

# **Modified EVA Encapsulant Formulations for Low Temperature Processing**

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# Modified EVA Encapsulant Formulations for Low Temperature Processing

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## ABSTRACT

We have developed several new ethylene-vinyl acetate (EVA) formulations modified on the basis of NREL-patented EVA formulations [1]. The new formulations can be cured to a desired gel content of ~80% in the ambient at temperatures 20-30°C lower than the typical conditions in vacuum (i.e. ~150°C). Glass/glass laminates showed transmittance spectra that are essentially the same as that of EVA 15295P in the visible and NIR regions but higher in the UV region. Results of fluorescence analysis of the ambient-processed new EVA formulations showed the concentrations of the curing-generated  $\alpha,\beta$ -unsaturated carbonyl chromophores, which are responsible for the UV-induced EVA discoloration and photodegradation, were considerably lower than that of EVA 15295P, therefore suggesting a better photochemical stability of new EVA formulations.

## 1. Introduction

Today a great majority of PV modules use EVA as the encapsulant, which is supposed to protect the modules with sufficient mechanical strength and high optical transmission of sunlight. However there are drawbacks in terms of performance reliability and manufacturability. Earlier commercial EVA formulations exhibited discoloration/degradation upon weathering, which can decrease module performance [2]. Recently, NREL scientists developed and patented new EVA formulations that showed superior photothermal stability against UV-induced discoloration [1].

However, the common method and conditions using vacuum lamination at ~150°C to process EVA, both commercial and NREL-patented formulations, present a bottleneck in the module manufacturing process. The curing at ~150°C is needed to produce a 70~80% gel in EVA to enhance its mechanical strength to support the crystalline-Si solar cell strings. Many of the multiple processes for manufacturing the crystalline-Si based and thin film modules can be automated except the vacuum encapsulation stage. The process typically requires manual handling of the module component stack and uses a double-bag vacuum laminator for careful control of vacuum, heating, and pressing profiles to ensure adequate lamination of module components and curing of the EVA, leading to high labor and energy cost and limited production rate. The vacuum process removes not only the air at the interfaces, but also the gaseous products (e.g., CO<sub>2</sub>) from thermal decomposition of the curing peroxides (e.g., Lupersol<sup>®</sup> 101 for EVA A9918 and Lupersol<sup>®</sup> TBEC for EVA 15295) used in EVA formulations, and both can potentially cause bubble

formation in PV modules. Therefore, encapsulant formulations that can be processed at lower temperatures and in the ambient are very desirable, not only to avoid the bubble formation but also to eliminate the vacuum requirement and significantly reduce energy consumption.

## 2. Experimental

### 2.1 Materials and sample preparation

Elvax 150, the raw material of the EVA copolymer (33% vinyl acetate) manufactured and trademarked by Du Pont will be specifically referred to as the matrix. Special cross-linkers, peroxide curing agents, including Lupersol<sup>®</sup> 231, and HPLC-grade tetrahydrofuran (THF) and methanol (MeOH) were obtained from Aldrich and used without further treatment. Films of commercial EVA formulations were supplied by PV manufacturers. For the new modified EVA formulations, the compositions of matrix, crosslinkers, and additives were varied according to the experimental designs. After mixing by a mechanical roller for at least 24 h, films were obtained by pressing the formulated mixtures at 85°C for 10 minutes in a vacuum laminator or by extruding using a Brabender mini-extruder. The film samples were cured at temperatures in the 110° – 160°C range for 5 to 30 min in the ambient, using a manually controlled, hydraulic mini-press. Laminates of 5.1-cm x 7.6-cm (2" x 3") size were made by encapsulating two layers of EVA film between two 3.2 mm (1/8") thick borosilicate glass plates using the mini-press in the ambient by following a custom temperature-pressure profile.

### 2.2 Analytical procedures and characterization

A number of film samples, including EVA 15295P, were studied. THF was used to determine the gel content by dissolving away the additives and non-crosslinked EVA from the cured EVA. The solvent-treated films were dried in a vacuum oven at room temperature for at least 24 h. The gel content was determined from the weight difference before and after THF extraction. Transmittance spectra were measured on a Cary 2300 UV-vis-NIR spectrophotometer with an integration sphere. Fluorescence emission characterization was performed on a SPEX Model FL 112 Fluorolog-II spectrofluorometer using a "front face" geometry [2].

