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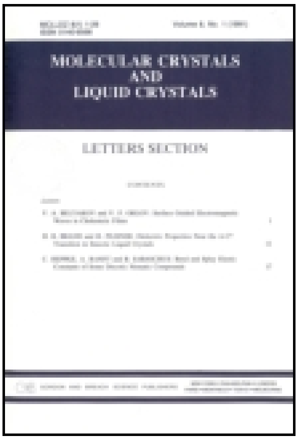


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

# Theoretical Study of Morphologically Modified EVA Film to Minimize Metal Grid Reflection Loss

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Published online: 08 Jan 2014.

To cite this article: Maengjun Kim , Sungho Lee & Sangho Sohn (2013) Theoretical Study of Morphologically Modified EVA Film to Minimize Metal Grid Reflection Loss, Molecular Crystals and Liquid Crystals, 585:1, 67-72, DOI: 10.1080/15421406.2013.849513

To link to this article: http://dx.doi.org/10.1080/15421406.2013.849513

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*Mol. Cryst. Liq. Cryst.*, Vol. 585: pp. 67–72, 2013
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ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2013.849513

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# Theoretical Study of Morphologically Modified EVA Film to Minimize Metal Grid Reflection Loss

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*Solar cell modules mainly consist of EVA film and a metal grid. The EVA film is used as waterproof and UV-resistant, which makes it an ideal adhesive film for solar modules installed outdoors. As well, standard crystalline solar cells are generally fabricated with the front grid pattern of silver paste contact. Metal grid cannot help accompanying with shading losses caused by the presence of metal on the top surface of the solar cell, which prevent light from entering the solar cell. The shading losses are determined by the transparency of the top surface, which, for a planar top surface, is defined as the fraction of the top surface covered by metal. In order to fabricate highly efficient solar cell devices, the shading losses should be minimized. In this article, a theoretical estimation has been made to construct a morphologically modified configuration of EVA film so as to minimize the shading losses. According to our numerical calculations and optical simulations, by adopting only slightly modifying the EVA film, the transparency of solar cell modules can be significantly increased by as much as 4%.*

**Keywords** EVA; metal grid; reflection loss; solar cell

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## Introduction

In a conventional silicon solar cell, metal fingers and grids are placed on the front surface to draw a current from the cell. In this scheme, due to the light reflection on the metal, optical loss of incident light by the fingers and buses cannot be avoided [1,2]. Many attempts have been made to reduce the shading losses [3–5]. Most of those studies consist of convex micro lenses which are used to trap light. They commonly suggest additional 2D lens array layer delicately patterned with photolithography method upon the solar cell device. However those suggested processes contain complicated procedures and increase fabrication costs remarkably. In this article, we suggest a simple method aimed at reducing shading loss without additional layers and cost consumption.

On the metal grid in solar cell modules, a sealing film is used which can effectively prevent solar cells from being damaged, prevent inferior degradation. The sealing film is composed of a film formed of ethylene-vinyl acetate (EVA) copolymer resin [6]. EVA

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film is used to attach the silicon cell which converts solar rays into electricity to the backing sheet and glass surface of the solar module via heat-induced molecular binding. In the fabrication of solar cell modules, EVA film must adhere to the solar cell with the appropriate lamination process. The EVA is provided as a relatively low molecular weight thermoplastic processable sheet with a thickness of several tens of a millimetre and contains additives like thermo-oxidative and UV stabilizers, (glass) adhesive promoters, rheology modifiers and most importantly an initiator which starts the radical cross-linking of the EVA. During the radical cross-linking step, the EVA is converted from a thermoplastic into a thermosetting material that provides the protection of the active PV elements in the module. The three basic steps in the lamination process are the heating of the module lay-up to about 150°C to perform the EVA cross-linking step, applying a vacuum to remove the air and other volatiles to prevent bubbles, and the application of pressure to ensure good surface contact and adhesion between the different layers of the PV module [7]. The lamination of PV modules is most frequently carried out using a so-called flat-bed laminator [8]. A flat bed laminator consists of a processing chamber that is divided by a flexible (silicon) membrane in an upper and lower chamber. Both chambers can be individually evacuated and the module lay-up is normally heated in the lower chamber by a heating plate, as shown in Figure 1(a). The lamination process starts with the insertion of the cold PV module lay-up into the laminator. In the mean time, the lower processing chamber of the laminator is evacuated to remove the air and other volatiles to avoid bubble formation in the processed PV modules. After obtaining a homogeneous temperature in the glass plate and crossing the so called EVA softening point at about 60–80°C, the PV module is directly pressed on the heating plate and the actual EVA cross-linking process is performed. The pressure

