Polymer development and selection criteria for thin-film and crystalline-silicon module manufacturing

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ABSTRACT

Although simple in concept, a photovoltaic solar cell is a difficult feat of technology in execution. The challenge of balancing cell structure design, material optimization and module technology to achieve efficient, low-cost modules that perform in aggressive environments for up to a generation is huge. The modules' structure has to support and protect a thin, fragile slice of semiconductor, while ensuring a stable environment free from contamination and moisture with little or no change in the incident light on the cell.

Key to the modules' performance are the first-level polymeric materials that contact the cell and conductor structures, hold the module together, and in many cases form the second-level protection of the cells from the environment. In this article we explore the industry dynamics in the supply of advanced materials for module assembly, the new technology directions, and how the market will develop over the next five years.

Module manufacturing needs

Modules are critical in protecting the various types of photovoltaic cells during the transport, mounting and life of the cells. With ever-decreasing thickness of the absorbers in the overall module build, the module is an integral part of the final electricity generating effort, and must be designed to protect the absorber while optimizing its efficiency. Furthermore, the module must meet the overall needs of cost, stability and weight required in the final installation.

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The market for cells in 2008 was still dominated by crystalline silicon cells of both the monocrystalline and multicrystalline wafer type. While there are multiple methods of creating these wafers (sawing, string ribbon growth, meniscus growth, cleaving, etc.), the methods used for these wafer-based modules is generally common in that a glass front panel provides the stability and the face to the sun, and the cells are embedded in layers of polymeric sheets to provide the cell insulation, protection and fixturing. Differences in the cells' interconnection from module to module derive mostly from the emitter architecture chosen by the cell maker, and whether the cells need to be contacted on both front and back, or just on the back. This article discusses this market segment as one despite these small differences in process and design, while focusing on the choices of the polymer films used.

The landscape of the thin-film segment is significantly different. There are many thin-film absorbers in production, and many more being developed. Cell architectures vary in their choices for substrate material, and whether the substrate used for manufacture performs as a substrate or superstrate in the final module. Additionally, the thin-film technology in question may be produced on a rigid substrate or on a flexible substrate – again, influencing the needs for any moduling materials. Finally, the thin-film absorbers vary from being stable, passivated inorganic materials that are tolerant to moisture and temperature, to being sensitive organic materials that require high degrees of protection from damaging radiation, moisture, oxygen and other environmental factors.

To put the moduling challenge in sharper perspective it is worth bearing in mind that the vast majority of modules are expected to survive in very harsh environments with a minimum of maintenance. By definition, the modules will be in direct sunlight with many years of high intensity UV exposure. Added to this, the modules will generally be exposed to all the variables of weather throughout the year, including rain, high and low temperatures, hail, snow, wind, sand and debris. Many modules are expected to withstand 20 to 25 years of exposure with precisely limited changes in performance detailed in the module delivery specification.

The only materials that regularly meet such stringent environmental challenges are ceramic (concrete, brick, tile, etc) or self-passivating metals (copper, aluminum, etc). Very few organic surfaces endure such high performance goals (perhaps with the exception of some fiberglass, bitumen, and a few speciality paints). A generic list of overall module requirements is given in Table 1.

C-Si modules

The generic crystalline cell module uses a well-proven design and material set to encapsulate and protect the cells. Cells typically consist of the following components and films:

Glass panel. Usually molded, structured low-iron soda-lime glass, sometimes tempered for strength. This glass is sometimes coated with an anti-reflecting layer, or a self-cleaning layer to improve the module performance.

Physical support of the cells
Mechanical protection
Radiation protection
Moisture protection
Electrical insulation
Oxygen protection
Shock protection
Sand and dirt protection
Manufacturable
Low cost
Architecturally attractive
Physical properties consistent with the cell (flexible or rigid)

Table 1. Module performance requirements.

Adhesive/encapsulant (front). An organic layer that adheres the glass to the front side of the cell, as well as physically encapsulating the cells and front-side interconnect metals. This film must be close to optically transparent at absorbed wavelengths, and must not degrade with exposure. Additionally, the layer must become liquid during module lamination to completely contact the cells.

