Trends and developments in the lamination process of PV modules (part 1)

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ABSTRACT

The encapsulation of solar cells is one of the most enduring 'traditional' process steps in the fabrication of a photovoltaic module. The need to protect the delicate semiconductor active solar cell with protective material to ensure long-term operation remains a critical step in the module assembly process. However, continued development of the lamination process and materials used for encapsulation are required to meet increased demands of 25-year guaranteed module operation in the field, shorter cycle-times and lower production costs. In this two-part article, we look at the challenges these and other factors are having on the lamination process, the equipment required and the developments taking place to meet module manufacturers' requirements now and in the future.

Sticking with EVA

Since the early 1980s, the conventional ethyl vinyl acetate (EVA) material has become the workhorse of the PV industry with respect to providing the required electrical isolation as well as protection for the solar cell from the elements when the PV module is operating correctly in the field. Photovoltaic modules by design and function need to be exposed to sunlight as much as possible. Therefore the materials used to support and protect the modules must be of the right construction and operate consistently for many years.

The required characteristics of adhesion via an adhesive agent proven with EVA-based encapsulant has meant that the PV industry has been able to progressively offer longer-life warranties for modules, which now typically run for 25 years and whose lifetimes are expected to be extended further in the future.

Although other fabrication processes are regarded as more technically demanding, correct encapsulation of the solar cells considerably influences the life expectancy of a module. This has led to the situation whereby module manufacturers are extremely conservative with material choice and developments in the lamination process.

Market demands

The rapid growth in the photovoltaics market is clearly demonstrated in Fig. 1. Such growth has had the effect of creating material shortages for extended periods of time, most notably and well documented in respect to polysilicon. However, there have also been periods of supply constraint in regard to encapsulant materials.

Oil-based plastics such as EVA and PVB (poly vinyl butyral) require refining. As demand for oil increased significantly over the last decade due to the economic growth in China and other emerging economies, refining capacity has been under severe constraints and the price of oil-based materials has also been subject to major increases as a result.

When coupled to the rapid expansion of capacity in module production (see Fig. 2) and the expected capacity coming on-stream over the next few years, concern has increased over the PV industry's dependence on EVA-type materials and renewed efforts have been made to find long-term sustainable alternatives.

According to Karl-Heinz Brust, Technical Manager at Krempel Group, a noticeable shift has taken place since