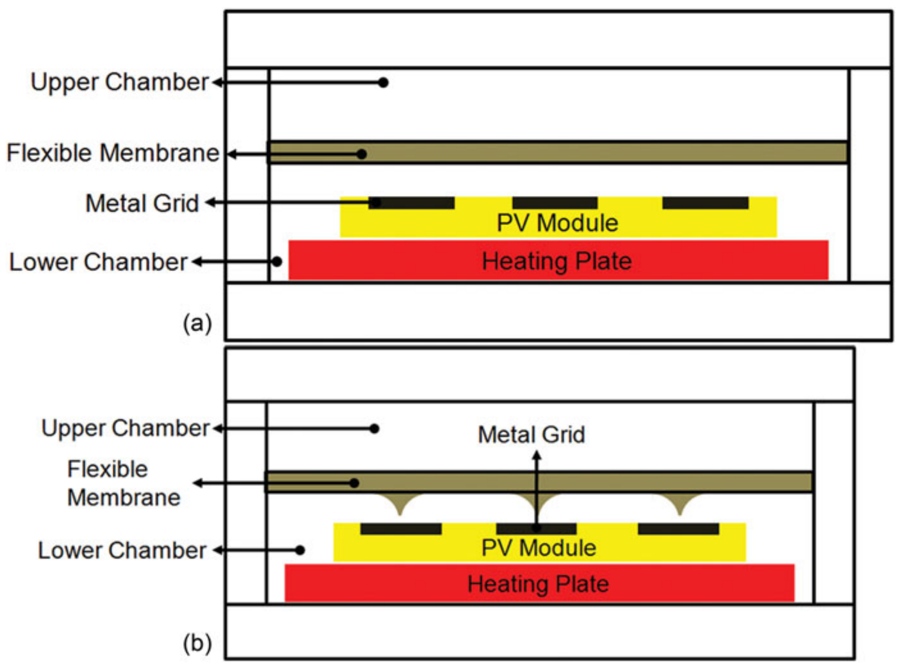


**Figure 1.** Schematic representation of a flat-bed laminator showing the processing chamber divided in an upper and lower chamber by a flexible membrane (a) and modified membrane.

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application on the PV module is established by venting the upper chamber. As a result, the flexible membrane, dividing the upper and lower chamber, is pressed on the PV module [7, 9]. During this process it is suggested that the conventional flat membrane can be reformed so that the EVA film has a cylindrical polymer lens. In other words, the flexible membrane might have some pointed pattern positioned where metal grid exist during the process of pressing the PV module, as shown in Fig. 1(b).

In this article, it is supplied that a theoretical estimation has been made to construct a morphologically modified configuration of EVA film during the lamination process so as to minimize the shading losses. As described above, EVA film layer can be reshaped for functioning similar with cylindrical convex lens which gathers up light to reduce reflective optical loss due to metal grids and buses.

Actually, this morphological structure is adopted by a CMOS image sensor (CIS) photodiode. The CIS chips sense light through similar mechanisms, by taking advantage of the photoelectric effect, which occurs when photons interact with crystallized silicon to promote electrons from the valence band into the conduction band. In this film structure, over 70 percent of the photodiode area may be shielded by transistors and stacked or interleaved metallic bus lines, which are optically opaque and absorb or reflect a majority of the incident photons colliding with the structures. These stacked layers of metal can also lead to undesirable effects such as vignetting, pixel crosstalk, light scattering, and diffraction. Therefore, the application of micro-lens arrays helps to focus and steer incoming photons into the photosensitive region and can double the photodiode sensitivity [10].

