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Advanced encapsulation for photovoltaics: where are the opportunities?

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ABSTRACT

One of the most important ways in which inorganic thin-film photovoltaics (TFPV) and organic photovoltaics (OPV) can distinguish themselves from more conventional crystalline silicon photovoltaics (c-Si PV) in the marketplace is through the commercialization of flexible photovoltaic products using those technologies. But flexible photovoltaics brings with it some challenges of its own in terms of excluding air and moisture from the cells; challenges that translate into opportunities for suppliers of advanced encapsulation materials and systems as well as for TFPV and OPV firms.

Although flexible PV has been talked about for many years, in reality it is limited to just a few products in very limited volumes. However, today there are a number of factors that are combining to push it more solidly into the market. For one thing, the PV market situation in the past couple of years has been dragged down by the worldwide economic downturn, and PV will increasingly need to turn to niche markets to achieve decent revenues, especially if governmental support for PV declines in the future, as we expect. Combine that with growing competition from commodity c-Si panels and the TFPV and OPV industries are looking for newer, higher value products that they can both sell and protect from competition.

As it happens, flexible PV offers an apparent route to achieving these goals. Flexible building-integrated PV (BIPV) products, such as flexible roofing shingles, open up new markets for PV; large markets that are concerned as much or more about aesthetics as they are about being 'green'. There is also a developing niche market for items such as rollable solar chargers for portable electronics, and PV applied to textile products like umbrellas, handbags and clothing.

At least two kinds of opportunities for encapsulation suppliers are created by the current situation. First, there is a need to improve on the existing glass substrate + glass encapsulation paradigm. This is an opportunity, not just because this is where the bulk of the market is right now, but also because rigid TFPV is often associated with the highest performance and there will always be a need for high-performance TFPV products. Second, there is the (still wide open) opportunity to create a novel flexible encapsulation method that will prove an enabling technology for intrinsically flexible products. We believe that this technology would – in the technical sense of the term – be a disruptive technology, in that it could prove to be a key enabling technology that opens up BIPV markets and perhaps even technically related markets such as intrinsically flexible displays.

Rigid photovoltaics products can generally be easily encapsulated in glass, which forms a suitably impenetrable barrier for air and water (with some exceptions, as will be discussed). Removing the glass from the outside of these modules leaves the devices within at the mercy of whatever barrier material is used instead. Plastic films – typically both the cheapest and the simplest encapsulation materials – are often not up to the task, especially for the more sensitive of the TFPV and OPV technologies. Firms that can produce robust, easy to use, and in some cases relatively inexpensive encapsulation solutions stand to benefit financially as they bring flexible applications within reach of TFPV and OPV, or even open entirely new markets to these PV technologies.

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On the flexible products side, the lack of an existing high-volume market of flexible PV to consume new encapsulation materials is of some concern to flexible encapsulation developers, but there is not as much risk as one might think. Big companies like Dow Chemical are getting behind flexible PV, and the nascent flexible encapsulation market is actually quite 'diversified' – that is, it does not rely solely on photovoltaics. Other highly sensitive emerging technologies are also waiting in the wings for better flexible encapsulation developments. Most notable of these is the market for OLEDs for both lighting and displays, as well as e-paper for signage and displays.

OLED materials are as sensitive to moisture as are CIGS and OPV materials; as with OPV, they are sensitive to oxygen. Like many flexible PV applications, OLED lighting is also at the transition from development to commercialization. Flexible encapsulation developers moving into commercialization will not have long to wait for a rapidly growing market.

As a result of the needs of flexible PV devices and the shortcomings of existing encapsulation technology, some segments of the PV industry are chomping at the bit for better encapsulation solutions; 'better' in this case being from the standpoint of either performance or cost. In order to make money in the encapsulation business, it is important to understand where performance enhancements are needed. NanoMarkets' research indicates that the best markets for advanced encapsulation firms to concentrate on are thus CIGS PV and OPV.

CIGS: different from other inorganic TFPV

Not all TFPV is created equal in terms of the types of encapsulation needed. In fact, in the inorganic TFPV segment, the differences in requirements are so great that, when the encapsulation industry talks about advanced encapsulation for 'inorganic PV', in most cases it is really referring to CIGS. The most moisture-sensitive of the inorganic thin-films commonly used for photovoltaics, CIGS has an inherent degradation mechanism in the presence of moist heat. The aluminium-doped zinc oxide (AZO) front electrode also contributes somewhat to its sensitivity.

The sensitivity of CIGS is in contrast to thin-film silicon PV, which is much less sensitive and can often use fairly simple encapsulation solutions, even polymer films. Furthermore, encapsulation for flexible CdTe PV is essentially a non-issue, since the CdTe sector is so completely dominated by a single company – First Solar – which is doing just fine supplying only rigid, glass-encapsulated products. Were First Solar or a competitor to introduce flexible CdTe PV devices, they would not be as sensitive as CIGS is to moisture.

