Flexible Substrates Markets—2011

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Chapter One: Introduction

1.1 Background to this Report

Flexible electronics have attracted a great deal of interest in recent years. At least in theory, they offer a number of important advantages for displays, lighting, solar panels and sensors. In addition, flexibility to some degree is implied in the notion of R2R processing. Each of these applications requires different strategic thinking about the appropriate flexible substrate to use, but there is also an important commonality which NanoMarkets believes will create a vibrant market for flexible substrates of all kinds.

1.1.1 The Big Problem With Selling Substrates into the Flexible Display Market: Flexible Displays Don't Exist!

Flexible displays have been proposed for about a decade now and have been on show at display conferences and exhibitions for about as long. They are frequently cited by literature in the printed and organic electronics disciplines as an important trend for the future. In addition, within the community of firms making materials suitable for flexible substrates, there is a view that there is considerable potential for making sales to a vibrant flexible display market of the future.

For the time being this potential is just that—potential and little more:

- We think that substrate firms should be careful not to talk themselves into believing that there is more here than meets the eye. Certainly, they should not expect much short term revenue from the flexible display sector. As yet there have been no flexible displays that are commercially available and promises made by a few firms to bring such displays to market have been broken.

- That said, flexible displays do seem to have the potential for real-world applications—if anyone could build them, that is—and the recent announcement by Samsung that it plans to introduce these displays to the market has lent them considerable credibility.

The main application for flexible displays would be to enable portable displays of reasonable size that can be plugged into a cell phone to serve better as a video device or IT tool. The first real rollable displays now look like they will as likely be OLED displays, since OLEDs can provide superb color, while the most common e-paper technologies are color-challenged:

- Conformability only would seem to be good enough for flexible substrates used in signage applications.

- From the substrate perspective, rollability will probably suffice for now in the display sector, but the idea of a display that can be crumpled up and put in one's pocket, implies three-dimensional flexibility—a technology that doesn't exist yet.

- Three-dimensional flexibility would seem to fit well with the e-paper concept, since real paper is flexible in this sense. For a time, "e-paper" and "flexible displays" seem to be synonyms for each other.

Substrates for flexible displays may be relatively undemanding in terms of durability, at least at first when they are used with cell phones; cell phones generally last between a year and two years. However, electrical and optical requirements for substrates used in displays may be more stringent. For example, a substrate that stretches a bit might be acceptable for a PV panel, but with a display it would tend to distort the picture. Very tight electrical specifications are required for much the same reason.

1.1.2 BIPV: The Future of Solar and Flexible Substrates?

For now, a much better candidate for the attentions of flexible substrate providers lies in the building-integrated PV (BIPV) sector. It is true that 2011 into 2012 seems like it will be a relatively weak period for the solar industry, whose subsidies are under threat in several important markets. However, we think that BIPV has a strong future because:

- BIPV can potentially introduce a new aesthetic that will translate into larger addressable markets and;

- BIPV can share the cost of the PV functionality and roofing/siding functionality on a common substrate.

What is important from the point of view of the flexible substrate market is that:

- BIPV substrates must often be conformable and may have to be actually flexible. This feature helps them with aesthetics, but also helps with installation, since building fabrics are generally not square nor do they present even surfaces (especially not in older buildings) and may be flexible themselves.

- Flexible solar panels could be easier to transport and install, particularly in building-integrated PV applications such as roofing and window laminates.

- Perhaps the biggest advantage of the BIPV sector from the perspective of the flexible substrates business is that, however bad the next 12 months may be for solar, flexible

BIPV is a here-and-now product. Flexible BIPV may be a niche-like product, but it is real. The same cannot be said about flexible displays.

The bottom line here is that for years to come, PV will represent by far the largest potential flexible substrate market by volume and one of the most demanding. PV devices are used outdoors, often in extreme climates, and are expected to last for 20 years or more. While crystalline silicon is a robust material in itself, thin film and organic PV technologies are especially dependent on substrate quality.

Of course, it is only certain kinds of PV that can ever be flexible:

- The PV industry remains dominated by the conventional technology which uses crystalline silicon as both an absorber layer and a substrate. Although there are some R&D efforts directed towards creating flexible silicon substrates, none of them have made their mark on the conventional PV industry as yet, and there are few materials that are less flexible than crystalline silicon.

