AZO	18.3	7.3	0.774	3.4
ITO/ATO/TiO ₂	9.8	10.7	0.813	6.4





Content

- Background
- Properties of ATO
- Applications of ATO thin films
- Photovoltaic applications of ATO
- **Wet chemical deposition processes of ATO**
 - Applications
- Concluding remarks



Wet chemical processes for ATO films

Deposition processes

- Spray based methods
- Dipcoating and spincoating based methods

Soft chemistry

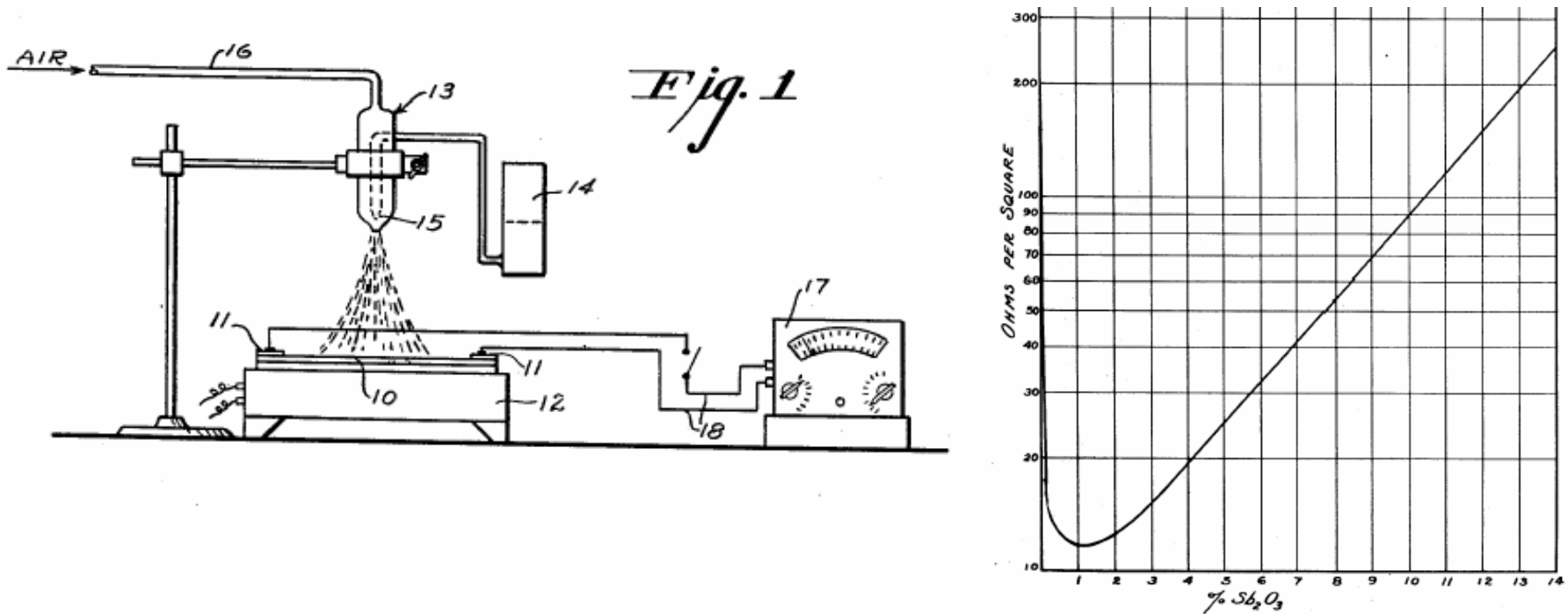
- Organometallic solutions
- Condensation of Nanoparticles from salts
 - Chemical
 - Thermal

Most promising

- Spray combustion of ATO solutions
- In line spray of nanoparticles on hot substrate & dipcoating

