NanoMarkets Report

LED Phosphor Markets – 2012

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This new NanoMarkets report provides an in-depth analysis and forecast of the LED phosphor market in the next eight years. It builds off the extensive experience that NanoMarkets has in the area of solid-state lighting and related materials.

This report examines the latest market strategies, products and technical developments in the area of LED phosphors. We identify how performance improvements are likely to help grow addressable markets for phosphors, with an especial focus on general illumination, outdoor/street lighting and backlighting and where the opportunities are to be found to make money in the LED phosphor market.

The report also includes NanoMarkets' assessments of the strategies of leading firms active in the LED phosphors space. And, as always with NanoMarkets reports, this report contains granular eight-year forecasts of the inorganic LED phosphors shipments in volume and value terms, with breakouts by type of phosphor. This report is required reading, not just for strategy planners at phosphor firms, but for those throughout the solid-state lighting industry.

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Chapter One: Introduction

1.1 Background to This Report: A Time of New Opportunities for LED Phosphor Makers

NanoMarkets believes that major opportunities are currently emerging for LED phosphor manufacturers. Broadly speaking, these opportunities are being driven by three factors:

- The underlying market for these phosphors is rapidly growing,
- Phosphor performance and characteristics are vital to the success of LED lighting products; and
- It is still possible for phosphor makers to create proprietary products and brands that can give these firms superior margins.

With regard to the first point, LED backlighting is already well established. However, many governments around the world are promoting the use of LED lighting in general illumination through regulations designed to force a phase-out of less-efficient incandescent lighting. Bans (or reductions) on incandescent lighting are going into effect—or have gone into effect—in many countries. Nonetheless, despite this huge push, LED light quality is not well-liked by many consumers.

1.1.1 Phosphors Enable the LED Industry

In NanoMarkets' view, this situation is creating an opportunity for LED phosphor manufacturers, because the choice of phosphors can impact the efficacy, correlated color temperature (CCT), color rendering index (CRI), and the color quality system (CQS) of LED lighting. LED phosphor manufacturers therefore, stand to benefit considerably with any strategy that can promote phosphors as a key enabler for the LED makers to gain market share:

- The specific choice of phosphor is strongly related to efficacy, which opens up opportunities for phosphor manufacturers to create value by developing and commercializing products that help LED manufacturers improve their products' performance. Today's standard white LED lighting product is made by down conversion of an indium-gallium-nitride (InGaN) blue emission LED with a coating or filter of yellow phosphor to create a white emission. Down conversion at least partially reduces overall luminous efficacy compared to the original blue LED.
- Light quality is inextricably linked to the choices of phosphors available to LED manufacturers.
- New phosphor deposition technologies are being sought that improve emission uniformity. Phosphor technologies that widen the viewing angle of LED lighting products would also increase penetration rates for LEDs in the general illumination market. LED color temperature and color rendering can also vary with viewing angle. This effect sometimes makes the experience of being in an LED-lighted room less than satisfactory, or it can reduce the color gamut of LED-backlit displays.

1.1.2 LED Phosphors: Not Just a Volume Play

But in NanoMarkets' opinion, the phosphor business is exciting because it is not just a volume play, but also a business in which there is still plenty of room for phosphor firms to create proprietary/intellectual property (IP) protected products:

- In particular, the LED lighting market is still open to new types of proprietary phosphor solutions, with the potential for phosphor firms to build their brands and create protectable IP.

- NanoMarkets believes that some phosphor suppliers will be able to break away from the rest by not only doing the obvious things, like improving performance and color gamut of their phosphor offerings, but also by establishing more downstream or value-added products, which can be done as a way to both capture more value and hedge against IP battles. The Intematix move toward selling phosphor-coated components for use in its remote phosphor technology is a key example of this trend.

- Display backlighting, streetlights, and general illumination each have their own requirements for color rendering and color temperature. As a result, we see an ongoing opportunity for phosphor firms to create products that are better able to provide the most appropriate CCT and CRI/CQS values for the various applications.

