A Single Layer Thin-Film Moisture Barrier for CIGS Solar Cells

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Introduction

•CIGS cells have very high demonstrated efficiency: ~20% for 1 cm² size.

•Flexible CIGS cells with module efficiency > 10% are attractive for building integrated application.

•But CIGS cells are moisture sensitive. Modeling studies [1,2] deduce that encapsulation with water vapor transmission rate (WVTR) of 10^{-4} to 10^{-6} g-H_2O/m²-day is needed for long lifetime (> 20 years).

Approach

• Develop ALD barriers and evaluate using Ca test

• Fabricate baseline 1 cm2 CIGS devices on glass at IEC by multisource evaporation

• Encapsulate using various barrier layers

• subject to damp heat (85°C, 85% RH) stress for 1000 hrs under ~ 1 sun illumination, Voc.

Atomic Layer Deposition (ALD)

• layer-by-layer growth process

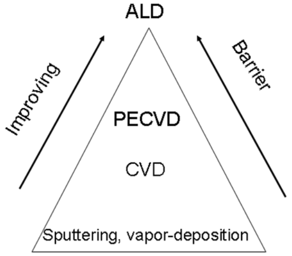
• self-limiting, sequential, saturating surface reactions

• produces pin-hole free inorganic films with ultra-barrier properties [3]

• this work, ALD process for growth of Al_2O_3 films from trimethyl aluminum and water.

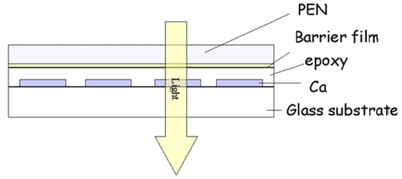
• ALD is a superior process for producing thin-films with ultra-barrier (WVTR~10^{-6} g-H_2O/m²-day) properties-

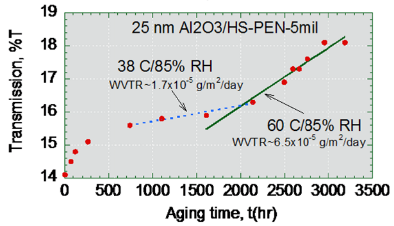
• **Significantly better than other processes.**



Moisture Barrier Properties of ALD thin-film Al_2O_3

Fig. 2. Ca-test for ultra-barriers

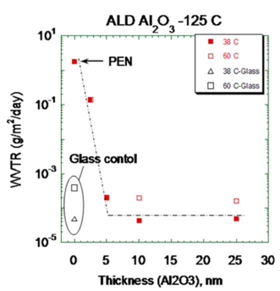




WVTR= ρ(Ca(OH)$_2$) × D(Ca(OH)$_2$)/t × 2 x m(H_2O)/m(Ca(OH)$_2$)

(g- H_2O/m²-day) [Ref. 4]; D(Ca(OH)$_2$) from optical modeling.

Fig. 3 Dependence of WVTR on Al_2O_3 thickness. Substrate is polyethylene naphthalate (PEN).



Temperature-dependent WVTR

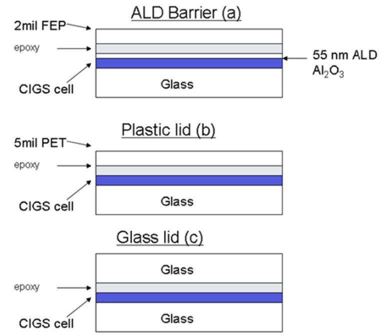
Temperature (°C)	WVTR (g/m²-day)
60	6.5×10^{-5}
38	1.7×10^{-5}
23*	**6.0×10^{-6}**

*Value at 23°C based on apparent activation energy of Ea= 52 kJ/mole

Three Encapsulants on CIGS Test Structures

(a) 55 nm thick ALD Al_2O_3
(b) a PET plastic lid
(c) a glass lid

Fig. 4 Test structures with glass/CIGS devices.



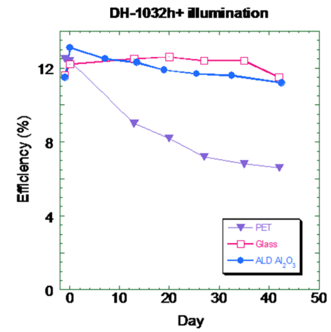
Efficiency of CIGS structures:

1000 hrs@ 85° C/85% RH+light at open circuit

• Cells protected with a single ALD Al_2O_3 barrier layer or a glass lid change little (<3%) after aging > 1000 hr. in "damp heat" (85°C/85% RH) with illumination

• Cells protected only with a plastic lid degrade significantly.

Fig. 5 Dependence of CIGS cell efficiency on encapsulation with damp heat +illumination.



Comparison of Voc, FF, and Jsc for CIGS with ALD layer (solid symbols) and glass lid (open symbols).

• With ALD barrier (solid)

-no change in Voc and FF

-decrease in Jsc attributed to "yellowing" of the epoxy, solved by a more robust encapsulant

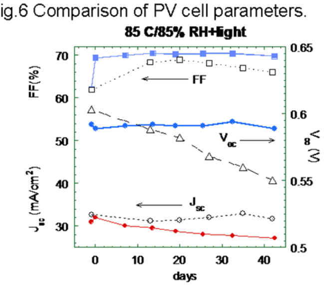
• With glass lid (open)

-Voc decreased 50 mV

• With PET lid (not shown)

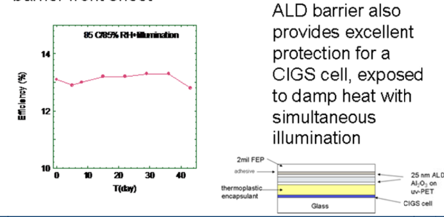
-all parameters decreased significantly, consistent with the ~50% decrease in efficiency

Fig.6 Comparison of PV cell parameters.



Flexible (PET) front sheet with ALD Barrier

Fig. 7. Damp heat test of CIGS cell with flexible ALD barrier front sheet



A flexible PET lid coated with a thin ALD barrier also provides excellent protection for a CIGS cell, exposed to damp heat with simultaneous illumination

Conclusions and References

From damp heat testing with simulated solar illumination, a single layer ALD Al_2O_3 thin-film ultra-barrier has been shown to provide superior moisture protection for CIGS cells, either by direct ALD deposition on the cell or with an ALD-coated plastic lid.

References

[1] M. D. Kempe, Modeling of rates of moisture ingress into photovoltaic modules, Solar Energy Mater. & Solar Cell 90 (2006) 2720-2738.

[2] D. J. Coyle, H.A. Blaydes, J. E. Pickett, R. S. Northey, and J. O. Gardner, Degradation kinetics of CIGS solar cells, in Proceedings of the 35th IEEE Photovoltaics Specialists Conference (2009).

[3]. P. F. Carcia, R. S. McLean, M. H. Reilly, M. D. Groner, and S. M. George, Ca-test of gas diffusion barriers grown by atomic layer deposition on polymers, Appl. Phys. Lett. 89 (2006) 031915-1-3.

[4] P. F. Carcia, R. S. McLean, M. D. Groner, A. A. Dameron, and S. M. George, Gas diffusion ultrabarriers on polymer substrates using Al2O3 atomic layer deposition and SiN plasma-enhanced chemical vapor deposition, J. Appl. Phys. 106 (2009) 023533-1-6.