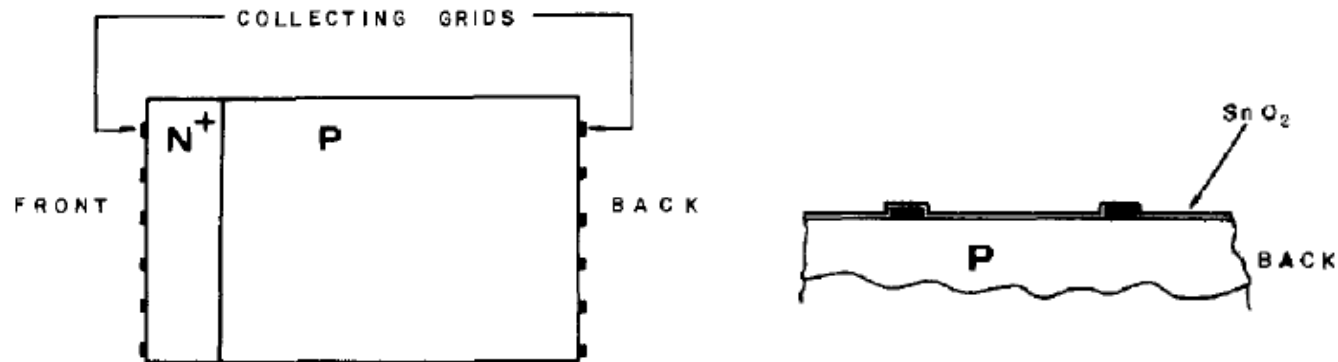
ATO thin films: Early results

- Spray pyrolysis was first used commercially more than half a century ago to deposit conductive tin oxide films on heated glass plates in batch processes.
- SnO₂:Sb (ATO) by spray pyrolysis J.M. Mochel, 1950



ATO on cSi solar cells

- Spray deposited at 300- 400 °C
- Antireflecting and conducting layers
- Drastic reduction of the surface recombination velocity at the interface is observed.
- Increased electrical conductivity on Sb doped SnO₂
- ATO provides high temperature stability





ATO on solar collectors

- ATO layer acts as a protective layer on black coatings and also provides low emissivity.
- Dipcoated of sol-gel nanoparticles
- Deposition on anodized aluminum
- Solar absorption greater than 0.90
- Hemispherical emittance at 100°C less than 0.30
- ATO increased thermally, chemical and mechanical stability



n-ATO/p-PSi heterojunction

- ATO/p-PSi photovoltaic sensor
- Band gap tuned
- Deposited by Spray pyrolysis method
- Sensor is employed for sensitive angle detection of a light source
- Improved signal detected 0 – 3.6 V (0 – 360 °C)