1.1.3 LED Phosphors: Material Trends

LED phosphor technologies can be broadly separated into the following categories based on the inorganic lattice or matrix composition. And, while each type of phosphor will benefit from the general trends and opportunities set out above, each also has its own unique roadmap.

Garnets: Garnet-based phosphors are the industry standard and can be found in almost all lighting applications. The yellow garnet phosphors, mostly cerium-doped garnets (YAG:Ce), make up the bulk of the phosphors used in LED lighting today, in combination with blue InGaN LEDs.

These phosphors are already widely available, and the procedures for manufacturing and using them are well established. *However, NanoMarkets notes there has been a trend towards improving the light quality towards warm color temperature by using yellow garnet phosphors in combination with europium-doped red nitrides.*

However, we also believe it is an open question as to how long this trend will continue:

- New materials are likely to replace the widespread use of garnets.

- IP surrounding the use of garnets is heavily controlled by the key LED firm Nichia. As a result, some LED manufacturers may opt for lower-performance silicate dopants as an alternative to obtaining a license from Nichia.

Silicates: The silicate-based phosphors are mostly europium-doped, but other dopants are also used. The silicates come in a variety of colors, but mostly orange, yellow and green, and are known for high brightness, although they may suffer at high temperatures. NanoMarkets believes two key facts will shape the markets for silicate-based phosphors:

- Silicates are particularly important in LCD backlighting applications because of their brightness. However, we note that LED-based backlighting is now beginning to reach full penetration in many display types, which may slow down the market for silicate phosphors somewhat.

- Silicate phosphors are generally only used for cool white systems, which is more important in Asian markets than in European or American ones, which is another limitation on this kind of phosphor. On the other hand, Asia is perhaps the largest market for LEDs at the present time.

Aluminates: Most of the aluminate phosphors are either green or yellow, and like the garnets, they must be used in combination with red phosphors to achieve high CRI white emission.

These phosphors are more expensive than the garnets, but have high stability (thermal and environmental), so are most suitable for high-power LEDs and outdoor lighting markets, and they give the best possible CRI and light quality when used with the right red phosphor.

Nitrides and oxynitrides: The nitrides, especially europium-doped (oxy)nitrides, represent a key development, in particular high quality, high purity red nitride phosphors that can be used with the classic blue LED plus YAG:Ce system to create better, warmer light with minimal reductions in efficacy. The red nitrides can also be used in combination with yellow aluminates and silicates for the same effect.

Sulfides and selenides: These phosphor types are problematic because of manufacturing issues surrounding the use of toxic hydrogen sulfide/selenide gas, the generation of sulfide and selenide waste products, and the fact that these phosphors tend to be more humidity sensitive than the ceramic phosphors (aluminates, garnets, nitrides, etc.).

Although red europium-doped sulfides are useful for conversion of cool white LEDs to warmer CCTs, these phosphors must also compete with less problematic europium-doped nitrides for the same application(s). Green emitting copper and aluminum doped zinc sulfides (ZnS:Cu,Al) can be used in combination with UV/NUV-emitting LEDs (along with other non-sulfide phosphors) to create white emission without the use of classic, blue InGaN LEDs.

Overall, NanoMarkets' understanding is that both the development and the use of sulfide/selenide-based phosphors is on the decline, at least in the LED lighting industry.

Others: A myriad of other phosphor technologies, too varied to discuss individually and generally outside the scope of this report, are also in varying stages of development and commercialization. *Most, however, are still in the R&D stage, and not generating significant revenues today.* Some potentially promising alternative phosphor technologies include the following:

- Quantum dots (QDs), while not classically phosphors, may be used in much the same way as LED phosphor coatings on LEDs to down-convert to white emission. They have the *potential* to be highly tunable with unparalleled color rendering, but they still suffer from high cost, short lifetimes, unrealized efficacy, and, most importantly, they are not currently widely commercially available on a large scale.

- GE's manganese-doped fluoride red phosphor may compete with other, up-and-coming red nitrides in the rush to close the warm white technology gap that still exists in much of the LED market today. Importantly, it is rare earth-free.

- Nanoscale phosphors can improve significantly upon the performance of their non-nanoscale counterparts with respect to efficacy.

