Developments in UV-LED based Curing Systems for UV Inkjet Printing

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1. Introduction

UV-LED based systems for UV curing continue to make strides in several different market and application areas especially where their key advantages – lower power usage, smaller footprint, significantly reduced heat loads, relative ease of integration and use, and environmental friendliness – make them an attractive option when compared to traditional mercury or xenon gas based lamp technology. UV Inkjet printing is one such area where the technology appears to be a perfect fit. In common with all new technologies UV-LED curing has barriers to successful adoption and a few still remain before implementation becomes mainstream. However there is significant development underway in many UV Inkjet applications to fully integrate UV-LED technology.

2. Background – UV-LED Curing system development

As a commercial product UV-LED curing systems generally became available around 2003 and became possible due to the interest in the general LED industry in developing blue and UV/Visible diodes both for direct commercial applications (Cell phone backlights, Automotive lighting clusters etc.) and as a way to indirectly product white light via the use of phosphors.

For UV Curing the early UV Curing systems were extremely limited in output and size and beyond smaller point and area sources they were generally considerably more expensive then existing mercury lamp technology. While small format UV-LED systems with relatively low outputs had some utility (and still do – especially in markets like spot curing of UV Adhesives) they were generally not useful for UV Inkjet applications where the predominant use of free radical chemistries, the reality of curing a heavily pigmented system and the process speed requirements meant that higher capability was required. In general this level of capability has become a reality relatively recently.

Commercially available UV-LED systems with "native" outputs of $4W/cm^2$ and systems with highly focused "thin-line" outputs with peak irradiance of up to $7W/cm^2$ (and sometimes higher) have been demonstrated and in many cases are currently being integrated into new UV Inkjet products. Most UV-LED systems are specified in terms of peak output (watts or milliwats per square area) and/or total output (watts or milliwats generated over the total output area of the system). The dose received by the material can the be calculated in terms of output to the substrate over time where 1 watt in 1 second equals 1 Joule of energy or dose. While focused systems for traditional UV lamps have long enjoyed commercial success the advantages of focusing UV-LED systems for maximum peak irradiance can often lead to an unacceptable trade off in efficiency of total UV energy transferred to the material being cured. While higher peak irradiances are beneficial there is little benefit to be gained if total power output is not sufficient for the curing process.

Figure 1 - Typical UV-LED System used for UV Inkjet and an example application in small format Single Pass UV Inkjet using HP TIJ inkjet technology. It has an emitting area of 20mm x 150mm which is attractive for small footprint Single Pass UV systems (Courtesy of Phoseon Technology/Accufast)

Do not confuse the output specifications of UV-LED systems with the typical specification of mercury lamps! Traditional lamps are specified in terms of input power/length of lamp or arc (e.g. 300Watts/Inch). Comparing traditional UV sources with UV-LED sources is not an “apples to apples” comparison because of the significantly different range of output wavelengths and as a practical matter is more clearly defined by the ability of the curable material to “accept” the wavelengths generated[1]. As an example a UV-LED system with an output area of 150mm x 25mm with a peak output over that area of 4 Watts/cm^2 has approximately the curing power of a 300W/inch arc lamp for materials that accept wavelengths primarily in the UV-A range. That does not mean the total energy outputs are necessarily equivalent. Mercury lamps in general will always produce significantly more output over a wide wavelength band but much of the energy has no practical effect on the cure of the UV material.

Today there are UV-LED systems available with curing power equivalent to many traditional lamp systems with more to come (typical peak and total UV output increase of 2X per year having been historically been achieved for many UV-LED systems – and this pace of development should continue for the near term) and the market pricing of UV-LED systems continues to drop sharply to a point where in many applications the cost of acquisition is comparable (or better) than traditional lamp solutions and the true cost of ownership (i.e. day to day running costs) are typically sharply lower.

3. UV Inkjet Printing Applications

UV curing as a general methodology to dry inks in large and industrial format inkjet applications continues to show very strong market growth and this general market growth is expected to continue. At a macro level Digital Printing of all types (including your home printer) only accounts for approx. 12% of worldwide production of printed pages[2]. There are in effect a several accelerating factors at play for UV inkjet –

- The general movement towards Digital printing from traditional "Analog" print methods such as screen, offset, litho and gravure
- The movement away from solvent and water based inkjet inks towards UV curable inks with better capability to print on a range of media (including non-porous media) and the avoidance of using environmentally questionable solvents.

UV Inkjet applications today come in many different "flavors" and innovative uses of inkjet technology continue to blossom. 2008 is a "DRUPA" year and significant new product development and development of technology demonstrators is accelerating. DRUPA is a true behemoth – it's the world's largest trade show for the printing equipment industry and happens once every four years (Attendance in 2004 was over 300,000 people – just slightly bigger than UVEB 2008!).[3]

For UV-LED based curing solutions there are several areas of interest and development:

1. Large Format and Grand Format UV Inkjet Printers – Today this is the largest potential market for UV-LED based systems. Largest end market for these printers is the making of signs. These systems typically utilize DOD (Drop on Demand) Piezoelectric Inkjet head technology.
2. "Narrow Web" Single Pass UV systems – This is an area with a very large range of applications that usually center around printing of variable data (bar codes, lot codes, numbering etc.) on existing printed stock although multiple color single pass systems are becoming more common. UV applications use DOD inkjet heads and more recently there has been interesting developments in UV curable inks for HP Thermal Ink Jet (TIJ) technology which may open up markets for UV in lower cost and smaller footprint systems.
3. Single Pass UV Inkjet Press – The "nirvana" application for UV inkjet with the potential to make significant inroads into existing press technology. There are still a limited number of commercially available products but expect significant movement at DRUPA. This application is challenging both for inkjet as a technology and for UV-LED curing systems (power and speed requirements). However the low heat generation and small footprint of UV-LED sources make them an obvious longer term fit perhaps in combination with traditional lamp systems.
4. Ink "Pinning" – There are some situations in UV Inkjet where the process requires the ink drop to be "fixed" or "pinned" (i.e. the drop no longer flows or slumps). The necessity for pinning arises when too much drop flow leads to a reduction in effective resolution and becomes more of an issue in single pass printing scenarios where multiple colors (therefore multiple inkjet heads) are required and the distance and time between ink deposition and final cure may be longer than desired and may be variable from color to color. The requirement is for "inter-head" pinning of the inks to freeze the drop and keep drop size and form consistent.

Figure 2 - An example of a Single Pass UV Inkjet Print System that can utilize UV-LED Curing (Courtesy of Atlantic Zeiser)

4. Hurdles for UV-LED in UV Inkjet

If UV-LED curing systems are truly a perfect match – why to date are the implementations of UV-LED curing in commercial inkjet systems very limited? And why have some of the implementations in early commercial systems had limited commercial success? As with all new technologies the reality of implementation is always associated with hurdles and obstacles – some of which are foreseen and some of which are only learned through experience.

Materials/Ink Chemistry – In general terms the availability of suitable materials is the largest hurdle to clear for successful adoption of UV-LED curing systems in any UV curing application. UV Curing chemistry has always focused around the available peaks of mercury lamps where there is a typically a wide range of available peaks in the 200-400nm range with specific outputs typically a function of the lamp doping. UV-LED systems by their nature emit narrow-ban UV (typically <40nm width) and are capable of producing significantly more power at a significantly more attractive cost/watt at higher UV wavelengths. For Free-Radical chemistries which predominate in most UV curable materials there are two main challenges:

1. **Finding a good photo-initiator and base material match for high wavelength UV-A**
   For higher wavelength UV-A (365-400nm) there certainly are photo-initiators available that already produce more than acceptable energy coupling. However for 365nm and above the PI choice becomes more limited and in all formulation changes there is risk that changes to produce optimal UV curing might have negative effects on other material performance characteristics. In addition some base materials (monomers/oligomers) appear to be preferentially suited for curing at higher wavelengths.

2. **Overcoming Oxygen Inhibition**
   UV-LED systems do not produce wavelengths in the UV-B and UV-C range which typically tend to leave more of their energy at the material surface and are more effective at overcoming the cure inhibition common in all free radical chemistries where the material is exposed to oxygen at the surface. Again the correct formulation can certainly minimize this effect.

While these are challenges for the ink formulators they are unlikely to be a long term barrier for adoption of the technology. Several of the larger commercial inks companies have either released - or are developing for release - formulations that work extremely well with both UV-LED and standard mercury lamp sources and in the next year or two the availability of suitable material will continue to increase significantly.

UV-LED Systems Capability – As a practical matter the availability of UV-LED systems with the appropriate levels of peak and total irradiance has only become practical relatively recently. Early attempts at the use and integration of UV-LED was primarily focused on ink drop "pinning" or freezing where the capability of the UV-LED system and of the ink to accept the energy was much less of an issue. Late 2007 and 2008 have seen the introduction of the first UV Inkjet systems using UV-LED – for bi-directional wide format printers and for single pass UV inkjet for variable data. More are likely throughout 2008 – especially at DRUPA.

Lack of Integration Experience – A UV-LED curing system is not the same as a traditional Mercury Arc lamp and for many of the early adopters the system integration required for success has not always been possible. This has been especially the case for large format bi-directional UV Inkjet printers where ink is jetted in two different directions and the laydown of the ink and ink colors is a deceptively complex process of interaction between the printer hardware, the inkjet head and the software (known as a "RIP"). Beyond the obvious issue of successful ink curing there are two other issues that often arise in UV curing for wide format printers. These are "banding", where printing is one direction is visually different than printing in the opposite direction, and gloss control. Many of the existing ink sets rely on the relatively high UV and thermal outputs of traditional UV lamps to produce a relatively consistent low-gloss or "flat" image which assists in minimizing the visual effects of print banding.

UV-LED systems have historically had a more difficult time consistently getting the same levels of cure on all colors (black and yellow being most noticeable) and without adjustments to printer layout or ink chemistry these can be problematic for print quality. Higher capability in terms of total UV output when coupled with print head adjustments can essentially eliminate these problems. The reality for large format printers is that UV-LED curing systems can rarely be a direct "drop-in" replacement in existing setups. But they certainly can be successful – both for pinning and full cure – where the printer and ink design are pulled together to work with the UV-LED curing unit as a true "system".

5. Conclusion

UV-LED based curing systems are still in the "early adopter" phase in most markets and the capability is just now truly getting to the point required for mainstream adoption. While wide format UV inkjet printers are a key market there are other applications for UV inkjet - especially single pass applications - where UV-LED curing has already been adopted successfully. The technical advantages, and the cost advantages that will become even more obvious over time, will ensure that the challenges that exist will be overcome.

References:

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2. “HP Perspective of Inkjet in Graphic Arts”, Jep Tarradas – IMI 15th Annual Ink Jet Printing Conference, St. Pete Beach FL, Feb1st 2006.
3. DRUPA Web Site – www.drupa.com