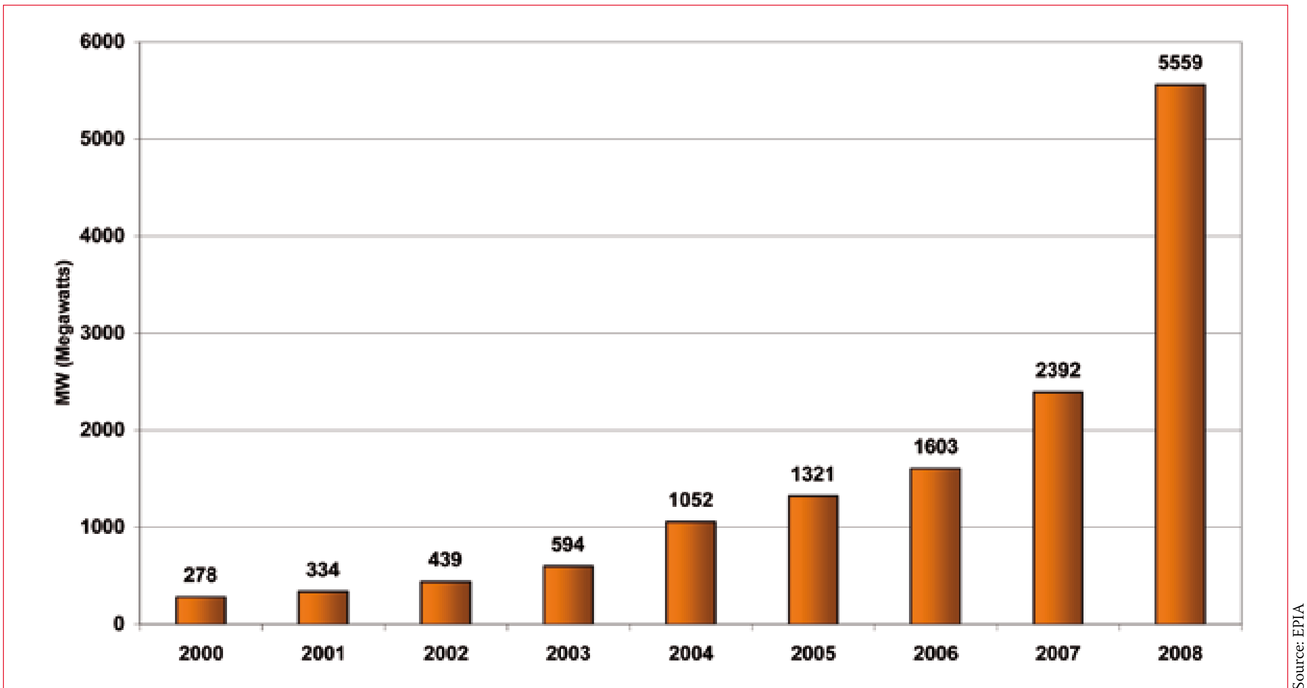

Figure 1. Historical global growth of PV installations through 2008.

2008 towards actively seeking these alternative materials. Krempel Group is known in the industry for its 'AKASOL' family of polymer backsheet film materials engineered from combinations of PET, PEN, PC, PVF and PVDF.

"The key is maintaining the high-quality requirements well known with conventional materials when developing alternatives", noted Brust. "Collaboration with chemical suppliers, equipment suppliers, research institutes and module manufacturers is required. Typically a development time of three to four years is required."

Krempel's product offerings conform to IEC 61730-1 and IEC 60664-1. The laminates are UL-recognised components and are listed in the QIHE2 category (E 312 459) and are compatible with all encapsulation plastics of relevance, such as EVA, PVB and TPU.

However, Brust warns that laminates being classed as conforming to IEC specifications is not a guarantee that the material will support module life/performance expectations. In his opinion there is an increasing number of backsheet materials now entering the market that, while they are claimed to meet the supply and cost issues, they have not been active in the field long enough to have been fully evaluated.

"The question is what is the behaviour of different materials over 25 years in different climatic conditions?" asked Brust. "It is often not possible to physically see the quality differences in the material after module assembly; the problems only arise later. It is a problem in the industry that we do not have sufficient accelerated tests to qualify new materials… therefore it still takes experience working with these alternative materials to determine what works and what doesn't."

Not surprisingly, Brust went on to explain that at Krempel, considerable in-house testing is carried out to ensure the long-term reliability of the material over and above the false economy of significantly cheaper materials. Brust believes that a small cost saving may be achieved with the right material development while retaining the high quality required for such a demanding application. Unfortunately, any significant cost reduction strategy that dictates development can mean risky business for module manufacturers.

Interestingly, Brust feels that a return to supply-and-demand balance would not necessarily mean a reversion to traditional materials and brands on the part of module manufacturers. The competitive landscape has changed; Brust sees potential for greater diversification in the type of materials being used. They are being better developed and are more geared towards the product market and different end-user applications, while some materials are better suited to utility-scale markets than residential rooftop applications.

Although more research is required to establish which applications could use cheaper, lower-quality materials, this move could potentially prove a significant step in the right direction for a market that is considered conservative. Closer collaboration will be required with module manufacturers on all aspects of the specific applications for a given module, helping to bridge the gap between cost considerations and life-span requirements.

Materials developments are coming thick and fast from a host of suppliers, such as Coveme SpA's recent introduction of 'dyMat PYE', a new backsheet material. In co-operation with DuPont Teijin Films, Coveme has developed a high-grade PET inner layer with a lifetime claimed to be five times longer than that of traditional polyester.

Research has shown that improving the hydrolysis resistance of polyester is key to achieving better performance from backsheets. Due to water permeation of the outer layer, the inner PET layer suffers, losing its protective properties over time.

The dyMat PYE laminate is based on two layers of polyester film. The cell side is treated with a special thick primer that provides high bonding capability to EVA. Laminate thickness has been designed to provide the best combination of properties in terms of electrical insulation and weatherability.

