Markets for OLED Encapsulation Materials—2011

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Chapter One: Introduction to OLED Encapsulation Technologies

1.1 Background to This Report: Where Are the Opportunities for OLED Encapsulation Materials?

1.1.1 Preamble

OLEDs are highly vulnerable to oxygen and water vapor, so they present an encapsulation issue; developments to improve barrier performance have been discussed in the OLED industry since its earliest days. Until recently, however, OLED encapsulation materials represented a relatively small market for chemical companies and a few start-ups. For many years there were few signs that OLEDs were going to break out of their niche market pattern, with almost all of the OLED market being accounted for by passive matrix displays for MP3 payers, cell-phone sub-displays, etc.

The situation was further complicated by the popular notion among OLED manufacturers that encapsulation was the least of their worries, since most OLEDs could be successfully encapsulated in a stack that often also included desiccant under glass using epoxy adhesives for edge sealing. The simple glass and epoxy encapsulation approach was not only all that was required for small displays, it was all that display makers were willing to pay for, and it continues to be the principal encapsulation strategy in place today.

Even as the size of the passive matrix OLED business grew, true opportunities for OLED encapsulation were highly limited, and few materials firms were able to sustain a business based on encapsulation materials alone. And although materials suppliers were initially happy to supply these applications, they did so with the expectation that markets large enough to justify their efforts would eventually emerge.

1.1.2 Finally, A Growing Market for OLEDs Emerges

Fortunately (at least for encapsulation systems makers), the opportunities have grown in recent years in important ways:

- OLED displays have at last been "mainstreamed" with the arrival of mass-market cell phones containing active-matrix OLEDs as primary displays; NanoMarkets has estimated that the size of the total OLED materials market exceeded $300 million in 2011.
- Meanwhile, OLED lighting is now on the market in the form of "designer" chandeliers and table lamps, and larger segments of the lighting market are likely to be penetrated by OLED lighting in the next few years.

- And while the first attempts to introduce OLED TVs stumbled, it seems that 2012 or 2013 will see the introduction of OLED TVs on the market with much greater chances of market success than the products that preceded them.

These trends mean that the addressable market for OLED encapsulation materials is rapidly growing and should continue to do so. *Importantly, the fastest-growing applications for OLEDs involve larger-area panels that by definition consume relatively larger amounts of materials. NanoMarkets predicts that the OLED materials market will reach over $5 billion in sales by 2018, and at least 10 percent, or about $500 million, of this revenue will come from encapsulation materials and technologies. But the success of the market is not a foregone conclusion; better encapsulation technologies at reasonable costs are required if larger-format OLEDs are going to meet their potential.*

Why? The glass and epoxy strategy may have worked for small format OLEDs—cell phones, smartphones, MP3 players, etc. But:

- The consensus is that these materials will not be sufficient for the larger-format OLEDs that are now growing in market share;
- Nor are these materials compatible with flexible and/or conformable OLEDs; and
- Although it has been relatively easy to achieve the barrier performance goals for small devices, it has been very difficult to scale up the technology for high-volume commercial production of larger panels for OLED lighting and TV displays. It is not just the fact that OLED TV displays and lighting panels are large, but that such products are expected to last longer than cell phones and MP3 players.

The new OLED markets have much higher product lifetime expectations, hence more sophisticated encapsulation technologies with better performance are required to enable real growth.

As a result of the trend toward large panels, NanoMarkets believes that:

- We are now looking at some real opportunities for the firms that have been working on the encapsulation issue, many of whom have poured resources into this area for several years.
- Furthermore, the opportunity space for these firms will only get better when conformable and flexible OLEDs start to make it to the market, which we expect to happen in perhaps four to five years. Truly flexible displays have yet to take off, and

the lack of cost-effective encapsulation technologies capable of meeting the strict water and oxygen permeation barrier requirements is at least partially to blame. Firms in the lighting and display industry are therefore beginning to see encapsulation as an area of strategic importance and are looking increasingly at specialized value-added encapsulation materials to meet their needs.

Currently, displays that can be flexed in one or two dimensions are a huge challenge to the encapsulation business, but one that potentially will generate a lot of revenues to those encapsulation providers that can bring stable encapsulation solutions to this performance dimension. NanoMarkets believes that even conformable OLEDs, which are closer to market than truly flexible ones, present an opportunity for encapsulation firms.