Cells. Finished, tested wafers assembled into strings of cells with tinned copper strips and connections that will lead to the junction box.

Adhesive/encapsulant (back). An organic layer that adheres to the back side of the wafers and the backsheet material. It also physically encapsulates the silicon cells and back-side interconnect metals.

Backsheet. A high-performance (and consequentially often high value) laminated polymer sheet that combines multiple properties. This layer must provide electrical insulation of the cells, withstand UV exposure from the exposed front side as well as the backside, and protect the cells from moisture and contaminants.

Backsheet

Approximately 90% of C-Si modules use backsheets. The backsheet material choice is highly dependent on the final module performance expectations. Typically the insulation is provided by polyethylene terepthalate (PET), and high breakdown voltages will be achieved with thicker PET films. As PET is sensitive to degradation by UV, modules designed with longer lifetimes will typically protect the PET with layers of fluoropolymer. The most commonly used fluoropolymer today is PVF (polyvinyl fluoride), although PVDF (polyvinylidene fluoride) is gaining in acceptance. In some cases the fluoropolymer is only applied to the back of the PET, but for increased protection it is applied to the front and back of the PET.

Contrary to popular belief, the moisture protection of the PVF/PET/PVF laminate is poor, and backsheet laminators offer the option of including an aluminum layer in the backsheet to reduce moisture ingress.

Variants of this relatively simple PVF/PET/PVF sandwich are common. In some cases an adhesive layer may be included on the inside of the laminate to reduce the complexity of lay-up of the final module. PVF layers may be colored to offer better reflectivity, or more pleasing aesthetics. A notable exception in the global market to these backsheet lamination schemes is in Japan, where many modules have been designed for shorter overall lifetimes. These modules use several (2 to 3) layers of PET and do not commonly incorporate a fluoropolymer layer. To mitigate UV damage the outer layers of PET will often be of a differing composition, and include UV absorbing dyes or pigments to shield the inner layers from damage.

The backsheets are laminated by specialist manufacturers, and require adhesives to ensure good adhesion of each component sheet within the laminate. These laminates are typically epoxies, but other compositions such as acrylics have been evaluated.

Adhesive/encapsulant

The most commonly used adhesive in C-Si module manufacture today is Ethyl Vinyl Acetate. EVA is a crosslinking elastomeric and is supplied as a partially crosslinked sheet that is rubbery and tacky in feel. The sheet is often supplied with a backing sheet, which is removed just prior to use. The elastomeric nature of the film allows conformal coating of the cells, a process that is completed in the curing operation and conducted in a vacuum laminator. Since the reaction occurring in the laminator is a crosslinking reaction that is time- and temperature-dependant, there is an inherent cycle time in the process that can be in the order of 10 to 15 minutes per module. For this reason, EVA curing of modules is often carried out on parallel laminators, or, increasingly, in stacked vacuum laminators which process multiple modules at a time.

A concern with the use of EVA is the outgassing of relatively corrosive byproducts on curing. These byproducts can limit the life of the laminator diaphragms, and require increased pump maintenance.

