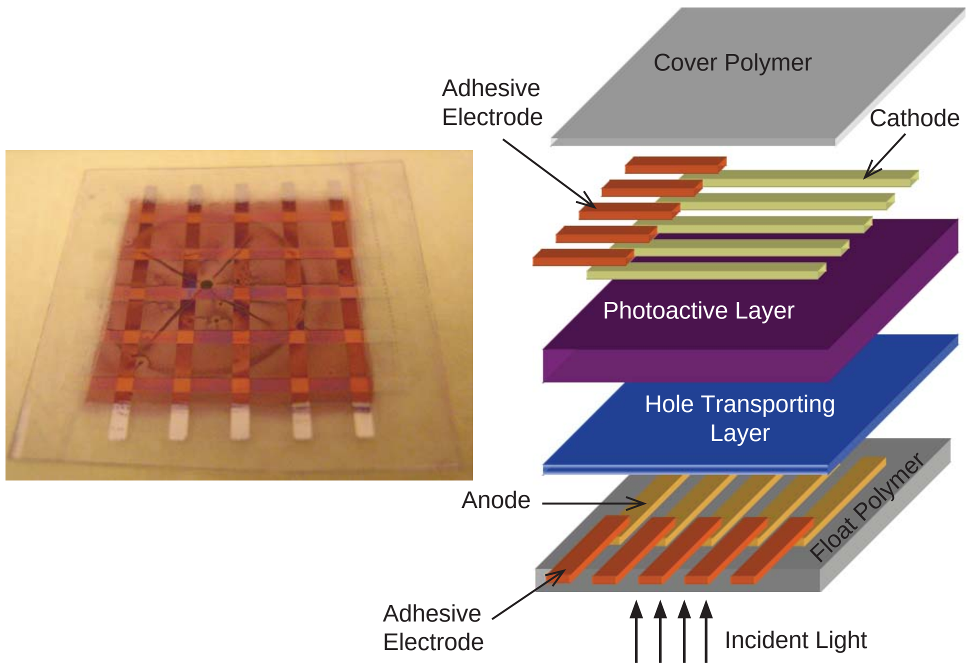
CRP

Cooperative Research Program

Hermetic Seals for Organic Semiconductors



Structure of a Sealed Polymer Photovoltaic Device

Summary Report SR0810

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Abstract

Organic semiconductor systems are becoming increasingly important for development of flexible photovoltaics and display systems. Seals for flexible photovoltaic systems are a critical need for protecting the photocell system, whether organic or inorganic systems are used. The organic materials are particularly sensitive to intrusion of air or moisture. Methods are needed to hermetically seal the devices. These devices are multi-layered and require specific substrates. The sealing materials cannot leach contaminants into the organic system or failure may result. Tailored joining/sealing techniques are needed to meet these requirements.

A laser sealing approach was selected to determine the feasibility of encapsulating photovoltaic devices with PEN film and PET substrate material with both ITO/In_2O_3 and aluminum strips. Once an appropriate sealing procedure was identified, active assemblies were sealed for longevity testing. The open-circuit voltage and current were measured for the enclosed active cells. Although the photoactive layer showed signs of deterioration ten days after sealing, this was well beyond the previous exposure lifetime of about one hour.

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1.0 Introduction

Researchers at the OSU Dept. of Electrical & Computer Engineering have been working with organic photovoltaic devices on flexible substrates in a controlled glovebox environment. A sealing technique is needed to encapsulate active photovoltaic cells for use outside of a glovebox environment.

Organic semiconductor systems are becoming increasingly important for development of flexible photovoltaics and display systems. The organic materials are very sensitive to intrusion of air or moisture and require hermetic seals. Because the chemical electronic materials involved are specific to their end use, custom joining technology plays a role in developing good seals with long life. These devices are multi-layered and require specific substrates. The sealing materials cannot leach contaminants into the organic system or failure may result, therefore, highly specialized joining/sealing techniques are required.