## 3. Results and discussion

### 3.1 Effects of ambient process conditions on gel formation of different EVA formulations

The gel contents for different EVA formulations as a function of ambient process conditions are given in Table 1. EVA Formulations I and II contained the special cross-

linker at a level of 20 % and 30 % by weight, respectively. The results show that, when ambient-heated at 130°C for 5 minutes, the two new EVA formulations were able to produce 60% and 61% gel while EVA 15295P produced 0%. The presence of cross-linker apparently promoted the cross-linking reaction of EVA at lower temperatures, compared with the typical curing temperatures (~150°C) used for commercial 15295 and A9918 EVAs. When ambient-heated at 130°C for 10 minutes, Formulation II produced a gel content of 84%, which is sufficient to mechanically support the crystalline-Si solar cell strings. For Formulations I and II, the gel content increased with the ambient heating temperature, as a result of increased decomposition rate of curing agent, concentration of free radicals, and hence the crosslinking reaction.

**Table 1.** Gel contents (%) as a function of ambient process conditions for different EVA formulations.

Formulation	Temp (°C)	Time (min)				
		5	10	20	32	40
I	120	36	44	42	47	55
	130	60	61	64	60	61
	140	68	76	78	76	61
II	120	57	63	63	64	70
	130	61	84	80	82	79
	140	78	91	83	84	70
EVA 15295P	130	0	10	21	25	35

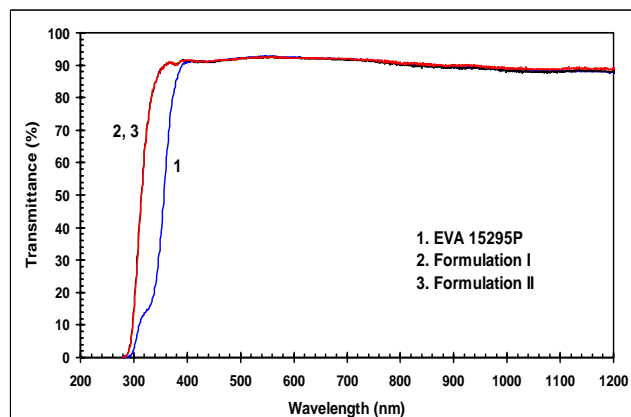
### 3.2 Spectroscopic characterization of new EVA formulations

Figure 1 shows the transmittance spectra for two new EVA formulations and the commercial 15295P EVA in glass/EVA/glass laminate configuration. It is seen that the transmittance of the new EVA formulations is essentially the same as that of EVA 15295P in the visible and NIR regions, but better in the UV region (280 – 400 nm). Figure 2 shows the fluorescence emission spectra for the three EVA formulations as in Fig. 1. The emission peak intensities at ~420 nm of the new EVA formulations are about half of that for cured EVA 15295P. The 420-nm peak intensity corresponds to the concentration of curing-generated,  $\alpha,\beta$ -unsaturated carbonyl groups, which are responsible for the UV-induced EVA discoloration and photodegradation [2,3]. A lower peak intensity indicates a lower concentration of the carbonyl chromophores and suggests a better photochemical stability of the new EVA formulations. At present, the long-term photothermal stability of the new formulations is under accelerated exposure testing.

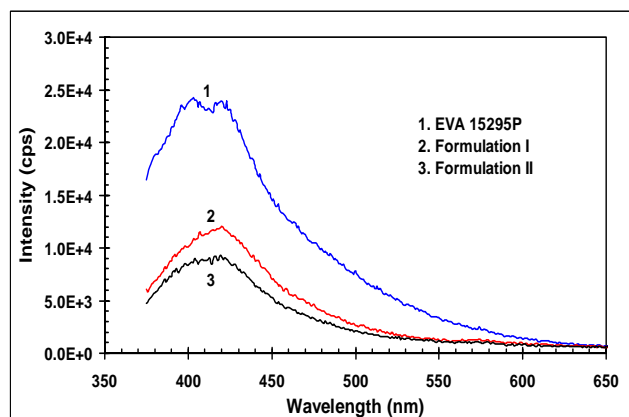
### 4. Conclusions

Preliminary new EVA formulations have been developed, which can be cured at 130°C in the ambient to achieve desired gel content of ~80%. Transmission measurements and fluorescence emission characterization results showed that new EVA formulations had higher transmittance in the UV region and lower emission

intensities at ~420nm than those of commercial 15295P. Optimizations in formulation and processing conditions and long-term photothermal stability are required for the newly developed EVA formulations.



**Fig. 1.** Transmittance spectra for glass/EVA/glass laminates of three EVA formulations made by a mini-press.



**Fig. 2.** Fluorescence emission spectra for the (cured) glass/EVA/glass laminates of three EVA formulations as Fig. 1 obtained with an excitation wavelength at 350 nm.

### 5. Acknowledgement

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