Acrylic Liquid Encapsulant for Photovoltaic Modules M. Einsla
Extended Abstract

Photovoltaic (PV) devices are used to convert solar energy to electricity and hold great promise for providing long term carbon emission free electricity. The demand for PV units is rapidly increasing and represents a growth opportunity for material suppliers. The solar cells themselves are typically packaged between several protective layers (Figure 1). PV encapsulants require materials with excellent optical clarity, good mechanical properties over a broad temperature range (-40 to 110 °C), and long-term UV stability (>20 years outdoor exposure or thousands of hours in accelerated testing). The encapsulant must also account for the mismatch in thermal expansion between the various dissimilar module components. As such, acrylic-based materials could provide excellent performance in PV encapsulant applications.

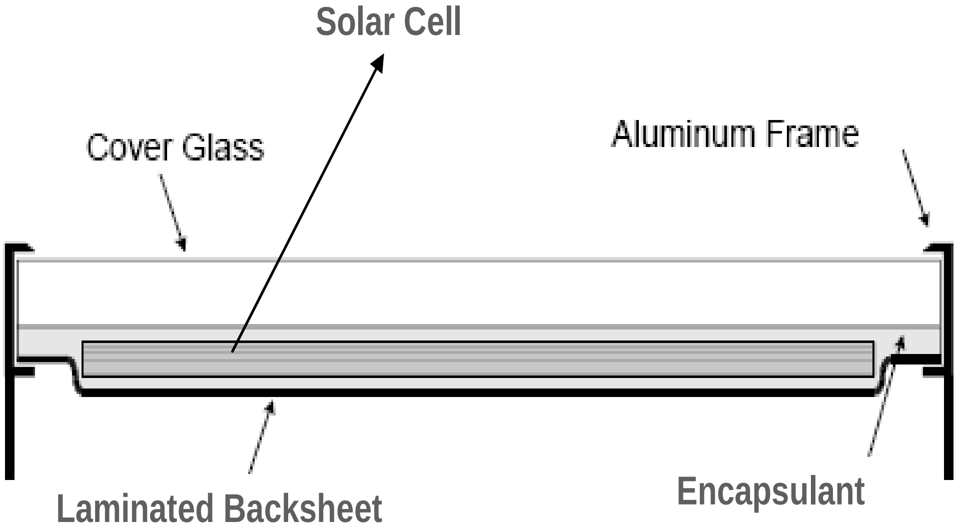
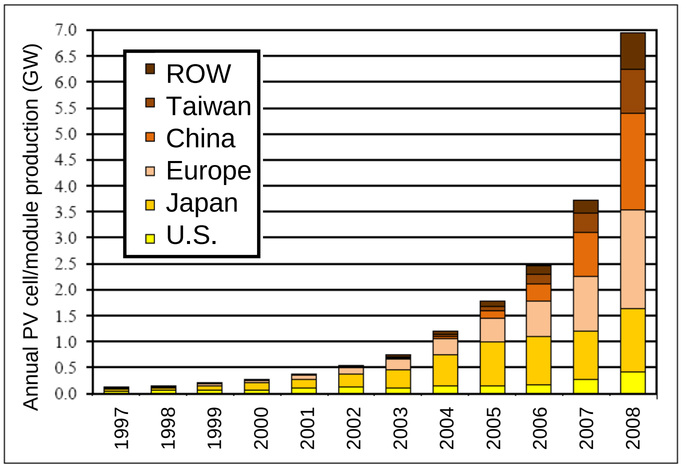


Figure 1: General structure of a crystalline silicon photovoltaic module.

Flexible solar cells are a growing sector of the photovoltaic industry (Fig. 2). For this technology, a liquid-coatable encapsulant which can be applied by a semi-continuous process has the potential to enable alternate routes to module production. Our liquid encapsulant material is an acrylic-based crosslinkable polymer of sufficiently low molecular weight which, when cured, produces a transparent, bubble-free rubbery material with good mechanical properties and long-term UV stability.