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## Results and Discussion

Figure 2 represents optical loss mechanism due to a conventional flatten type EVA film (a) and morphologically modified EVA film (b) respectively. By using simple geometrical optics, it is important to accurately know the optical loss from the metal fingers in the encapsulated solar cell since most solar cells will be encapsulated with EVA film prior to their use in the field. For metal fingers and buses with a curved cross section, some of the reflected light will be internally reflected at the air-glass interface as depicted in Fig. 2 [11]. Any light deflected by more than the critical angle will be totally internally reflected. However, any light deflected by less than the critical angle will be reflected into the air, which is estimated as optical reflection loss. Therefore, all photons incident into the solar cell can be categorized as three type.

a. A light can reach into the active photovoltaic conversion area without any reflection
b. A light can reach into the active photovoltaic conversion area with some reflection satisfying the total reflection conditions at the air glass interface
c. A light cannot be absorbed within the active area due to one of reflection not satisfying the total reflection conditions at the air glass interface before reaching up to active area

For the cylindrical convex lens type EVA film has an advantage to minimize type c light contributing to reflection loss by converting into type b light. As shown in Fig. 2, type c light which cannot be absorbed in the case of the conventional EVA film can be utilized into photovoltaic conversion by reducing the incident angle at the EVA/glass interface.

In order to verify quantitatively the effectiveness of our suggested morphologically modified EVA film, 3D optical simulation has been obtained by using the commercially available Light Tools simulation program. At first, geometrical modeling was done by using a computer based design tool simulation program. For a practical estimation, a dimension

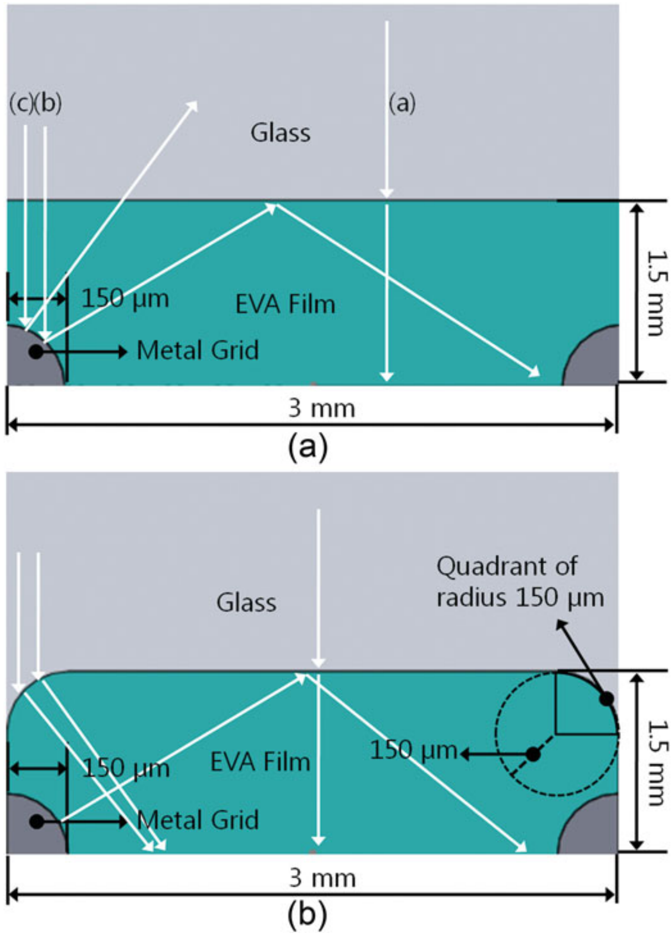


**Figure 2.** Cross sectional view and optical loss mechanism with regular type EVA film geometry (a) and a suggested morphologically modified EVA films schematic diagram (b).