Similarly, Wacker's recent introduction of 'Tectosil', a silicone-based, thermo-formable elastic polymer sheet claims low costs and ease of manufacture. The sheet's thermoplastic properties allow quick and inexpensive processing without curing or chemical reactions. The lamination process therefore benefits from a shorter

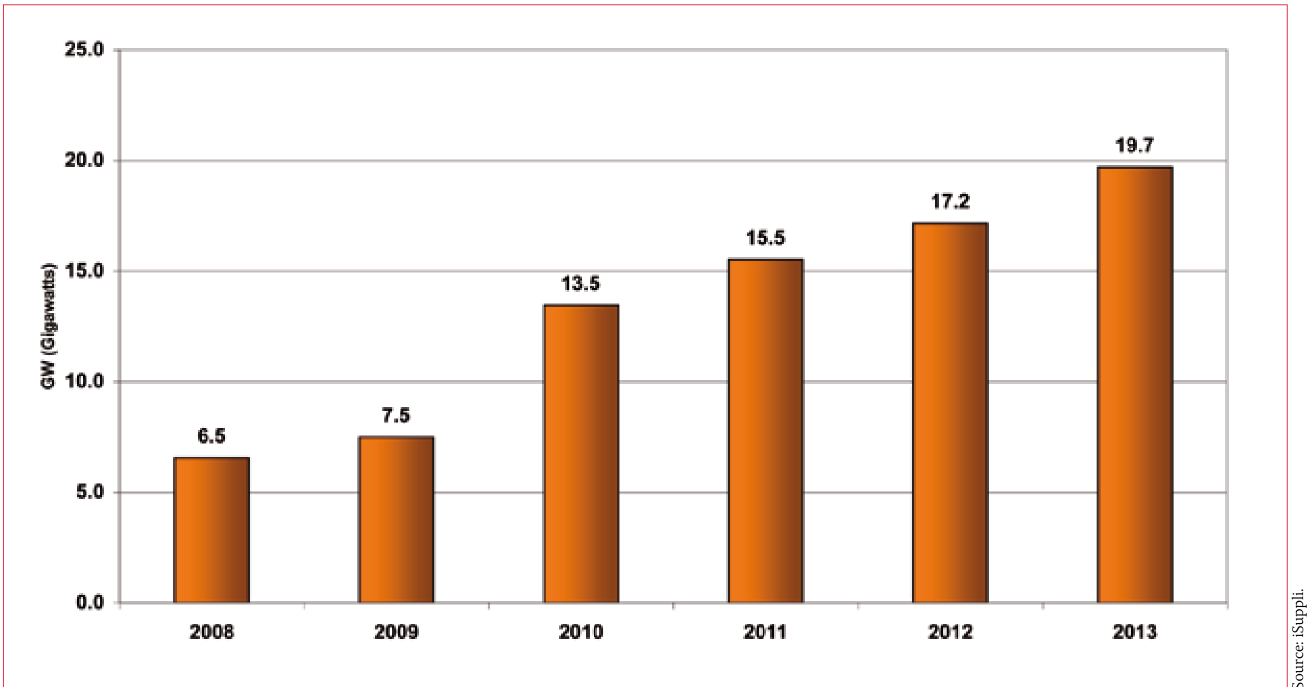

Figure 2. Global PV module production forecast (iSuppli).

production cycle and a high tolerance to local temperature differences within the laminator. Tectosil can be used to make any type of module and is suitable for either vacuum laminators or continuous processes.

Although far from providing an exhaustive review, these examples demonstrate the innovations taking place in the PV materials realm with the aim of enhancing module protection and the ease of fabrication.

Laminator market

According to VLSI Research, there are approximately 50 equipment suppliers that offer either dedicated lamination tools or laminators as part of a suite of systems for module assembly. This figure includes those that offer laminators as part of a turnkey production solution.

The laminator equipment market exceeded US$300 million in 2008, a CAGR of approximately 100% compared to 2007. In alphabetical order, the Top 5 suppliers (by US$ revenue) were 3S Swiss Solar Systems (Switzerland); Bürkle (Germany); Meier Solar (Germany); Nishimbo (Japan) and NPC (Japan).

Other lamination equipment suppliers include Spire Corporation, Komax, ecoprojecti, as well as P.Energy and 3S, discussed in the following section.

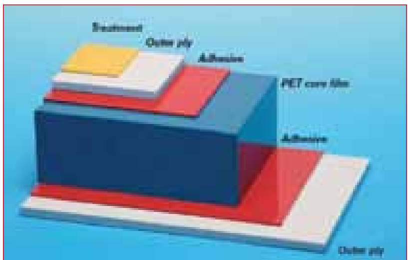

Figure 3. Krempel's 'AKASOL' polymer backsheet film design.

Lamination process

The ability to use EVA material in sheet form quickly led to the development of the 'roll-to-roll' lamination process, which rapid took over as the standard method of encapsulant processing.