Applications

Meteorology

Agriculture and horticulture

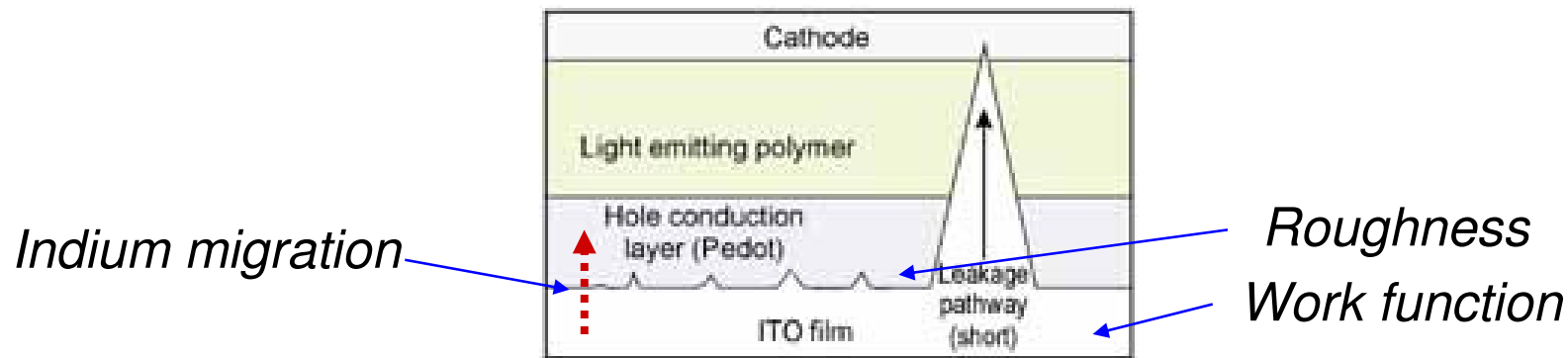
Greenhouse management

Solar radiation intensity

Emergency services

Interface layer in OLEDs and OPVs

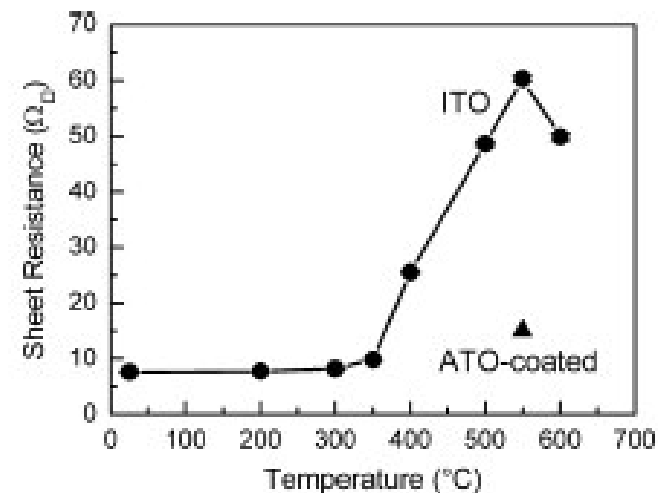
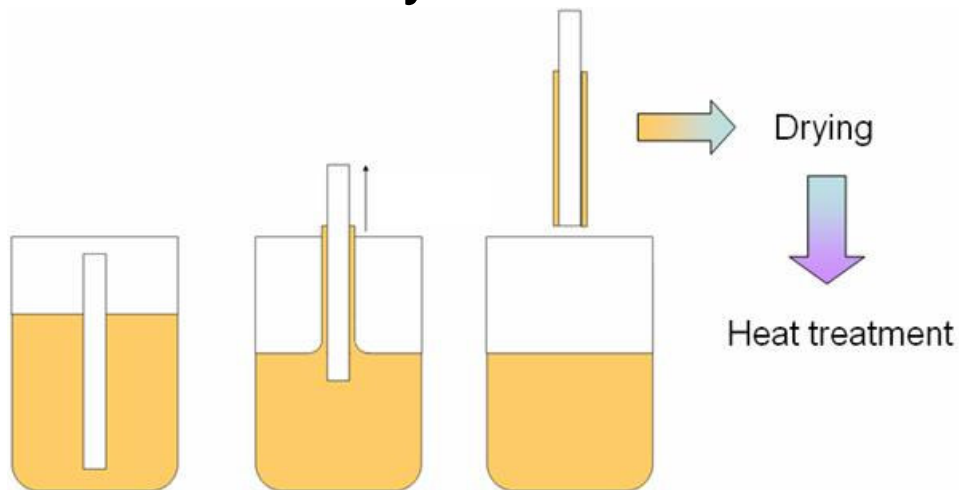
- Issues in OLED devices:



- Smoothness is critical in OLED devices
- High effective hole injection needed
- Similar issues for OPVs