CIGS needs advanced encapsulation for flexible products, to extend lifetimes and improve reliability. This is especially important because the CIGS industry has its sights set – more so than any of the other PV technologies – on flexible BIPV products. These solar shingles and other flexible products aim to offer the double whammy of high performance and flexibility, all in a package that is both aesthetically superior to conventional panels and accessible to the mainstream building markets where flexible building materials are the norm for things like roofing. Such products now exist only using thin-film silicon PV technology, but they are very limited in conversion efficiency and thus performance. CIGS PV stands to double the performance of current products, allowing higher power output on limited-size building surfaces and thus demanding a substantial premium. It is also important that the modules last as long as the conventional building materials and conventional solar panels; however, this is the very goal of advanced encapsulation for CIGS.

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As is the case for CdTe PV and most other PV technologies, CIGS's encapsulation problems are negligible for the most part in rigid products as glass surrounds and protects the cells. CIGS can certainly have a robust market – provided the supply can be developed – in rigid products, but NanoMarkets predicts that flexible applications will make up a much larger proportion of the market for CIGS PV than it does for the other inorganic PV technologies. Producers and developers of flexible CIGS products will pay a premium for encapsulation that works, and will take advantage of cost reductions as they become available.

OPV needs encapsulation

So if CIGS needs advanced encapsulation as 'icing on the cake', OPV needs encapsulation as the cake batter itself. OPV is so sensitive to air and moisture that even the lifespan of glass-encapsulated modules is limited by intrusion of these elements. That is, for conventional OPV panels, besides being much lower in power output and not much different in price versus other PV, they also have much shorter lifetimes. As a result, advanced encapsulation is needed for glass-encapsulated OPV products.

> "OPV cannot compete unless it carves out niches for itself where other forms of PV cannot or will not compete."

But advanced encapsulation has a lot more to offer than just marginal increases in lifetime. OPV is a struggling technology; there can be little demand for a product that is far lower in conversion efficiency than other widely available technologies, and that is not much – if at all – cheaper besides. OPV cannot compete unless it carves out niches for itself where other forms of PV cannot or will not compete. There is no significant market for OPV without these niches, nor without reasonable product lifetimes for those niches.

This represents the big difference between the needs of OPV and CIGS. While CIGS has both the conventional PV panel market and the rigid BIPV market to fall back on without advanced encapsulation, OPV is standing on the edge of the abyss. Perhaps OPV can distinguish itself enough in some short-lived portable or embedded products – indoor chargers, perhaps – but to really achieve significant volumes and money, OPV needs to be deployed outdoors, and this will certainly not happen in the form of conventional panels.

Advanced encapsulation is thus the key to OPV-based BIPV products, even before it meets the need to distinguish itself in the marketplace from other PV technologies. Whether OPV can position itself into some BIPV niches, be they sectors that require high flexibility, transparency or sustained performance in low light (all features where OPV outperforms other PV), depends first on OPV meeting the lifetimes required for BIPV installations.

The same can be said for glass-encapsulated OPV-based products. For example, one big potential market for OPV lies in the BIPV glass segment. OPV will likely be among the first PV technologies to achieve BIPV glass panels with a uniform, tinted appearance instead of the striped patterns typical of inorganic TFPV-based BIPV glass or the large silicon cells that are periodically spaced within the glass in c-Si BIPV glass. Uniformly tinted BIPV glass can certainly open new markets to PV, for example in windows where clear visibility is required or an opaque pattern is simply undesirable.

Nevertheless, this transparent BIPV glass market cannot exist if the products are not up to the standard lifetimes of BIPV glass, which currently stands at around 30 years. OPV is not yet suitable for BIPV glass largely because encapsulation systems are not yet robust enough. But the premium for BIPV glass is so much higher than the cost of conventional PV panels that even quite costly encapsulation solutions can be lucrative for both the encapsulation supplier, who makes money selling a high-value, high-margin product, and the OPV-based BIPV glass producer, who finds a virtually limitless market opened.

Because this niche for transparent BIPV glass cannot be filled by other PV technologies, it seems likely that OPV would be able to command a premium for such products, even given OPV's low conversion efficiency. NanoMarkets believes that it is not the low conversion efficiency of OPV that is keeping it from the BIPV glass market, but the lack of sufficient encapsulation solutions and the resulting short product lifetimes. This is