Encapsulant processing typically involves a sheet of material being placed onto the glass, onto which the pre-sorted and connected solar cells are placed. Another layer of sheet encapsulant is then placed on top of this, followed by a final insulating film layer on the back of the solar panel. The completed laminate is then placed into a laminator machine, which is heated to an optimum temperature to melt the encapsulant material. A vacuum process is then applied to remove any air bubbles trapped during the heating process, resulting in a sealed solar cell array that is bonded to the glass surface.

The result is a mechanism whereby the electrical connections are suspended in an EVA matrix. While the glass provides the required durability, rigidity and surface transparency, the backside's protective backsheet provides physical protection, electrical insulation and a barrier to moisture ingress.

Laminator developments and requirements

With the exception of exotic encapsulants that are available on the market, there seem to be few material and laminator equipment suppliers that face any specific processing challenges other than achieving optimum process settings. Confidence in mainstream materials built up over many years of market involvement is most likely the reason for this optimism.

However, equipment suppliers must develop tools that are compatible with or capable of adapting to different lamination materials or to the extreme

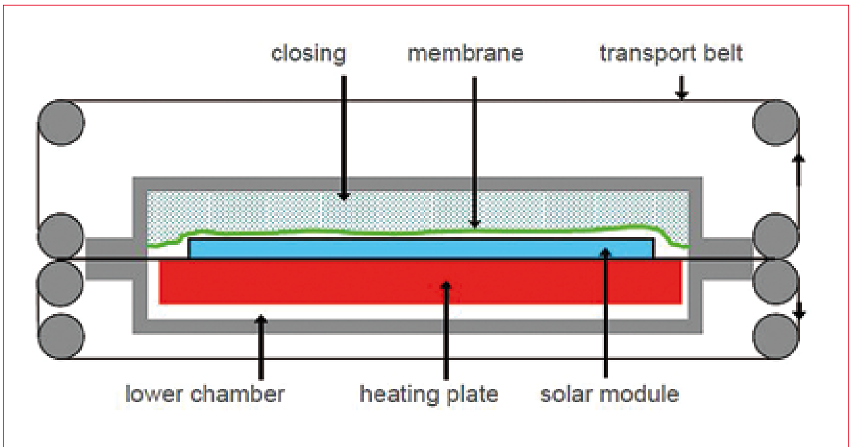

Figure 4. Schematic of roll-to-roll laminator (source: Kuraray Group).

heat procedures used in the lamination process. Electrical heating plates or oil-based tube heaters can be used for this application, while recent developments have seen hybrids of these two systems become available that are intended to further optimize the process. As a result, there has been a gradual trend towards improved process optimization and cycle-time reduction that has been at the heart of equipment-related developments.

Optimized process control dictates three key aspects of the tools' function: heating, curing and cooling. This process has been tightened to within a few degrees, and can be flexible in accommodating the varying specifications of the materials being used.

As with the trend to towards a greater degree of collaboration between material suppliers and module manufacturers, lamination equipment suppliers are having to better meet the needs of the customers.

Italy-based P.Energy has made a successful business of catering for the emerging Italian module manufacturing market. This comes on the back of favourable feed-in tariffs and the Italian government's attempts to promote domestic manufacturing to meet demand for solar installations.

Since December 2008, P.Energy has supplied four automated production lines to module manufacturers in Italy, and one to Portugal. The 10MW automated line shipped in December last year was for Torri Solare Srl, located in Brescia, Italy. In January 2009, GOOSUN of Porto, Portugal received another 10MW automated line, the first automated line in the country, said a spokesperson.

More recently, P.Energy delivered a 20MW automated production line to V-Energy srl in Biella, Italy in April 2008, while the company has customers such as Solar Semiconductor as far afield as India.

On contacting Gabriele Pettenuzzo, President of P.Energy, the equipment supplier executive was quick to reiterate the need to meet evolving customer demand. A key attribute currently requested from his customers was temperature uniformity in the heat plate, citing a need for a temperature range within ± 2°C.

To enable this level of temperature uniformity, Pettenuzzo noted that: "In our laminator we have from eight to 20 PID temperature control points – the number depends on the work area of the laminator in question. Besides, we design special heaters for different heating performance from the head to the tail of the electric heater, and with the power increase in this way we can warrant ± 2°C across the plate."