Smoothing layer

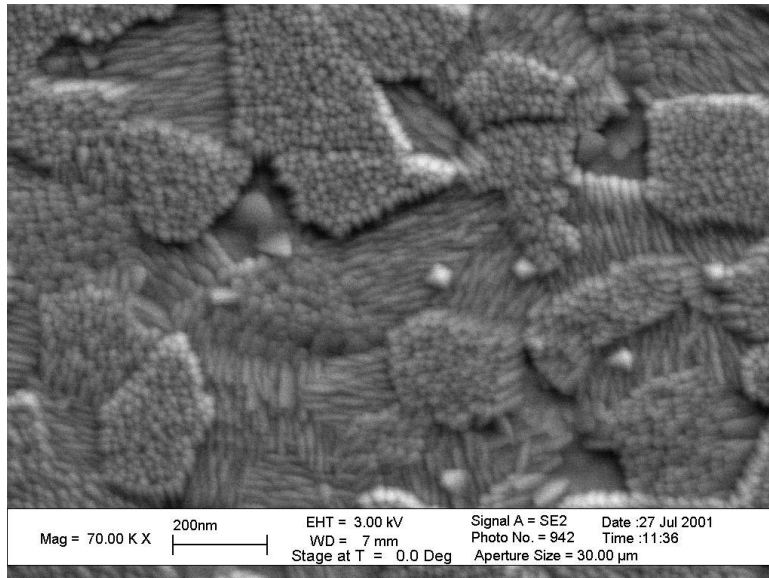
- Alternative: Dipcoating process
 - Low impact on resistivity
 - High smoothing effect
- Material: ATO
 - High work function match OLED or OPVs
 - Thermally stable



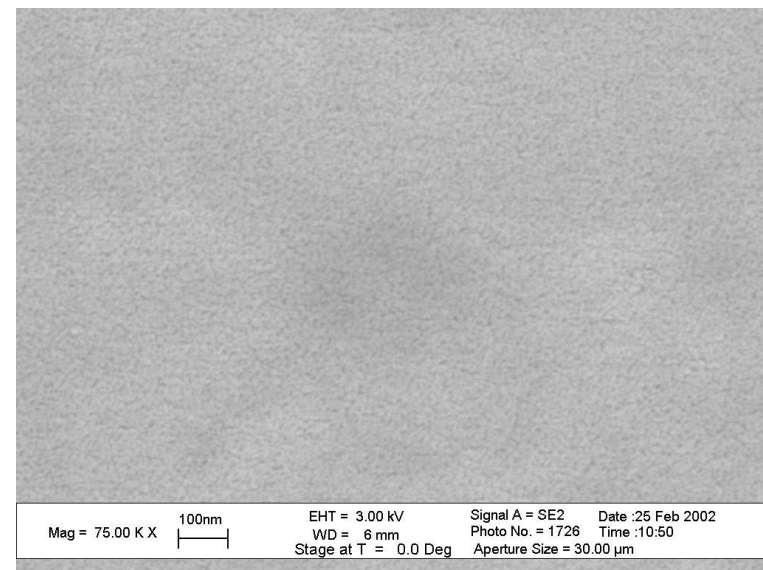
Smoothing layer for ITO

- Effective smoothing observed by SEM after dipcoating

Sputtered ITO



ATO on Sputtered ITO



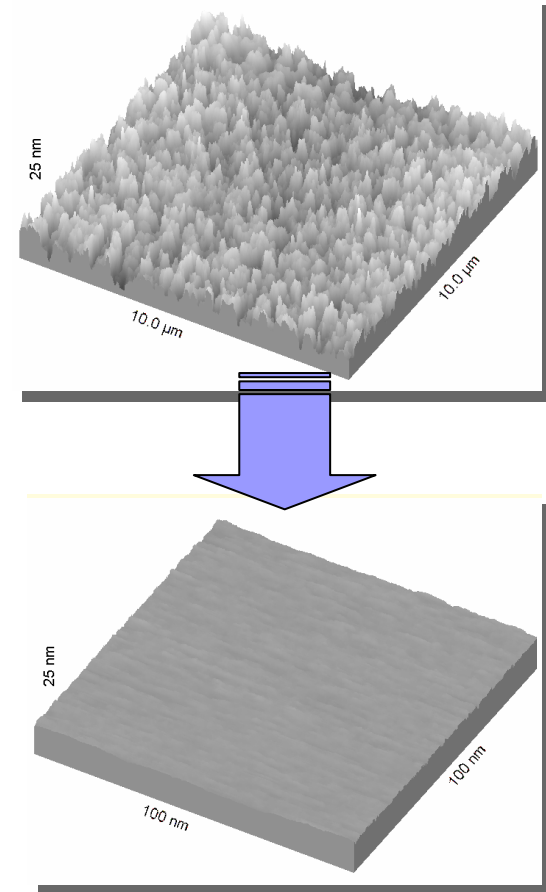
Smoothing layer: Low roughness

- Physical properties
 - Work function increased
 - Low impact on electrical conductivity