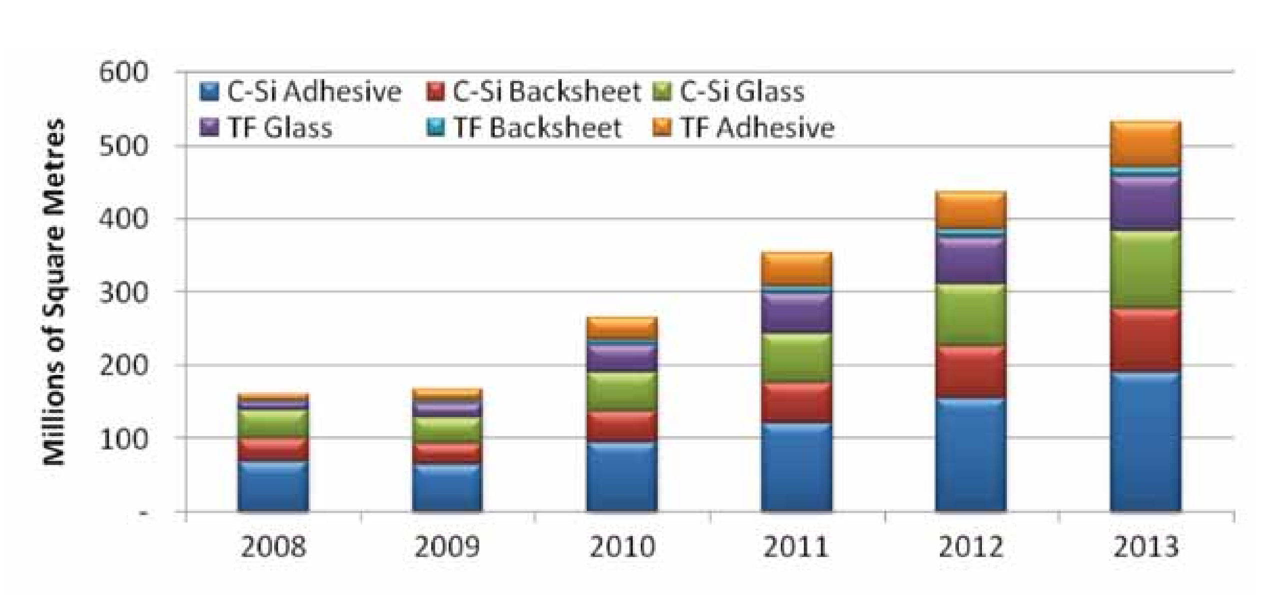

Figure 1. Moduling material demand (in millions of square metres).

An emerging alternative material for use as an adhesive is polyvinyl butyral (PVB), a thermoplastic. Having been used in thin-film glass-on-glass modules for some time, improved PVB materials are coming to market that show equivalence with EVA, without the requirement for long cure times. The PVB becomes liquid above the glass transition temperature, and care needs to be taken that the module is physically supported during lamination and cooling until the adhesive has solidified. PVB has the advantage of not needing the long cure, and can be applied in roll lamination.

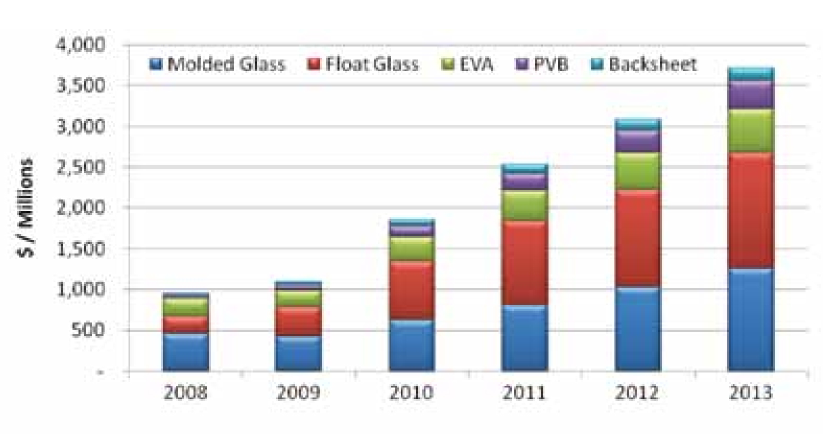

Figure 2. Moduling material market forecast.

"A concern with the use of EVA is the outgassing of relatively corrosive byproducts on curing."

Challenging these film-based solutions is the promotion of a recent development of silicone-based encapsulants. These materials are applied as a liquid and cured in situ, resulting in encapsulants that have excellent stability, high transparency, and good moisture blocking characteristics.

Module quality

In the final analysis, the moduling approach for C-Si cells relies as much on proven technology as on the pros and cons of each technology, either established or novel. Accelerated testing of the finished modules is not perfectly predictive of their performance in use, and real-life testing is not an option for items with such long life expectancy. Thus, there is always hesitancy in introducing new processes and replacing known quantities with proven track records.

