Advanced Deposition Control for High Quality Coatings for "Green" Windows

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Abstract

Thin films of high quality transparent conductive oxides (TCO) can be synthesized for energy efficient windows and other applications by filtered cathodic arc deposition (FCAD). Aluminum-doped zinc oxide, ZnO:Al or AZO, is a well-known n-type TCO with great potential in a number of applications currently dominated by indium tin oxide. In the Plasma Application Group, the optical and electrical properties of AZO thin films deposited on glass and silicon by pulsed FCAD are systematically studied. The best films, grown at a temperature of about 200 degrees C, have resistivities in the low to mid 10-4 Ω cm range with a transmittance better than 85% in the visible part of the spectrum. However, the electrical properties are highly dependent on the oxygen partial pressure during growth, which can fluctuate significantly over the duration of the growth.

In order to reproducibly deposit the best quality AZO films, the conditions must be precisely controlled before and during the experiment, especially the oxygen partial pressure. Previously, oxygen pressure was simply set before growth and allowed to evolve. In this work, the LabVIEW software package was used to devise a simple feedback control system for the oxygen pressure during growth using mass spectrometers and flow controllers. This system is expected to improve the reproducibility of the depositions, which is a key factor for controlled studies of film properties.

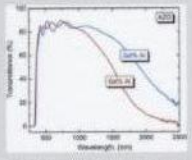
Motivation

The United States has been striving for several decades to improve energy production, utilization efficiency, and to lower consumption. LBNL has been at the forefront of this effort. The ***Plasma Applications Group and Dr. Andre Anders*** have pioneered experimental and applied research in the areas of "Filtered Cathodic Arc Deposition(FCAD)" techniques to increase the energy efficiency of windows in the future. These research techniques can also be applied to other technologies and product development with procedure modifications and combining research methodologies (i.e. Metallic nitride-TiAlN- thin films coatings on metallic tools can greatly increase the hardness of the tools surface). Plasma Applications Group's objective, and my focus, is to work on collaborative project(s) exploring new materials for next generation designs to enhance windows, and therefore building, energy efficiency.

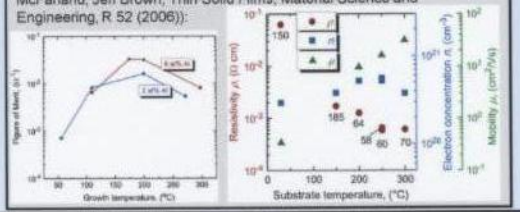
Zinc Oxide

>>Currently ITO is the leading industry standard for TCOs applications
>>Due to the limited resource, the cost of indium is very high compared to Zinc

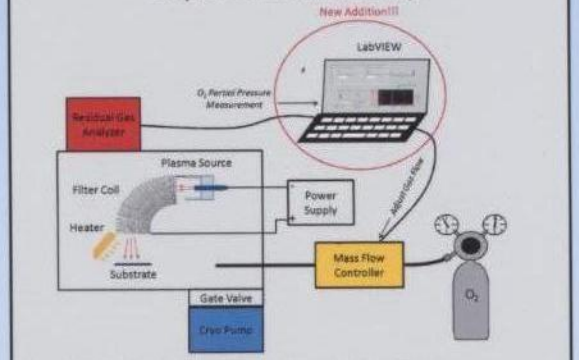
In (Indium): (~$10/g)
Ag (Silver): (~$4.40/g)
Cu (Copper): (~$3.50/g)
Au (Gold): (~$35/g)
Zn (Zinc): (~$0.90/g) *
*Price is dependent on purity: this is for a 99.98% pure lump



>>The range of substrates on which ITO can be used is limited due to its brittleness and the need for high deposition temperatures.
>>AZO films grown at 300 degrees C have good electron concentration, mobility and low film resistivity as a function film thickness (André Anders, Sunnie H. N. Lim, Kin Man Yu, Joakim, Johanna Rosen, Mike McFarland, Jeff Brown, Thin Solid Films, Material Science and Engineering, R 52 (2006)):

