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Rheological and Mechanical Considerations for Photovoltaic Encapsulants

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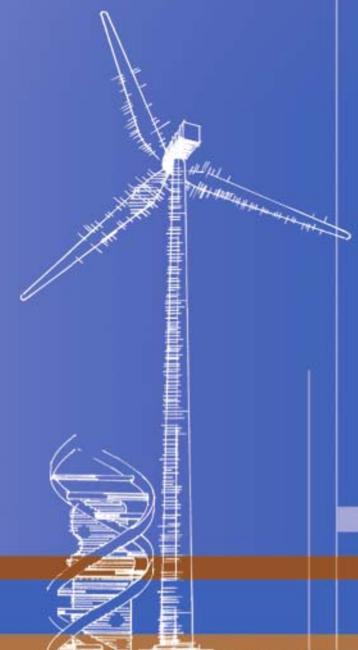
Conference Paper
NREL/CP-520-38972
November 2005

Presented at the 2005 DOE Solar Energy Technologies Program Review Meeting
November 7–10, 2005
Denver, Colorado



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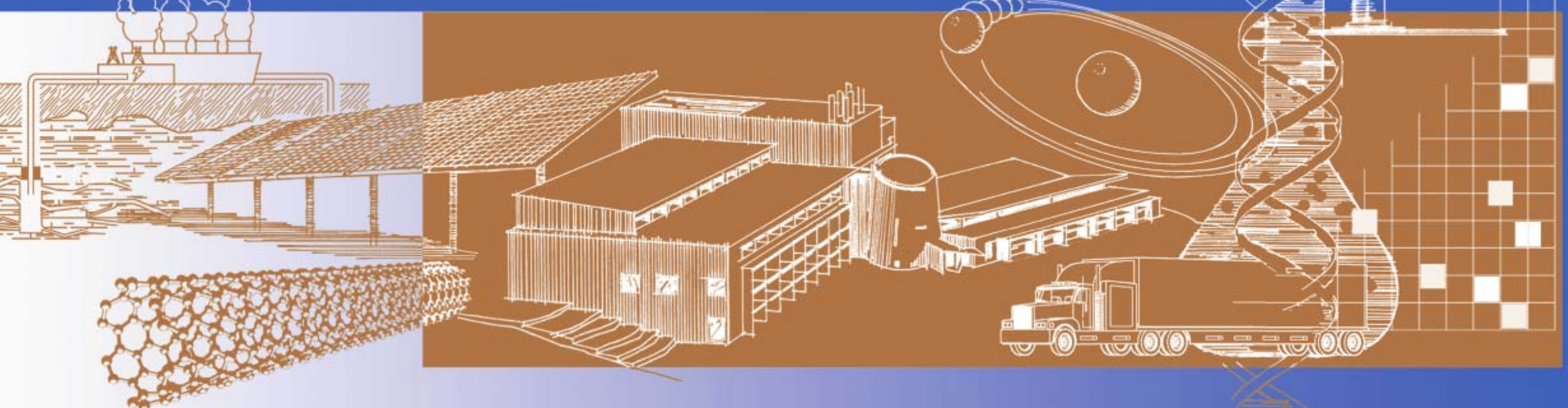

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Rheological and Mechanical Considerations for Photovoltaic Encapsulants

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ABSTRACT

Photovoltaic (pv) devices) are encapsulated in polymeric materials not only for corrosion protection, but also for mechanical support. Even though ethylene-vinyl acetate (EVA) suffers from having both glass and melting phase transitions at temperatures experienced under environmental exposure, its low cost and good optical transmission made EVA the most commonly used material for PV modules. These transitions, however, cause EVA to embrittle at low temperatures (~ -15°C) and to be very soft at high temperatures (>40°C). From mechanical considerations, one would prefer a material that was relatively unchanged under a wide temperature range. This would produce a more predictable and reliable package. These concerns are likely to become more important as silicon based cells are made thinner.

1. Objectives

Photovoltaic (PV) modules are often exposed to harsh environmental conditions involving the simultaneous application of moisture, temperature cycling, and mechanical loads. As discussed in the Solar Program Multi-Year Technical Plan, a major impediment for flat-plate PV systems is the limitation in cost and reliability of module packaging.[1] Both crystalline-silicone and thin-film technologies require advanced module packaging to survive in harsh operating environments. This project investigates the viscoelastic behavior of encapsulant materials to evaluate their use in PV modules.

2. Technical Approach

Dynamic mechanical analysis was performed on a TA Instruments Ares Rheometer equipped with an IGC Polycold Systems Inc. cryogenic refrigeration unit model #PGC-100 which is capable of producing temperatures of -60°C when used with the Ares forced convection oven. A rectangular torsional testing fixture was used because the polymers were highly cross-linked elastomers. Samples were about 3-mm thick, 12-mm wide, and 25-mm long with about 12-mm of the length covered by the clamps holding the sample.

3. Results and Accomplishments

Because PV encapsulant materials provide mechanical support to the cells[2], rheological measurements were made to determine at what temperatures the phase transitions occur and their effect on the dynamic mechanical moduli.[3] Over the temperature range from 80°C to -40°C the moduli of EVA increased by a factor of about 500 (Fig. 1). This large change in mechanical properties is caused by the presence of both a melting and a glass transition (T_g) at or near temperatures that are commonly experienced by a module.

In the melt (T >~65°C), the moduli are determined primarily by the distance between chemical cross-links and relatively little dependence on temperature is seen. As the temperature is lowered EVA crystallizes and a large increase is seen in the dynamic moduli along with a decrease in the phase angle. Finally, at temperatures beginning at about -15°C, EVA goes through a T_g as seen by a temporary increase in the phase angle and by a very large increase in the dynamic moduli.[1,2] When the same data was taken while cooling, the crystallization transition occurred more abruptly between 40°C and 45°C rather than over the range from 35°C to 65°C.