The purpose of this program was to demonstrate the effective sealability of a low-permeability polyester film, polyethylene naphthenate (PEN), to materials such as glass, polyethylene terephthalate (PET) polyester, aluminum metal electrode traces, and doped indium oxide ceramic electrode traces.

To encapsulate the photovoltaic device and create a hermetic seal, a polyethylene naphthenate (PEN) film was selected. PET film was chosen as the base substrate material for final samples due to ease of In_2O_3 application and seal quality obtained between PEN and PET. A laser sealing approach was selected to precisely control the melt area with minimal damage to the anode and cathode.

Five patterned strips of In_2O_3 anode material and five additional strips of Al cathode material were coated on the PET substrate perpendicular to each other. There is an intervening layer of photoactive material. The technical goal was to seal a PEN film around the active stack layered on the PET substrate while allowing electrical contact to the Al and In_2O_3 strips outside the seal. The sealing process would keep moisture and oxygen from the active cell. A successful seal would extend the lifetime of the photovoltaic device and permit it to be used outside of a glovebox environment. The sealing had to be done under argon inside a polyethylene bag to protect the system during the sealing operation.

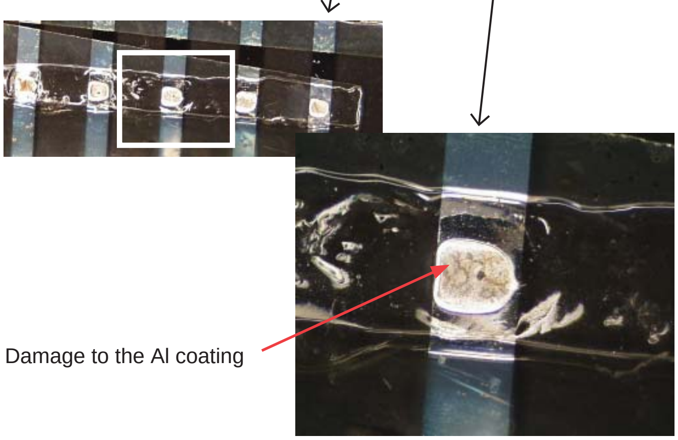


Figure 1. PEN Sealed to Glass Substrate with Al Strips

While this sealing technology is enabling for organic semiconducting systems, it also may be applicable to inorganic systems, such as those based on polycrystalline silicon.

2.0 Objectives

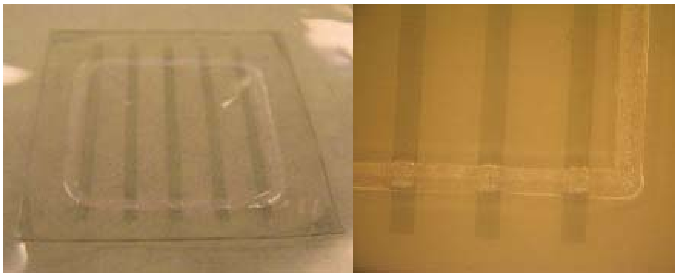
The objective of this program was to examine the feasibility of laser sealing to encapsulate organic semiconductors on glass substrates and on PET substrates.

3.0 Scope

To meet the objectives of this study, a laser sealing approach was selected to determine the feasibility of encapsulating photovoltaic devices with a 1-mil thick Teonex® Q51 PEN film. Substrate materials of PET and glass with both ITO/In_2O_3 and aluminum strips were included. A thin coating of infrared absorber (Gentex Clearweld® LD140B) was applied to the PEN film using an acid brush. The absorbed infrared energy is converted to heat to create a seal at the interface. Delta Technologies, Ltd 8-mil PET with In_2O_3 coating was used as the substrate for the final samples. Excess In_2O_3 coating was etched to leave a pattern of five parallel strips. The active cells' substrate also included thin strips of aluminum coating perpendicular to the In_2O_3 strips and a photoactive layer. Preliminary trials included sealing PEN to aluminum foil, generic PET with aluminum strips, and glass. Once an appropriate sealing procedure was identified, active assemblies were sealed for longevity testing.