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of the solar cell module is determined as a present standard solar cell module geometry. However, the illustrations in this article were all redrawn to show the specific part which is near the metal grid and this portion of the module is our only concern. Therefore, some distortion of the geometrical dimension used for simulation has been adopted for the display. Optical specifications of EVA film are determined with a refractive index as 1.482 and a transmittance as 98%. These numbers are also quoted from conventional EVA film manufacturers. As seen in Fig. 3, the specific dimensions were well described in detail for simulation. For simplicity, only two fingers with semi-infinite length were considered for simulation due to the regularity of the metal grid pattern on the commercial solar cell module. To be more particular, the cross sectional geometry of the finger consists of a semi-circle which has a diameter of 150 micrometers and the distance between the fingers is set a 3 mm. For simplicity, only two fingers with semi-infinite length were considered for simulation due to the regularity of the metal grid pattern on the commercial solar cell module. In addition, as shown in Fig. 2(b), the specific dimensions were well described in detail.

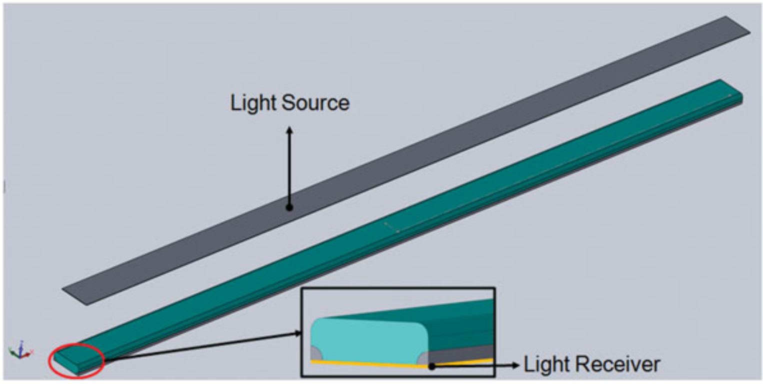


**Figure 3.** Schematic simulation configuration illustrated with Solid Work.

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The light source used for this simulation is a standard 6000 K black body radiation spectrum which is associated with air mass 0 with vertically incident light on the solar cell surface. The light receiving area was distributed throughout the whole area as shown in Fig. 3. The average irradiance (W/mm$^2$) was compared between conventional type and suggested morphology modification of EVA film. The integrated spectral irradiance has been made to confirm to the value of the solar constant accepted by the space community; which is 1.37 mW/mm$^2$. In other words, the maximum irradiance which can be achieved from this work is 1.37 mW/mm$^2$. The result of this simulation is 1.24 mW/mm$^2$ for flatten type EVA film structures and 1.31 mW/mm$^2$ for cylindrically convex lens shaped EVA film. In the simulation, the portion that the metal grid occupied was 5% of total area (which is simply estimated from 150 micrometer (metal grid diameter)/3 mm (pitch of the grid). Therefore, only 1% of the total incident light can contribute to the optical reflection loss by adopting the EVA film morphology having cylindrical convex lens. Assuming that the cell has a quantum efficient of 1.0 throughout the whole wavelength range, most of the light can generate electron hole pairs without any obstacles. In addition, if one regards the ultimate photo-conversion efficiency of the solar cell as 20%, about 1% efficiency increase can be expected according to our simulation results.

## Conclusion

In this paper, a theoretical estimation has been obtained in order to confirm a morphologically modified configuration of EVA film so as to minimize the shading losses. According to a simple geometrical optics study and 3D optical simulation results, by adopting only a small modification of EVA film, the transparency of solar cell modules can be significantly increased by as much as 4%. This quantity can result in an approximately 1% efficiency increase in conventional crystalline silicone solar cells.

## Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NO 2011-0006092).

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