BAPVC Annual Project Report

Project Title: Tailoring Electrostatic Interactions to Produce Hybrid Barrier Films for Photovoltaics

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Summary:
In this program, the Kippelen/Graham groups at Georgia Tech have developed barriers coatings using a combination of vacuum deposition methods (PECVD and ALD) that were tested on various photovoltaic systems ranging from crystalline Si to organic photovoltaics. Encapsulation of devices has been achieved by using either a direct deposition process of the barrier layers onto the device or by using indirect methods where the barrier is laminated to the device structure. During the past year, barriers with various structures including ALD nanolaminates, and PECVD/ALD hybrid structures have been studied and characterized in terms of effective water vapor transmission rate measured during damp heat testing. All of these structures were tested using optical Ca tests. High performance was achieved through control of the mechanical properties and film architecture.

Key Accomplishments:

I. Integration of Hybrid Barriers With Perovskite (with McGehee Group, Stanford), CdTe Solar Cells (with Wolden Group, Colorado School of Mines): The performance of the newly developed hybrid barrier films was tested on perovskite solar cells fabricated in the McGehee group at Stanford. The barrier films were prepared on PEN substrates at Georgia Tech and used to encapsulate the devices as shown in Figure 1. The SiN_x film was deposited using plasma-enhanced chemical vapor deposition (PECVD), and the Al_2O_3 and TiO_2 films were deposited using atomic layer deposition (ALD). Afterwards, the prepared barrier films were applied on the perovskite solar cells using a UV-curable adhesive. While good stability was observed in packaged perovskite cells stored in ambient laboratory conditions (see Fig. 1b), the cells were found to degrade rapidly under continuous light soaking experiments possibly caused by a reaction between the UV-curable epoxy and the perovskite layer.

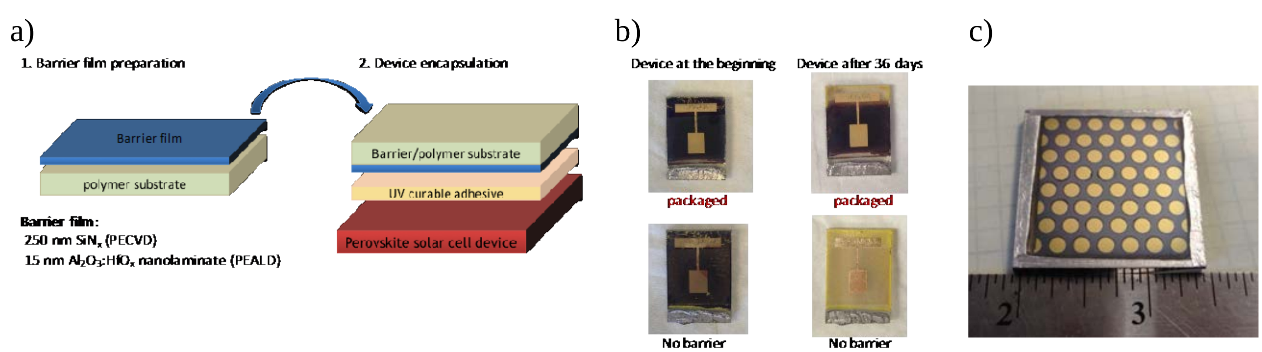

Figure 1: a) Device encapsulation procedure for perovskite solar cells; b) Photographs of encapsulated cells and reference cells stored under ambient conditions; c) Photograph of CdTe solar cells encapsulated using the direct deposition of hybrid barrier layers.

The performance of the hybrid barrier films was also evaluated on CdTe solar cells received from the Wolden Group at the Colorado School of Mines. As an initial test, the barrier film was directly deposited onto the CdTe solar cells (see Fig. 1c) and no degradation in performance was observed after the encapsulation process. Studies are underway to test the lifetime of these cells under harsh damp hear environmental conditions.

II. Reducing the Impact of Residual Stress on the Mechanical Reliability of Hybrid Barrier Films: The Kippelen/Graham groups have shown that the use of polymer layers to passivate particle defects on the surface of devices prior to the growth of atomic layer deposition (ALD) barrier films can result in the spontaneous cracking of the barrier layers. Such cracking renders the performance of the barrier film unacceptable. For this study, two barrier architectures were grown on fluorinated polymer (Cytop) coated Ca sensors that were used to monitor the permeation of moisture and oxygen (Fig. 2a). The cracking in ALD Al_2O_3 and HfO_2 nanolaminates deposited on Cytop planarization layers increased with increasing thickness of the Cytop layer (Fig. 2b). This is due in part to the high tensile residual stresses that exist in low temperature deposited ALD film combined with the stress concentration around particle defects, and the reduction to constraint of channel cracking in the ALD layer with thicker polymer films. By inserting a compressively stressed SiNx layer between the ALD layer and the Cytop (Figure 1), the cracking of the barrier films on Cytop was eliminated.

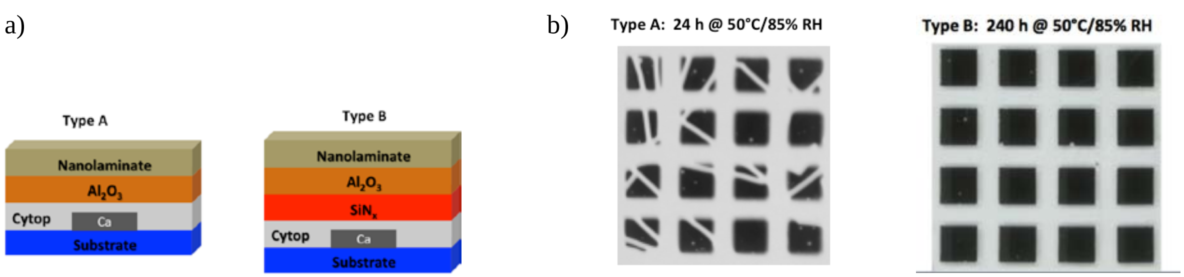

Figure 2: a) Structures of the two multilayer barrier film architectures studied. Type-A: ALD barrier deposited directly onto Cytop layer; Type-B: ALD layer deposited on SiN_x layer on Cytop. b) Type A barrier film on Ca sensors on glass with a 1000 nm Cytop polymer layer. and a Type B barrier film on Ca sensors on glass with SiNx and a 1000 nm Cytop polymer layer. Sample structure Type A is after 24 h at 50°C/85% RH where the Ca degradation along the crack defects are clearly visible. Sample structure Type B is after 240 h at 50°C/85% RH.

Future Work:

While the barriers developed in this program show good performance, these hybrid barrier structures are complex in nature, and methods to further reduce the processing time and complexity are needed for broader adoption by industry. Following the leads from previous studies on multilayer barrier films, the Kippelen/Graham groups will focus on testing PECVD SiNx/Polymer multilayers where the polymer layer consists of a nanocomposite. The polymer nanocomposites incorporate metal-organic frameworks (MOFs) that have been chosen for their low permeability for water vapor, low cost, and their thermal and chemical stability. Initial testing of these films is underway.