Pettenuzzo sees this as a key differentiator with his company's laminators. He also noted that special care and different curing cycle-times were often needed with thinner or different backsheet materials.

Conventional heating elements create a wide range of temperature differences and hot spots that result in inconsistent sealing. High-volume applications require greater levels of temperature homogeneity with maximum temperature difference on the heating plate of 2°C absolute.

3S Swiss Solar Systems is another major equipment supplier that has focused considerable attention on the need to precisely control temperature homogeneity with maximum temperature difference on the heating plate of 2°C absolute. The patented 'Hybrid Heating Plate' is claimed to combine the advantages of both electrical and oil heating techniques that generates higher temperature homogeneity, boosting yields and throughput.

The heating system has 40 electrical rod elements of 2kW each. Heat carrier oil transmits the heat from the rod elements to the heating plate at high speed allowing for very short heating times. After lamination, the cooling press permits controlled cooling of the module. 3S claims that the technology shortens the time between lamination and post processing, as well as reducing interior stress in the module.

Alessio Maiocchi, Product Manager at 3S for its laminator line, commented that as the lamination process determines the lifetime of the module, it is imperative that a complete understanding of the process is assured.

"The lamination process is more than cooking a cake in an oven", commented Maiocchi. "A deep understanding of what happens during lamination is necessary to optimize cost and quality for long-life solar modules in order to reach grid parity."

Maiocchi described the company's MLS (membrane lifetime extension strategy) as testament to work done to observe the lamination process and obtain a deep understanding of the dynamics at play. "How

Figure 5. P.Energy's L900A is a fully automatic photovoltaic module laminator.

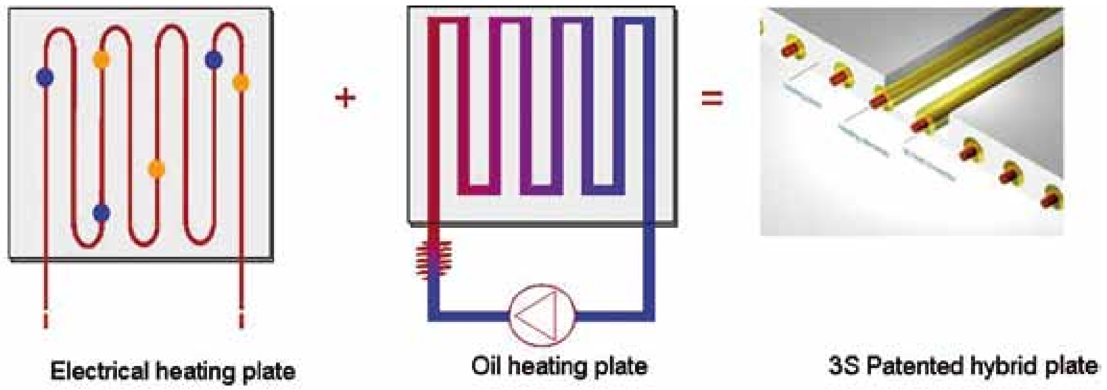

Figure 6. 3S Swiss Solar Systems' 'Hybrid Heating Plate' design.

we handle the material membrane inside the laminator during processing is critical to a long-term operation of the module. A key aspect is not to put mechanical stress on the membrane as this ultimately reduces the module lifetime", he said.

The company use an inbuilt camera and specially developed vision system to observe the lamination process. According to Maiocchi, the membrane lifetime can be drastically extended while achieving a TCO reduction of 25% over a five-year period.

"For recipe optimization we work with design of experiments. Our recipes are based on experiments, thus on statistical values", noted Maiocchi. "The benefit for our customers from this is the optimization of their lamination process and the quality of the modules. This results in lower process costs and thus a real competitive advantage".

Time and again in speaking with Maiocchi, the issue of direct customer collaboration and the company's in-depth understanding of not only the lamination process but the full module assembly process came through as key aspects that were required to provide the performance that customers require today.

Conclusion

Although much of the emphasis in the topics covered within this article have focused on the material quality issues and attention to detail on process control, high-volume manufacturing requires a concerted effort to constantly improve productivity of the lamination process and in turn the productivity of the total module manufacturing line.

Such is the competitive landscape that greater attention to these factors is becoming a key differentiator for both equipment suppliers and module manufacturers. In the next edition of *Photovoltaics International*, the second part of this article will look closely at developments undertaken to improve cycle-times of the lamination process and overall productivity improvements.