- With this situation in mind, flexible BIPV mostly involves either (inorganic) thin-film PV (TFPV), organic PV (OPV) or dye-sensitized cells (DSC).

- However, OPV and DSC have arguably been the two PV technologies that have had the most difficulty in developing high-volume commercial markets. They simply can't match the conversion efficiency and durability of crystalline silicon or inorganic thin-film PV; although there is still a large community of interest that thinks these PV technologies will in time. But for now, this sector of the PV/BIPV market would seem to offer limited opportunities for flexible substrates, although from a technical point of view the OPV/DSC absorber layer is inherently flexible.

- Within the TFPV space, the conversion efficiencies are much better than for OPV/DSC, and the thin-film nature of TFPV implies flexibility to a large degree. CIGS appears to be the TFPV material with the greatest potential for flexible BIPV. Nonetheless, glass remains by far the most frequently used substrate material for TFPV in general.

1.1.3 R2R: First for Flexible

While BIPV and displays require flexibility that can be sold to end users, there is another and more immediate reason for using flexible substrates. Roll-to-roll (R2R) manufacturing processes require it:

- Printing or coating is likely to be used in these processes, and they have been much touted as a way for reducing costs because (at least in theory) less expensive fabrication equipment is used and there is less material wastage. In addition, R2R processing is often associated with room temperature processing.

- Unfortunately, the reality of R2R is often less than encouraging. Much of the enthusiasm for R2R seems to have been dampened over the past five years by less-than-successful R2R projects that have not lived up to expectations. One apparent source of these problems: R2R processes often lead to fabricated devices that have lower performance than equivalent devices that are fabricated using the standard equipment/processes associated with conventional semiconductor, manufacturing.

Nonetheless, R2R thinking in the fabrication realm is very much alive, in part because it appears to promise the ability to create very low-cost electronics, something that will be essential if a number of technologies are to grow and evolve. Two examples that one might cite here are RFID and OLED lighting, both of which cannot become ubiquitous unless they are offered at a very low price.

However, the reason why R2R is so important in the context of flexible substrates is that it represents a simpler more immediate entry point for a firm interested in selling flexible substrates. All that is required for an R2R process is a flexible substrate and a viable process itself. For an intrinsically flexible substrate, one must add flexible encapsulation and the ability to market the final product, which typically is being sold into a market that does not know about it or know that it wants the product.

Not only does printing present all the economies associated with R2R processing, but since it is a low-temperature process, it means that high-temperature metal foil or polyimide substrates can be shunned in favor of low-temperature plastics (such as PET), reducing substrate costs by perhaps an order of magnitude. In time, this trend would mean opportunities for suppliers of inexpensive plastic films like PET to enter electronics markets in volume, and for electronics manufacturers to recognize a cost advantage by using these materials. Though silicon wafers will likely hold a performance advantage for the foreseeable future, R2R printing could enable a new class of disposable devices for packaging, labels, and similar applications.

1.1.4 Materials for Flexible Substrates: Plastics, Metals and Beyond

That displays, PV, R2R, and a few "nichier" markets offer the main opportunities for flexible substrates somewhat begs the question of what these substrates will consist of. Flexible substrates have so far fallen into two general categories—metal foils and polymer films:

- Metal foils like aluminum and stainless steel have taken the lead in flexible PV because they are generally more heat resistant and less easy to deform than polymers while still offering good flexibility. They also offer a higher level of barrier protection for the back side of the PV cell versus polymer films. Due to their durability, metal films are the substrate of choice for aerospace applications of PV. Metal foils are a mature product that also has a lot of potential for thinning—and thus cost reduction.

- But polymer films are also a strong possibility as substrates for flexible PV, although they require either low-temperature processing or a high-temperature polymer like polyimide. So far, manufacturers are taking the polyimide route to produce flexible PV cells on polymer substrates while still processing the cells at relatively high temperatures. In any case, efforts to use flexible substrates for thin-film PV have often touted the advantages of roll-to-roll processing. Polymer films can be made extremely thin and should become a much smaller proportion of total device cost over time, especially if process development allows cheaper, less temperature-tolerant plastics to be used.