	Thin-Film PV Market Share
2003	5%
2008	14%
2012 (projected)	16-34%

Figure 2: Annual Growth of PV Module Production, with Thin-Film Market Share[1].

For a curable liquid encapsulant, cure time is a key parameter. Cure time was measured using both Fourier Transform Infrared Spectroscopy (FTIR) and Dynamic Mechanical Analysis (DMA). The crossover between G' and G" represents the transition from liquid-like behavior to solid-like behavior, while the chemical cure time was defined as the time required for complete chemical reaction. The cure profile at various temperatures is summarized in Table 1.

Table 1: Physical and Chemical Cure at Various Temperatures.

Cure Conditions	G'/G" Crossover Point	Mechanical Cure Complete	Chemical Cure Complete
80 C	6.9 min	~50 min	~2 hr
100 C	4.0 min	~20 min	~1.5 hr
120 C	2.8 min	~10 min	~50 min
150 C	2.1 min	~6.5 min	~15 min

Optical clarity is one of the most critical properties for photovoltaic encapsulants. Because our liquid encapsulant is so clear, a very thick pathlength (20 mm) was required to accurately measure the light transmission (Fig. 3). From this data, the transmission through a thinner film was predicted (Fig. 4).

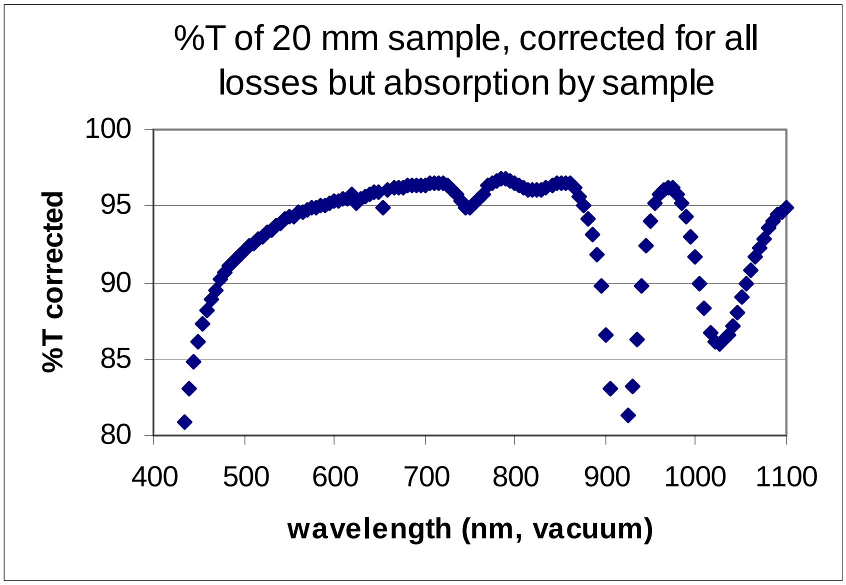


Figure 3: Transmission of encapsulant at 20 mm thickness, corrected for interfacial losses.