1.1.3 OLED Encapsulation Strategies

Cover glass for rigid OLED devices: As noted above, glass encapsulation strategies are the most prevalent today, and the dominant suppliers are Corning and DuPont.

The majority of current OLEDs, especially bottom-emitting structures, are encapsulated using a cover glass, desiccant (or getter), and an edge-sealing epoxy in a batch process strategy that works especially well for small displays like those used in cell phones, etc. First, in these smaller devices, the high barrier properties required are not so difficult to achieve, and the product lifetimes of many of these smaller OLEDs are relatively short anyway. NanoMarkets believes that even for larger, non-flexible OLEDs, glass/getter/epoxy encapsulation is likely to continue to be a leading choice for OLEDs.

- This approach will benefit from its "tried and true" status, and without the need for flexibility or conformability, there are few compelling reasons to consider other options, especially if the glass/getter/epoxy suppliers can demonstrate reduction in processing costs and complexity.

- While these arguments may be difficult to uphold for very large size panels and high throughput manufacturing, this situation will not be the case for manufacturing of smaller and mid-sized panels used in smartphones, netbooks, tablets, etc.

Flexible glass? For bottom-emission OLEDs, the emergence of viable flexible glass substrates that are compatible with R2R processing cannot be ignored. Both Asahi Glass and Corning have announced the development of 0.1-mm thick flexible glass rolls.

If the firms can also demonstrate ways to include adhesive and desiccant for top-emission structures, they could successfully overcome the biggest impediment to using glass for encapsulation, namely the cost.

Multilayer barrier films: The most common non-glass approach to OLED encapsulation is the use of a multilayer barrier film of alternating polymer and oxide layers deposited by physical or chemical vapor deposition (PVD or CVD):

- Multilayer barriers—whether in the form of pre-formed film laminates or monolithic thin films deposited directly onto the OLED devices—have been touted as having the potential to greatly reduce costs compared to rigid cover glass designs through use of cheaper materials, thinner layers, and easier processing.

- Monolithic encapsulation has been more prevalent than laminates, since monolithic encapsulation of the OLED devices minimizes (but does not always eliminate) the need for adhesives and getters to improve edge imperviousness. Unfortunately, in reality the cost advantages have been elusive, often because so many layers are needed to achieve the required barrier performance that any processing cost benefits are lost.

The fundamental problem with multilayer barriers is that defects such as pinholes, cracks and grain boundaries are common in the thin oxide films used, especially when fabricated onto plastic substrates.

To solve this problem, multilayer barrier technologies have focused on using alternating organic and inorganic multilayers, or dyads, which stagger the defects in adjacent layers. This creates a "torturous path" for water and oxygen molecules; the idea is to make the pathway long enough so that water and oxygen simply will not be able to make it to the sensitive OLED stack.

Unfortunately, the more layers that are employed, the less flexible is the finished product, so although multilayers are promising candidates for encapsulation based on their excellent barrier performance, they have struggled to meet the needs of flexible, R2R-manufactured OLEDs on plastic substrates.

Today, 3M dominates the market, small though it is. Other firms with multilayer dyad films are Dow, GE, Alcan Packaging, and Fujifilm. An early developer of technology in this area was Vitex Systems, which made a strategic deal in 2010 with Samsung and now appears to have been largely absorbed by Samsung Mobile Displays and Samsung Cheil, which continue to work on barrier systems.

A second, and perhaps even more important, major problem for most dyad films on the market today is cost, which can be as high as $70 to $100 per square meter. Efforts are thus ongoing to reduce the number of layers required to achieve the desired barrier properties. An added benefit from reduction of the number of layers is that flexibility could also conceivably be improved.

Multilayer barriers based on ALD: Atomic layer deposition (ALD) strategies for multilayer barrier films have also garnered much interest in recent years. ALD is considered to give better film qualities than CVD or PVD methods; the number of film defects is reduced, so both layer thicknesses and the number of layers can, at least in theory, be reduced.

We note, however, that these advantages are meaningful only if there is a concurrent reduction in the cost of the layers. NanoMarkets believes that there is promise in this area, but remains skeptical about the ability of ALD manufacturing to handle high throughputs or R2R processing—especially for flexible OLEDs. Instead, ALD encapsulation strategies may be practically limited to higher-end and/or batch process OLED lighting markets.