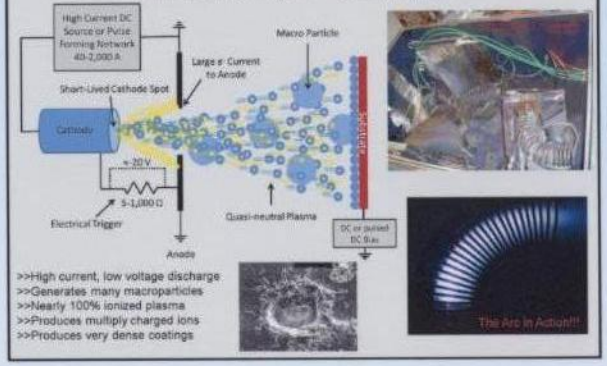


Experimental Set Up



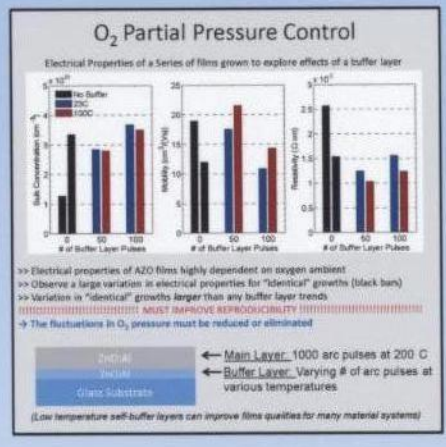
>>The cathode material is zinc doped levels of aluminum (0–6 at.%) (ZnO:Al).
>>Pure oxygen is injected into chamber using an MKS mass flow controller
>>Process gas composition is monitored by differentially pumped quadruple mass spectrometer
>>Main chamber is cryogenically pumped to a 10-4 Pa. base pressure with an adjustable gate valve.
>>Glass microscope slides typically used as substrates, heated to 200-400 C

Filtered Cathodic Arc Deposition

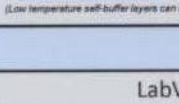


>>High current, low voltage discharge
>>Generates many macroparticles
>>Nearly 100% ionized plasma
>>Produces multiply charged ions
>>Produces very dense coatings

O_2 Partial Pressure Control



>> Electrical properties of AZO films highly dependent on oxygen ambient
>> Observe a large variation in electrical properties for "identical" growths (black bars)
>> Variation in "identical" growths *larger* than any buffer layer trends
MUST IMPROVE REPRODUCIBILITY
→ The fluctuations in O_2 pressure must be reduced or eliminated



← Main Layer: 1000 arc pulses at 200 C
← Buffer Layer: Varying # of arc pulses at various temperatures

(Low temperature self-buffer layers can improve films qualities for many material systems)

LabVIEW

A graphical programming language for instrument integration and control.

>>Integrates 1000s hardware devices to develop customized measurement, test, and control systems.

>>Uses intuitive graphical icons and wires to show the program "flowchart" and experiment dataflow.

>> Provides hundreds of built-in libraries for advanced analysis and data visualization – all for creating virtual instrumentation.

>>Since LabVIEW is the industry leader it is used by millions of engineers and scientists facilitating the portability of its' control programs and facilitating reproducible test, monitoring, data acquisition, analysis, and reporting conditions

Conclusions and Future Work

>> RGA gas sensor may not respond fast enough for adequate control

>> On relatively long time scales (2-3 seconds) simple ratio control provides decent control

>>Applying a full proportional-integral-derivative (PID) control may help to improve the stability of the feedback system

>>Automate control of the chamber vacuum gate valve and cryo pump, the substrate surface infrared temperature monitor for additional fast and accurate pressure and temperature control.

>>Add "on demand" logging and reporting of control and experiment data acquisition.

>>Use LabVIEW Simulation and Visualization capability expand and explore research to analyze new materials, support design and operation of TCO coated windows in Net Zero Energy buildings

Acknowledgements

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