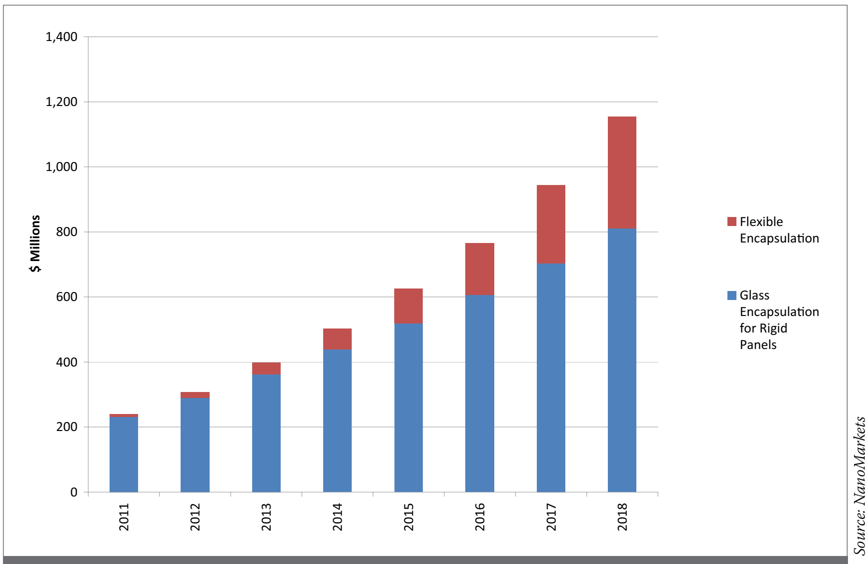

Figure 1. Encapsulation market for thin-film and organic PV ($ millions).

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why there is such a huge opportunity for developers of new, advanced encapsulation materials and systems.

All this points to NanoMarkets' conclusion: CIGS PV and OPV developers will be willing to pay premiums to get their hands on the best encapsulation materials. The marketing of premium encapsulation products needs to be appropriate. In our view, encapsulation firms have had the importance of cost emphasized to them so much over the past few years, that it might be something of a shock to the collective system to refocus their marketing and business development efforts on an encapsulation product that delivers better performance at higher cost.

As we have noted, encapsulation is now quite literally essential to the survival of the OPV industry, so encapsulation firms can almost hold this industry hostage. Furthermore, the premium nature of CIGS PV – BIPV products in particular – certainly also leaves room for the use of premium encapsulation materials, provided they produce real and marketable improvements in device lifetime and reliability.

Of course, premium encapsulation solutions are not the only kind for which opportunities exist. There are plenty of applications for both CIGS and OPV that can be served by existing encapsulation technology, and cost reduction is always an important motive. For example, flexible PV chargers would likely have a service life of only a couple of years and would thus not need the most advanced encapsulation technology, even if built with OPV. For portable charging, the pertinent question is how the charger is used. One would not cut corners on encapsulation for an OPV-powered solar umbrella, for instance, as the high exposure to the elements would quickly degrade the device. But for some applications such as portable chargers for personal electronic devices, the power-consuming devices are typically protected from the elements regardless of the power source, and an OPV-powered portable charger could reasonably be expected to be provided the same protection. Portable chargers paired with a personal electronic device also benefit from the short replacement cycle typical of cell phones and other devices; a charger might not be expected to last much beyond two years.

There are also several claims in the CIGS space that the flexible encapsulation challenge has been solved to the extent needed for flexible BIPV products. Currently, the most effective solutions for transparent, flexible encapsulation of these highly sensitive devices are dyad systems. These systems combine layers of two different kinds of materials – generally a polymer and a ceramic – in alternating fashion, typically for multiple dyads or layer pairs.

The idea is for the ceramic to plug pinholes in and slow diffusion through the polymer while the polymer seals the defects in the ceramic. The more layers that are built up, the greater the reduction in moisture penetration. With enough layers the performance can certainly be adequate, but these systems become costly and time-consuming to apply. Furthermore, the deposition and curing conditions may cause damage to heat-sensitive underlying layers. There is certainly an opportunity for less costly and more user-friendly encapsulation solutions for CIGS and for OPV in applications where lifetimes are already long enough.

Opportunities of a lesser kind

Advanced encapsulation developers and suppliers will have to weigh the opportunities on offer by CIGS and OPV, the two PV technologies most in need of new materials. On one hand, CIGS offers higher volumes than OPV, even though the encapsulation requirements are not quite as high. On the other hand, advanced encapsulation – with very high performance – is critical to allowing OPV to break out of the relatively low-volume short-lived and indoor markets and venture out into the 'real world'. So, while CIGS PV will probably provide more money to advanced encapsulation suppliers, OPV should not be overlooked simply because it is low in volume.

NanoMarkets believes that advanced encapsulation suppliers and developers will be largely wasting their time peddling their wares in markets where mainstream polymers will suffice or where glass encasement already provides an impermeable barrier. Crystalline silicon has relatively low encapsulation requirements. These are rigid cells that are not particularly sensitive to air or water, and tend to be encased in glass regardless. Encapsulation is not a problem beyond using polymers to seal the edges; perhaps even in place of one pane of glass. Advanced encapsulation does not concern c-Si PV.

The story is similar for CdTe. While more sensitive than crystalline silicon, it is also currently always packaged in glass, providing good barrier protection. First Solar has dominated this category and has sold only conventional panels; both of those facts appear unlikely to change soon.

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There are some opportunities for cost reduction for encapsulation of thin-film silicon PV, as flexible versions of these devices do need some protection from the elements, particularly when they are used for BIPV. As these devices are not nearly as sensitive to air or water as are CIGS and OPV, polymer films can generally suffice; cost reduction efforts are generally to use lower-cost polymer films or simpler application processes. And rigid products are again encapsulated in glass, providing protection far beyond the minimum required.

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