Glass Substrate

A 100 watt JDSU industrial diode laser with a wavelength of 915 nm was used to evaluate the feasibility of sealing PEN to glass having strips of both indium-tin oxide (ITO) and Al coatings. There was success sealing PEN to glass with moderate peel strengths. However, identifying process conditions that resulted in moderate seals with PEN to glass, ITO coating, and Al coating was problematic. Damage to the Al coating occurred at conditions that yielded moderate seal strengths between the PEN film and glass substrate. A micrograph of seals between PEN and glass substrate with aluminum strips are included in Figure 1. Damage to the aluminum strips can be seen in the center of the seal region.



Figures 2-3. Seal Enclosure with PEN and PET with In_2O_3 Coating Rounded Corners (left) and 90-deg. Corners (right)

PET Substrate

A JDSU industrial diode laser, operating at 915 nm (100 W) was used to minimize the damage to the In_2O_3 coating during sealing by avoiding high peak power pulses. For the initial experiments, PEN coated with an IR absorber was sealed to PET with In_2O_3 coating on the entire sample. Sealing conditions were found that provided moderate peel strengths while maintaining some degree of electrical conductivity through the seal. The next step was to enclose PEN with PET having patterned, etched In_2O_3 strips. Parameters were screened including power level, travel speed, and spot size. During these trials, linear laser passes were made across the five In_2O_3 strips. The seal region expanded at the In_2O_3 strips due to increased absorption. A fixture was designed to weld the final active photovoltaic cells with a 17 x 17 mm perimeter seal. Figures 2-3 show enclosures with perimeter seals with rounded and 90-deg. corners, respectively. Initially, rounded corners were used to avoid hesitation by the motion system, but it was later found unnecessary at slow travel speeds.

Enclosure samples were tested for seal strength and electrical continuity through the seal region. Both of these requirements were equally important. Sealing conditions that yielded moderate strengths with minimal damage to the In_2O_3 or aluminum strips were difficult to identify. Compromise was made by focusing more on the continuity of the In_2O_3 strips than seal strength. For the In_2O_3 strips, there were few conditions that resulted in a very high measurable resistance.

Active Photovoltaic Cells

Active cells were prepared at OSU and supplied to EWI for sealing. These consisted of PET substrate with In_2O_3 coated strips, spin-coated PV organic material, and over-plated aluminum coated strips. To protect the exposed photoactive layer from air and moisture, each active cell was placed in an argon-filled sealable bag with an infrared absorber-coated PEN film. The argon (99.999%) was allowed to bleed out of the bag until it was deflated enough to place the shielded assembly in the weld fixture. Figure 4 shows an active cell with an infrared coated PEN film on top. The positioning laser was used to align the laser system with the positioning table.

Final enclosures were sealed around the perimeter of the photoactive layers using the following laser parameters:

- Laser power: 3.5 watts
- Travel speed: 7 in. per minute
- Focal distance: 0.2 in. out of focus
- Approximate spot size: 2 mm

In Figure 5, the laser seal can be seen overlapping the photoactive layer. The seal is more apparent at the In_2O_3 crossovers due to the additional absorption. There is no apparent damage at the aluminum crossovers. By observing the In_2O_3 crossovers at higher magnification, the photoactive layer can be observed in the sealing region and the appearance of the In_2O_3 is altered.

The open-circuit voltage and current were measured for the enclosed active cells. The measured current was very low from the high resistance of the damaged In_2O_3 coating.