It remains to be seen whether other substrate materials will succeed for flexible PV:

- Perhaps the most likely contender is the new type of flexible glass that companies including Corning and Schott have developed. Presumably, these ultrathin sheets would remain almost as impermeable and heat tolerant as rigid glass panes while allowing a level of flexibility. But these materials are not yet viable options for thin-film PV.

- Other new materials for flexible substrates are likely to be applied in more specialized markets, such as sensors of various kinds. Here we find the need for such novel flexible substrates as paper and textiles. But mostly in this area we find exciting prototypes and proofs-of-concept, but not so many actual market opportunities. Our analysis seeks to identify the most promising niches for flexible substrates of these kinds.

As we have seen, different flexible electronics/flexible PV applications have different needs and these different requirements impact the choice of flexible electronics:

- Plastics and metal foils are less expensive than crystalline silicon or glass. These cost advantages would accrue even for displays or PV panels destined for installation in rigid frames.

- In other situations, the flexibility of the substrate improves the device performance in some way, for example by reducing transportation and installation costs.

- Finally, in some applications, the flexibility is an enabling attribute of the device. Electronic textiles are often used as an example of this last category, while a less fanciful example might be a sensor network able to conform to the surface of a structure being monitored.

These different demands, in turn, place different constraints on the substrate:

- At one end of the spectrum, we find thick foils with a limited bending radius along only one axis at a time. At the other, there are materials that crumple or stretch in three dimensions.

- Some applications require only that the devices be able to withstand the rigors of manufacturing and shipping on the way to a rigid, final installation. In others, the device must be able to tolerate repeated cycles of bending, stretching, or crumpling.

- Suitability for a particular application will depend on the mechanical and electrical qualities of the substrate, but also on optical characteristics, permeability to air and water vapor, and cost.

1.2 Objectives and Scope of this Report

The objective of this report is to show how new business revenues can be generated through the emergence of substrates for flexible electronics. This goal is reached through analysis of the current and future needs of flexible devices, taking into consideration the application markets to which they are targeted.

In this report we also provide detailed forecasts for the markets for flexible electronic substrate materials. Substrates covered in this report include plastic and metal foils as well as such emerging materials as textiles and flexible glass.

This report is international in scope. The forecasts are worldwide forecasts and we have not been geographically selective in the firms that we have covered in the report or interviewed in order to collect information.

1.3 Methodology of this Report

The information for this work is derived from a variety of sources, but principally comes from primary sources including NanoMarkets' ongoing interview program with technologists, business development managers, and academics involved with photovoltaics, advanced materials, and emerging electronics of all kinds. We also drew on an extensive search of the technical literature, relevant company Web sites, trade journals, government resources, and various collateral items from trade shows and conferences.

Much of the market information for the underlying device markets comes from other recent NanoMarkets reports. Our forecasting models are continuously being updated and we incorporate the latest market data into this report. Where information has been used from an earlier report, it has been reinvestigated, reanalyzed, and reconsidered in light of current developments and updated accordingly.

The forecasting approach taken in this report is explained in more detail in Chapter Four, but the basic approach involves identifying and quantifying the underlying flexible electronics markets, the substrate needs for those markets, and the technological and market pressures that affect the extent to which each type of substrate material penetrates into the market.

The stated plans of the key firms are, of course, of special interest, although NanoMarkets critically considers these claims in light of all available data. In addition, we note that the ongoing economic turmoil that impacts nearly all aspects of global industry certainly affects the markets discussed here and this impact has also been taken into consideration.

1.4 Plan of this Report

In Chapter Two, we examine the substrate materials themselves, their unique features, and the needs of the underlying device markets. In Chapter Three, we explore the markets for each of the substrate materials and the features and strategies that will match the materials with commercial opportunities. We also explore the unique characteristics of the underlying device markets and how—and to what extent—flexible substrate materials will help devices to compete for those markets.

Finally, Chapter Four contains our eight-year forecasts of these materials. Our forecasts are broken out by type of material and by device technology.