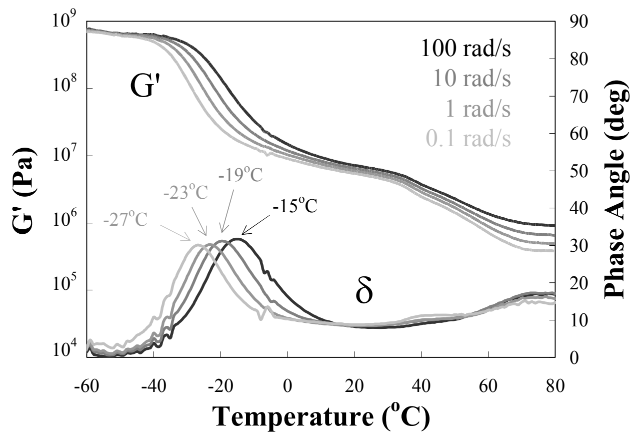

Fig. 1. Shear storage modulus (G') and phase angle (δ) as a function of temperature measured at frequencies of 100, 10, 1 and 0.1 rad/s. Glass transition temperatures are also indicated. Data was taken while heating the sample.

For frequencies of 100-rad/s the T_g was measured to be -15°C, which is much higher than the values of around -40°C frequently reported in the literature.[4] The T_g is typically determined using differential scanning calorimetry. This kind of discrepancy is common for polymers because the two methods are measuring very different phenomena associated with a second order transition.[5] Because the primary purpose of using an encapsulant is to provide mechanical support, the T_g measured using dynamic mechanical analysis is more relevant.

Cuddihy et al.[1] examined stresses in a glass superstrate module caused by a combination of thermal coefficient of expansion mismatch (with ΔT=100°C) and wind loading. They modeled a 161-km/hr wind loading on a 1.2-m square module as a

2400-Pa loading with the edges being supported. The silicon cells were modeled as 10-cm square, 381-μm thick, and able to withstand a 55.2-MPa bending stress. They found that the wind loading forces dominated and that a 3.2-mm thick glass module with a polymeric back-sheet requires at least 0.10 mm to 0.13 mm of EVA to mechanically protect silicon-wafer-based PV cells at 25°C. Their models also demonstrated that the required thickness varied linearly with the Young's modulus of the encapsulant. Because the shear moduli are linearly related to Young's modulus, reduction of the module temperature is predicted (Fig. 1) to significantly increase the minimum thickness of EVA to around 1-mm below -10°C and about 10-mm at -40°C. To confidently produce a module capable of long-term exposure to temperatures below -10°C, one would need to use several millimeters thick EVA encapsulant films.

Many other encapsulant materials do not have the same problems with phase transitions in the operating range of PV modules. We show three such materials in Figure 2. The TPU and the BRP-C materials do not have melting transitions but they both have glass transitions at -31°C, -38°C, and -40°C for TPU and -36°C, -40°C, and -44°C for BRP-C at frequencies of 100 rad/s, 10 rad/s, and 1 rad/s respectively (Fig. 2). DC 186 is a two-part-addition-cure polydimethyl siloxane which has a melting point of -33°C. But upon cooling from the melt, we observed significant hysteresis in the rheological measurements with the freezing point being observed at -58°C. Because of these significantly reduced transition temperatures, these encapsulant materials should perform much more predictably and reliably over a wide variety of environmental conditions.

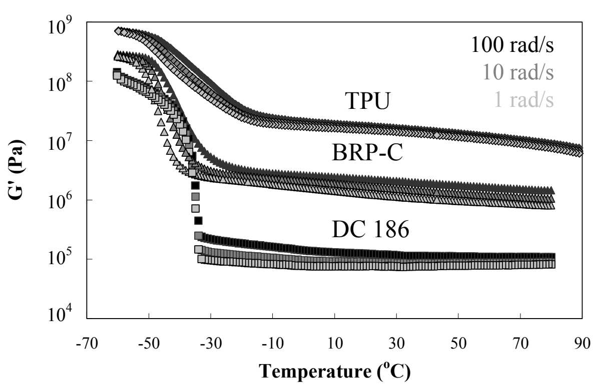

Fig. 2 Dynamic moduli for three encapsulant materials: a thermoplastic polyurethane (TPU) from Etimex, an experimental material from BRP Manufacturing, and a silicone Sylgard™ 186 from Dow Corning.

4. Conclusions

For many environments a temperature of -15°C is often experienced by PV modules, making EVA-based modules significantly more sensitive to sudden impacts and/or wind loading. PV modules are typically rated for use in environments as low as -40°C, but this may be too extreme. This low temperature is based on passing a qualification test (UL 1703) where the temperature of a module is cycled between 90°C and -40°C. High winds at low temperatures could cause a module to flex, possibly breaking some components. Inclusion of some mechanical bending at low temperatures would be a good addition to UL 1703.

If a module is found to be sensitive to the mechanical properties of the encapsulants, alternative materials, similar to those identified, could be used to expand their operating range.

ACKNOWLEDGEMENTS

This work was performed under DOE contract DE-AC36-99-GO10337.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2005

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Rheological and Mechanical Considerations for Photovoltaic Encapsulants

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
M.D. Kempe

5d. PROJECT NUMBER
NREL/CP-520-38972

5e. TASK NUMBER
PVB6.7201

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-520-38972

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
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15. SUBJECT TERMS
Photovoltaics; solar; photovoltaic encapsulants; PV; NREL

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER (*Include area code)*