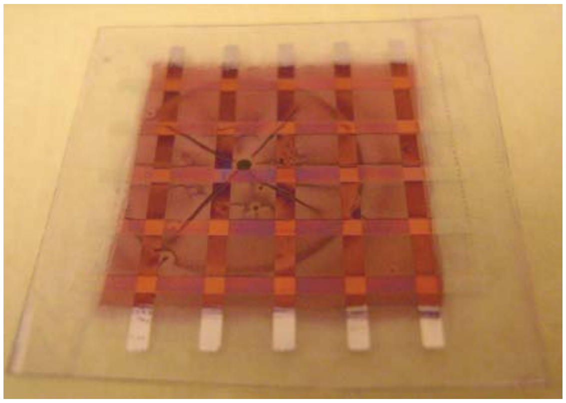


Figure 4. Active Cell with Coated PEN on Top

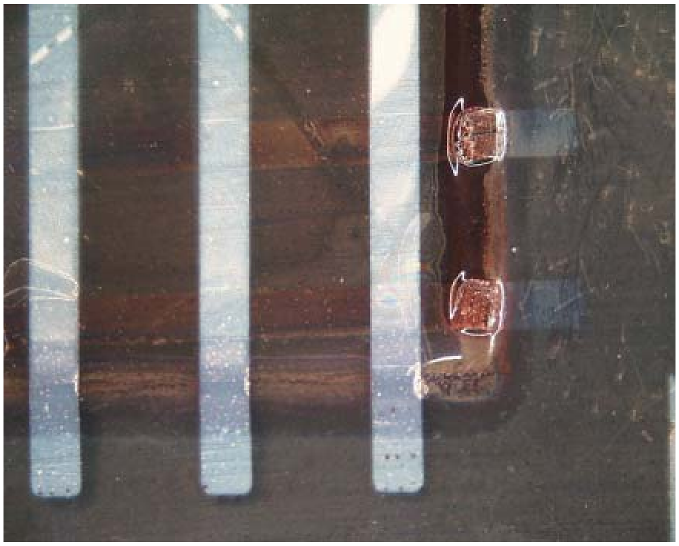


Figure 5. Perimeter Seal of Active Photovoltaic Cell

Additional photovoltaic cell assemblies were sealed to be monitored for longevity testing. Immediately after sealing, one sample was exposed to sunlight and the voltage and current were measured using a multimeter. The voltage varied with sunlight exposure, however the measured current was low.

On one sample, the open-circuit voltage and current were measured ten days after sealing. The open-circuit voltage was found to be much lower than what was measured just after sealing. Therefore, a perfect hermetic seal was not obtained. The weakest seal strength was between the aluminum bar strips and the PEN film. This was expected because the sealing energy was adjusted downward to combat the damage to the In_2O_3 strips. Overall, it appears different sealing parameters will be needed for different sections of the device. This could be achieved using existing parameter controls for welding, however, that type of optimization was outside the scope of this project.

4.0 Conclusions and Recommendations

This project successfully demonstrated the feasibility of using a diode laser source to seal flexible thermoplastic photovoltaic devices with anodes and cathodes, such as aluminum and In_2O_3. Throughout the study, moderate seal strengths were obtained for each material combination. Active photovoltaic cells were encapsulated and their operation was verified. Although there were cracks in the In_2O_3, it was possible to measure an open-circuit voltage. Although the photoactive layer showed signs of deterioration ten days after sealing, this was well beyond the expected lifetime outside of a controlled glovebox environment.

There can be many material combinations involved when sealing flexible devices. Sealing parameters need to be screened to determine an appropriate procedure. It is possible to seal dissimilar materials, but their effectiveness depends on the material combinations.

Additional work is recommended to further refine the technique for particular applications, including:

- Extending laser sealing to other substrate and anode/cathode materials
- Optimizing the process for each material combination
- Consider masking In_2O_3 crossovers to minimize damage
- Evaluate transmission characteristics of ITO and In_2O_3
- Minimize damage/cracking of In_2O_3

5.0 Acknowledgements

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Ohio Department of Development

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