Thin film

The dominant moduling technology for thin-film absorbers is glass-on-glass. In this technology a glass sheet is used as the manufacturing substrate, and once complete, a second glass sheet (either a superstrate or substrate) is laminated to the completed cell on the glass sheet, providing front and back protection for the cell, and requiring only an edge seal to make the final module hermetic.

About 20% of thin-film modules use polymer-based encapsulants, either in the form of backsheets similar to c-Si technology, or as front-side protection for cells fabricated on substrates like steel as a transparent protection layer over the cell.

Glass on glass

The most common approach to thin-film modules uses a PVB film between two float glass sheets. The inherent strength and protection afforded by the two glass layers provides excellent protection for the absorber. In fact, in two common embodiments (tandem junction silicon and CdTe modules) there is no specified frame, and in some cases no edge sealant is used. These simple modules are laminated with niprollers and cured in an autoclave. This technique has been demonstrated in very large module dimensions (up to 2.5m on a side), showing savings in support frames and Balance of Systems.

Backsheet on Glass

Dual glass sheets incur a penalty in weight, which may be unacceptable on rooftop applications. An alternative approach is to laminate the cell and glass front with a polymer backsheet. On the face of it, this should not cause major concerns due to the generally unreactive nature of the semiconductor absorber; however, this technique is likely better suited to Si-based cells.

Frontsheet on glass or steel

In the case of some CIS/CIGS designs, and some specific Si-based dual and triple junction designs, the front side of the absorber must be covered by a transparent encapsulant. Commonly used encapsulants are fluoropolymer-based films such as ETFE, which offer good environmental resistance, as well as flexibility in the case of cells built on steel.

Market outlook

Linx Consulting, together with Alternative Energy Investing, have developed forecast models for the materials demand in the PV industry. Despite a poor prognosis for 2009, we anticipate that the cost competition in the down year will act to further spur growth in 2010 and beyond, and increased concern for the provision of alternative energy will drive subsidies and feed-in tariffs to support adoption of PV projects. Although overall growth may not parallel that seen in the past few years, we still expect double-digit compound rates and strong demand for moduling sheets and materials from 2010 onwards.

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Figure 1 shows a forecast for the various moduling materials in square metres. The largest segment by module area is that of the c-Si adhesive, since each module uses two sheets. Figure 2 is a forecast of the market growth for the materials shown in Figure 1. While dominated by the cost of glass, the predictions still show a US$220 million polymer market growing to more than US$1 billion in 2013.

New challenges

An underlying principle of the whole photovoltaic market is the continual need to reduce the cost per watt of power generation capability. Integral to this goal is the reduction of the purchase cost of modules. Since most of the components of the module are already based on materials that are largely commoditized (glass, aluminium, stainless steel, polymer sheet, etc.) the prices are largely market driven, and scale effects are mostly irrelevant. However, the cost of specialization of these materials will reduce as volumes increase, and the market prices will approach the commodity levels.

Despite this potential route to cost reduction, any competitor in this market must include a continuous, relentless approach to cost reduction; at least until grid parity is reached to a broad extent, but also to ensure competitiveness even after this juncture.

Product differentiation through technical performance is critical to developing improved module and cell efficiency, and thus the aggressive Levelized Cost of Energy targets needed to achieve grid parity must be met. Incremental improvements in technology will lead to cells and modules that are better suited to the segment needs, whether on-grid or off. These changes will take time to implement due to the inherent difficulty of knowing if they are durable for the intended life cycle of the modules, but the current module designs will likely not survive unchanged in the relentless quest for grid parity.

About the Author

Mark Thirsk is Managing Partner of Linx Consulting. Mark has over 20 years' experience spanning many materials and processes in wafer fabrication. He has served on the SEMI Chemicals and Gases Manufacturers Group (CGMG) since 1999, acting as Chairman between 2001 and 2003.

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