Beneq Oy, an ALD equipment maker and technology developer, is the clear leader in this sub-market of the OLED encapsulation industry, but other firms including SunDew Technologies and ALD NanoSolutions have also entered the fray.

Other kinds of barrier strategies: To meet cost and flexibility goals, the development of a "single layer" barrier has been something of a "holy grail" in the encapsulation industry. To the best of NanoMarkets' knowledge, this objective has not yet been achieved, but several firms appear to be getting closer:

- Tera-Barrier Films is commercializing an innovative barrier film that is purported to solve the defect problem of traditional dyad films by literally plugging the defects in the barrier oxide films using nanoparticles, thereby reducing the number of barrier layers needed in the construction of the barrier film down to just two layers—an oxide and a nanoparticulate sealing layer.

- In addition, Universal Display Corporation, a longtime advocate of Vitex's Barix, is now also advertising its own "single layer" system, which, if real and cost-effective, could revolutionize the industry.

1.2 Objectives and Scope of this Report

In this new report from NanoMarkets, we analyze and quantify the opportunities for encapsulation materials and technologies in the fast-growing OLED market. The report covers the commercial implications of technical developments in both materials and deposition equipment, and we identify the key factors for success for encapsulation materials suppliers in this space. This report is entirely 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.

The report also contains detailed, eight-year forecasts of the materials used for OLED encapsulation broken out by product type and application wherever possible. Finally, we examine the product development and marketing strategies of the major players in the OLED encapsulation materials sector from large to specialty firms, and we attempt to indicate which are the "companies to watch" and which will be the likely winners and losers in the encapsulation materials space.

1.3 Methodology of this Report

NanoMarkets has been covering the OLED materials markets for several years and is widely regarded as having reliable reports on this topic. To determine where the opportunities are, we have based this report on both primary and secondary research:

- Primary information is gathered largely through NanoMarkets' analysis of relevant applications markets and market trends based on ongoing discussions with key players in the OLED materials community, including entrepreneurs, business development and marketing managers, and technologists involved with OLED materials and emerging display products of all kinds.

- Secondary research is drawn from the technical literature, relevant company Websites, trade journals and press articles, and various collateral items from trade shows and conferences.

Some of the applications-related market information in this report comes from our most recent reports on the covered applications areas. Reports from which some data have been taken include "*OLED Lighting Materials Market Trends and Impact*" of June 2011, *"Markets for OLED Materials"* also from June 2011, *"OLED Lighting Global Market Forecasts"* from May 2011, *"OLED Lighting in Asia"* from April 2011, *"OLED Lighting in Europe"* from May 2011, and *"Encapsulation and Flexible Substrates for Organic and Dye-Sensitized Photovoltaics"* from January 2011. Where information has been used from another report, it has been reinvestigated, reanalyzed, and reconsidered in light of current information and updated accordingly.

The forecasting approach used in this report is explained in more detail in Chapter Four, but the basic approach is to identify and quantify the underlying OLED application markets, the barrier requirements for those applications, and the technological and market pressures that affect the ability of different encapsulation and barrier technologies to penetrate those markets.

We consider both the specific performance needs of the various OLED applications and the broader economic developments that impact the size and rate of growth of the OLED markets for each application area. Activities and developments at key firms are, of course, of special interest, although NanoMarkets critically considers these claims in light of all available data.

1.4 Plan of this Report

In Chapter Two, we provide an analysis of the different materials sets and deposition technologies for OLED encapsulation. As part of this analysis, we briefly examine the focus and strategies of the principal manufacturers and suppliers, and we pay particular attention to innovations and strategies being followed to reduce costs, increase performance, and customize products for particular markets and applications.

Chapter Three of this report provides a more in-depth analysis of the major applications where OLEDs are being used now or will be used in the future, from mobile-phone displays to flat-panel televisions and solid-state lighting. The idea here is not to provide a comprehensive analysis of OLED markets, but rather to offer a survey of the addressable markets for OLED encapsulation suppliers.

In Chapter Four, we provide detailed, eight-year forecasts of the OLED encapsulation markets with breakouts by technology type and by application type wherever possible.