- "Hybrid" phosphor technologies that combine the characteristics of both the classic inorganic phosphor coatings with polymeric phosphors and/or quantum dot phosphors have the potential to allow LED makers to further fine-tune and optimize emissions for particular applications.

1.1.4 Phosphor Technology: Still Improving

All of the drivers for the LED phosphor industry mentioned above are being amplified by ongoing performance improvements that began during the past year or so. For example, Intematix has introduced a new deep-red phosphor that enables the production of LEDs with 98 CRI and 2700 K CCT—indeed very high quality, warm white light. And by the end of 2012, Philips says it will be selling a dimmable, warm white, 100-W equivalent bulb (1700 lumens and 23 W) with 20+-year lifetime under the name "EnduraLED". The price of this bulb is estimated to be under $50.

Such developments are setting increasingly high standards for both the LED lighting industry and the LED phosphor industry that supplies it.

1.2 Objectives and Scope of This Report

The purpose of this report is to examine the opportunities and challenges for manufacturers of phosphors used in LED lighting applications over the next eight years. Specifically, this report provides a market analysis of recent developments in the LED phosphor industry.

In the report, we examine the latest products, strategies and technical developments of the industry. We identify how performance improvements are likely to speed adoption of LED lighting as traditional, inefficient incandescent lighting is phased out, and how changes in the phosphors industry are likely to improve LED lighting's chances against other, emerging alternative lighting technologies. Specifically, we examine the potential opportunities for phosphors in the following key LED applications:

- Display backlighting,

- Street lighting and other outdoor applications, and

- General illumination applications.

In all of these applications, which require white LEDs, the demands on phosphors are different, so we consider each application area individually.

The report also appraises the commercial significance of the notable developments that have taken place within the LED lighting industry that are directly related to improvements or changes in phosphor technologies, such as the availability of new red phosphors that enable the fabrication of "warm," high-brightness, high-quality white LEDs. In addition, the report includes NanoMarkets' assessments of the strategies of leading firms active in the LED phosphors space.

And, as always with NanoMarkets' reports, this report also contains granular, eight-year forecasts of LED phosphor shipments in volume and value terms, broken down by application.

1.3 Methodology of This Report

This report is the first from NanoMarkets that looks closely at the LED phosphor industry, and forms part of series of reports from NanoMarkets that focus on energy efficient lighting applications, such as OLED lighting, solid-state lighting in general, smart lighting, and other, related areas.

- The information for this report is derived from a variety of sources, but principally comes from primary sources, including NanoMarkets' ongoing interview program of entrepreneurs, business development and marketing managers, and technologists involved with solid-state lighting and emerging electronics of all kinds.
- We also used information from secondary sources, such as relevant company and industry organization websites, commercial databases, trade press articles, technical literature, SEC filings, and other corporate literature.

The basic forecasting approach is to identify and quantify the underlying markets for LED phosphors, along with their materials needs, and the technological and market pressures that affect growth prospects for the white LEDs produced using those phosphors. We also assess the competitive landscape to determine the suitability and likely volume of LEDs produced over the next eight years, and we consider broader economic developments that impact LED phosphor development and commercialization.

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

1.4 Plan of This Report

In Chapter Two, we discuss the materials, technology, and products of the LED phosphor marketplace. We examine the standard conversion strategies used to produce white LEDs, as well as emerging and competing strategies that may influence opportunities for phosphor manufacturers in the near- to mid-term. We also discuss how the choice of phosphor or phosphor deposition technology can make or break the opportunities for white LEDs.

In Chapter Three, we look at the LED phosphor value chain, and we assess the various LED lighting applications that rely on phosphors, with a particular focus on those applications that are expected to be the biggest revenue generators, like general illumination markets. We also look at the challenges currently faced by the phosphor supply chain, such as China’s control of the rare earths market, intellectual property issues, and health, safety and regulatory issues surrounding some phosphor technologies.

Chapter Four contains our eight-year forecasts of the markets for LED phosphors. We have broken out the materials forecasts by lighting application and by phosphor type.