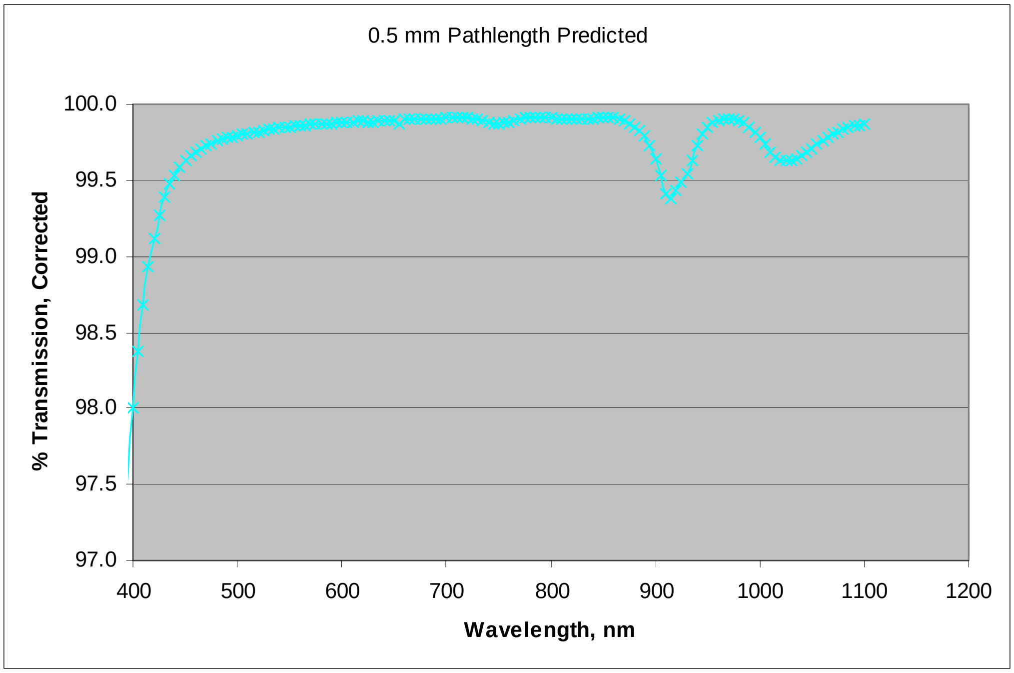


Figure 4: Prediction of %T of encapsulant material at 500 μm thickness.

While good initial optical properties are very important, photovoltaic encapsulants must maintain this performance over many years of outdoor exposure. To accelerate the aging process, samples were exposed in a Xe arc weatherometer according to ASTM G 115-05a. Two encapsulant prototypes were formulated both with and without an unoptimized photopackage and exposed for 4000 hours (Table 2). Yellowness index (YI) was measured throughout the exposure. The best candidate exhibited excellent UV stability as evidenced by the lack of yellowing under these harsh conditions.

Encapsulant	Photopackage	YI (0h)	YI (500h)	YI (1000h)	YI (2000h)	YI (3000h)	YI (4000h)
Experimental Encapsulant	Yes, unoptimized	1.4	2.1	3.0	3.9	3.8	4.6
	None	1.8	7.0	10.0	14.3	14.8	37.3
Dow Development Candidate	Yes, unoptimized	1.1	1.3	2.0	2.0	2.1	1.6
	None	1.2	1.5	2.0	2.0	3.8	3.3

Table 2: UV Stability of Cured Liquid Encapsulants in a Xe Arc Weatherometer.

The curing behavior of the Dow liquid encapsulant was studied with various catalysts. A good balance of pot life and cure time is required for liquid coatings. The pot life was measured with several different catalysts (Fig. 5) and catalyst levels (Fig. 6). Work is ongoing to optimize the pot life/cure time balance and minimize EH&S impact of the catalyst.

