Adhesion and Cohesion Testing in Square Solar Cells

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Abstract:

A thorough understanding of environmental effects on adhesion and cohesion in solar cells is necessary for continuing improvements in their efficiency and longevity. A novel technique for adhesion and cohesion testing of square solar cells is developed using a modified double cantilever approach with load pins at the corner of square samples. The resulting method has greater sample versatility, control in testing and ease in sample preparation than other configurations. A closed form solution to obtain the energy release rate, G, for this configuration is derived. Using this approach, we can easily prepare and test samples in glove box environments. Validation of methodology for testing of encapsulated solar cells in controlled environments is obtained using a proportional–integral–derivative (PID) feedback control system.

Introduction:

Increasing demands for reliable solar cell technology place ever increasing expectations on their durability. Solar cells are exposed to moisture, ultraviolet (UV) light, and contaminants which can slowly break down the cell's layers, leading to the growth of internal cracks, flaws and consequent cell failure. The study of adhesive strength within solar cells is necessary for an understanding of their durability. Adhesion is quantified as the energy cost of extending a crack, equivalent to the rate at which energy is released as a crack propagates through, and is called the energy release rate, or G. Environmental conditions such as relative humidity and oxide (O_2) concentration may influence the strength of a sample and edit its energy release rate. It is desirable to understand how G is dependent on those environmental factors.

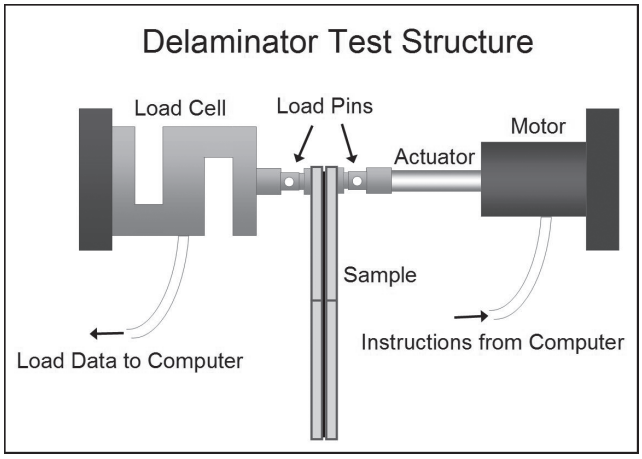

Figure 1: Delaminator test structure for DCB testing.

Test Structure:

The energy release rate of a sample was measured using a double cantilever beam (DCB) test in which a sample was sandwiched between two beams and placed in a delaminator. The delaminator consisted of an actuator which applied a displacement to one end of the sample and a load cell which measured the load experienced by the sample (see Figure 1). The displacement forced a crack to propagate down the sample. The changes in load, in combination with the displacement data from the actuator, were used to determine the energy release rate.

The conventional DCB sample preparation is both time consuming and low yield. Typically, each solar cell is fabricated on a glass square which must be sawn into strips for the DCB test configuration since beams form the basic structure of a DCB test. The dicing required to cut the square samples into strips is destructive because it exposed the sample to water and oxygen, and produced an uneven edge. In order to test square solar cell samples in a controlled environment, a different method for adhesion testing was developed.

The standard DCB method was modified so that the samples were left in their square form to avoid dicing. Displacement through the delaminator was applied through load pins attached to the corner of the square. Since the solar cells were fabricated in squares as required for a square-DCB test, no dicing was necessary, damage and contamination to the sample was minimized, and glove-box preparation was made possible.

A consequence of the square-DCB configuration was that G did not depend on the crack length. For a specific test with constant conditions and displacement rate, a plateau formed in the load by time graph. It then followed that the energy release rate was directly proportional to the load in each test. As a result, each test did not need to be closely monitored, and data analysis and the calculation of G was simplified. Figure 2 illustrates a plateau obtained from a square-DCB sample test. The load fluctuated as the sample's pre-crack developed a meniscus, resulting in the variations seen before 1700 μm. The plateau shows a constant load as expected and results in an energy release rate falling within the margin of error for standard DCB test results of the same film.

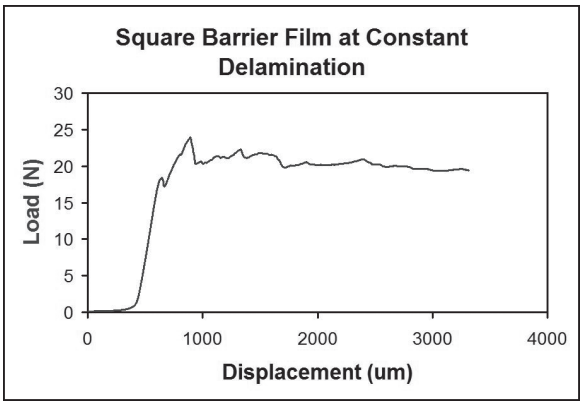

Figure 2: Delamination of a square barrier film at a constant rate (1 micron per second).

When samples were tested at extremely slow delamination speeds, or sub-critical speeds, only critical crack propagation was observed. Samples would crack suddenly rather than slowly and continuously. This created a saw tooth pattern in the load-by-time graph rather than the desired plateau. Delaminator testing by displacement-control was deemed insufficient for sub-critical speeds and a load-control system to control the displacement rate was required.

Load control was achieved by writing a PID computer controller using Labview. The PID controller is a loop-feedback computer controller which determines the displacement velocity of the actuator in real time based on the load. For example, if the load was below the set-point

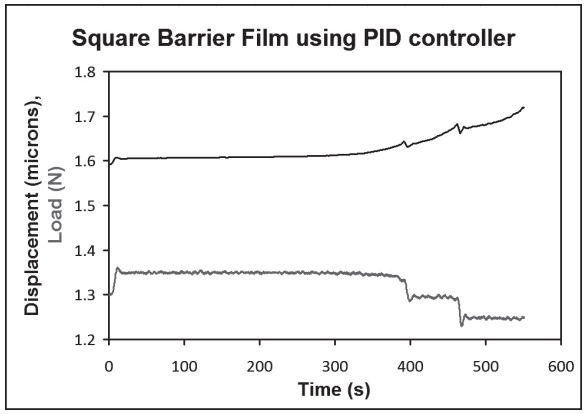

Figure 3: Delamination of a square barrier film using the PID computer controller.

determined by the user, the program would increase the displacement velocity, thereby increasing the load toward the set-point and the desired energy release rate.

Figure 3 shows the delamination of a square-DCB sample which used the PID control system to set the load. The lower curve shows the minor fluctuations in load as the control system maintained the set-point. The decreasing stair-step occurred as the user lowered the set-point. The top curve shows the actuator's displacement developing into a quadratic relationship with time. The decreasing quadratic slope of the displacement curve correlates with the three set-points as expected.

Conclusions and Future Work:

The square DCB method for sub-critical analysis was confirmed by the PID load-control experiment. The method may be used to perform sub-critical and critical tests in a glove-box (0% relative humidity, 0.01 ppm O_2) or an environmental test chamber for varying humidity and temperature.

The complete method with full results of organic solar cell tests will be published by Fernando Novoa.

Acknowledgments:

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