Properties of sol-gel ATO coatings and ATO coated and bare ITO substrates

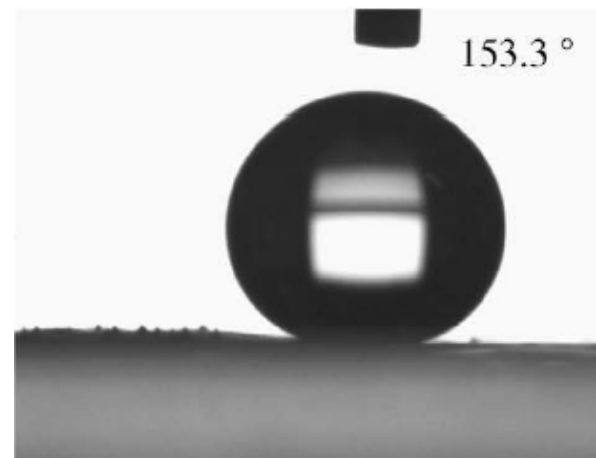
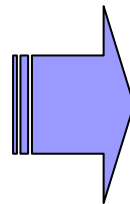
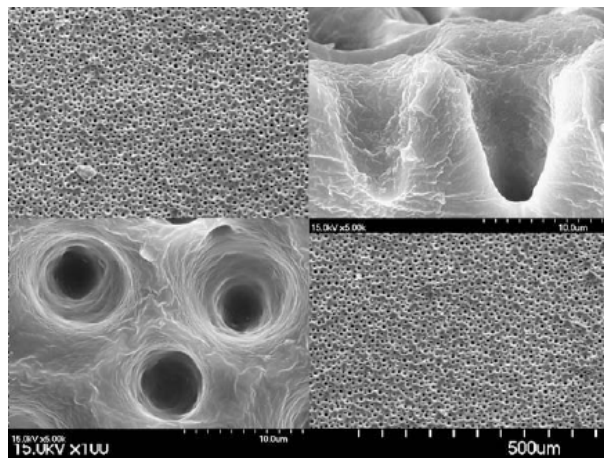
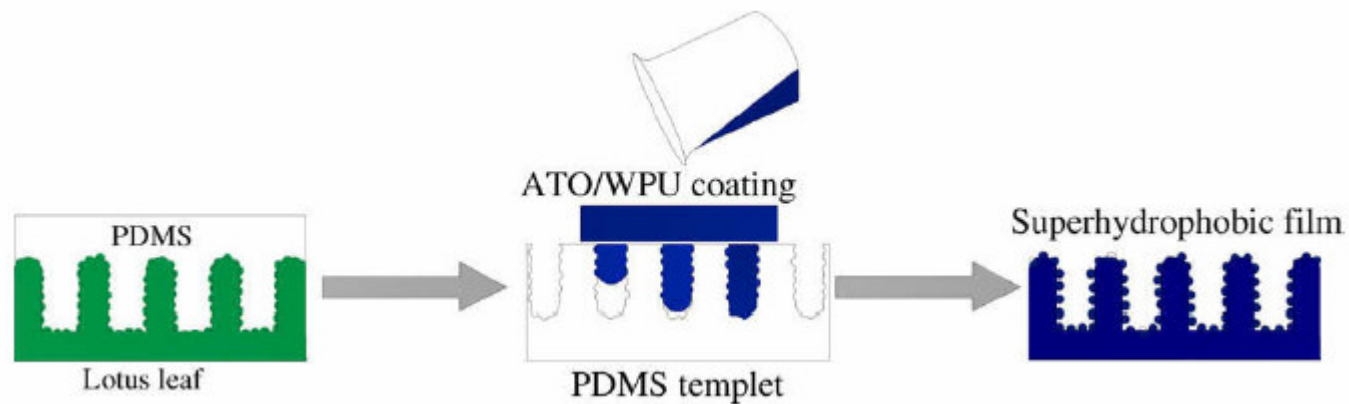
Coating	Thickness (nm)	Sheet resistance Ω_{\square}	R_a (nm)	R_{pv} (nm)	Work function (eV)
ITO	192±2	7.7±0.1	3.8	31	4.3 - 4.6
ATO	45±1	5.4x10 ³ ±21			4.8 - 5.2
ATO/ITO	238±4	17.0±0.5	0.4	3.8	4.8 - 5.3