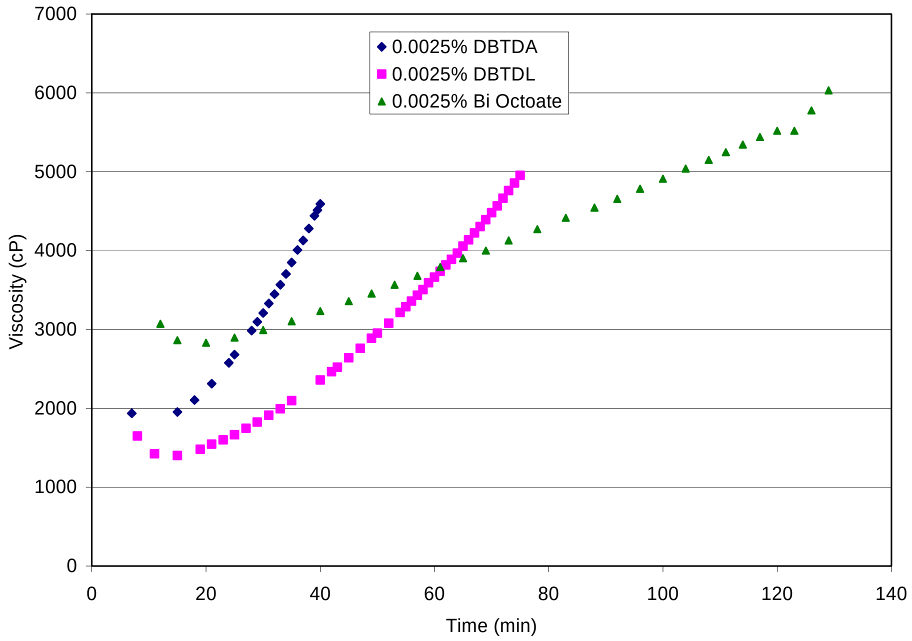


Figure 5: Pot Life of Liquid Encapsulant with Various Catalysts.

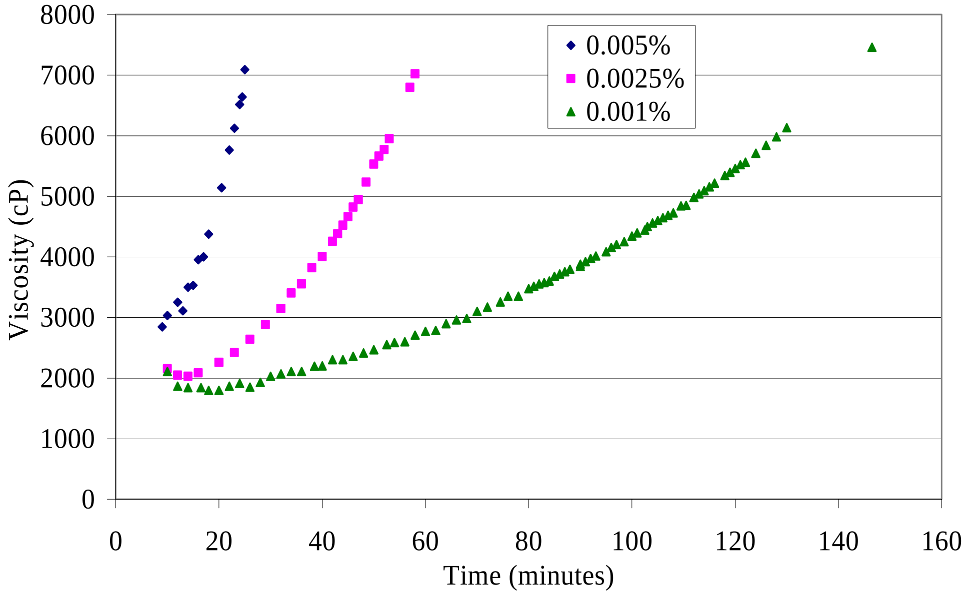


Figure 6: Pot Life of Liquid Encapsulant with Different Levels of Dibutyltin Diacetate Catalyst.

Electrical properties of our liquid encapsulant were measured and are shown in Table 2 compared to other commercial encapsulants. The electrical properties of the Dow liquid encapsulant appear to be comparable to and in some cases better than competitive materials.

Table 2 Electrical Properties of Dow Liquid Encapsulant Compared with Commercial Encapsulants.

	Dielectric Strength (V/mil)	Volume Resistivity (Ω-cm)	Surface Resistivity (Ω^2)
Dow Liquid Encapsulant	1280	2.97×10^{15}	$>10^{16}$
DNP Encapsulant	2065	1.2×10^{15}	2.0×10^{17}
STR 15295 EVA	1600	8.17×10^{14}	N.M.
Dow Corning PV 6010 Silicone	425	2×10^{-14}	N.M.

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[1] 2008 Solar Technologies Market Report, U.S. Department of Energy, January 2010