R_a and R_{pv} were determined by AFM on scale of 100x100 nm²



Super-hydrophobic and heat insulating ATO

- Softlithography used to cast ATO/WPU composite lotus leaf like hierarchical structures



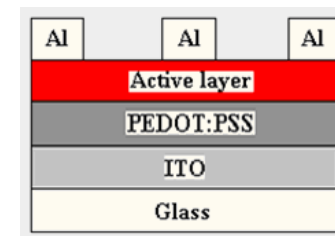


Content

- Background
- Properties of ATO
- Applications of ATO thin films
- Photovoltaic applications of ATO
- Wet chemical deposition processes of ATO
 - Applications
- **Concluding remarks**

«New thin film material for PV»

- Dipcoating is an effective technique to significantly reduce roughness. In particular for organic thin film solar cells
 - May be adapted choice to small or large size for photovoltaic cells
- The high work function of ATO may be good interface layer to increase cell efficiency
- ATO stability may increase cell durability and reliability
- Super-hydrophobic for clean surfaces on solar cells or solar collectors



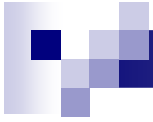
Concluding remarks

- **Might be good balance cost/stability/quality**
 - Conductivity ITO>AZO>**ATO**~FTO
 - Cost ITO>**ATO**>AZO→FTO
 - Stability (electrical/thermal) **ATO**>AZO>FTO>ITO
 - Stability (environmental/chemical): **ATO**>ITO>FTO>AZO
 - Visible optical transmission similar for all these TCOs
 - UV and IR properties depends of the material & device
- **Due to Sb low doping, no significant issues to use ATO**
- **Low roughness films from dipcoated films**
- **Recent results of ATO could be advantageously adapted to PV applications**
 - ATO opens new possibilities to improve modern photovoltaic cells



■ REFERENCES

- Chambouleyron 1979 – I. Chambouleyron et al.; Solar Energy Materials 1 (1979) 299-311
- Feng 2009 - J. Feng et al.; Journal of Colloid and Interface Science 336 (2009) 268
- Gordon 2000 – Roy G. Gordon, MRS Bulletin August 52-57 2000
- Guzman 2006 – G. Guzman et al.; Thin Solid Films 502 (2006) 281 – 285
- Mochel 1950 – J.M. Mochel, U.S. Patent No. 2,522,531 (1950).
- Naghavi 2003 – N. Naghavi et al.; Solid State Ionics 156 (2003) 463– 474
- Sabaapathy 2007 – R. Vivek Sabaapathy et al.; Ionics (2007) 13:311–317
- Shanthy 1999 – S. Shanthy et al.; Cryst. Res. Technol. **34** (1999) 8 1037–1046
- Sukeguchi 2009 – D. Sukeguchi et All.; Beilstein J. Org. Chem. 2009, 5, No. 7
- Sun 2009 – J. Sun et al.; Nanotechnology 20 (2009) 335204 (5pp)
- Varol 1996 – H.S. Varol et All.; Solar Energy Materials and Solar Cells 40 (1996) 273-283
- Yoo 2008 – B. Yoo et al.; Solar Energy Materials & Solar Cells 92 (2008) 873–877



THANK YOU FOR YOUR ATTENTION