LumeJet - a new Photonic 'Inkless' Printing Technology

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Abstract

The result of 10 years of research, LumeJet is bringing to market a new photonic ‘inkless’ technology for ultra high quality printing and patterning applications. Similar to Ink Jet – but without the inks – LumeJet comprises custom designed print heads (moving or static) with multi-LED arrays and special fiber taper optics. Using light, rather than ink, increases throughput and image quality, whilst reducing media costs. LumeJet is a continuous tone process that can resolve down to 1pt colored text and graphics, which would require at least 8-colours and over 4000dpi with inkjet and toner systems. Applications for LumeJet technology have also been identified in label and package printing and printed electronics.

The LumeJet Concept

LumeJet® patented print head technology comprises an all solid-state multi-LED (Light Emitting Diode) array and unique fiber taper optics, together with a micron-accurate media delivery system.

Similar in concept to Ink Jet, configured either as a moving head (Figure 1) or a static page-wide bar (Figure 7), LumeJet has the advantage of being ‘inkless’ and prints using finely focused, independent, parallel beams of light onto a range of photo-activated coatings. This can significantly increase print speeds and quality over ink systems, in a number of applications, while also reducing media costs.

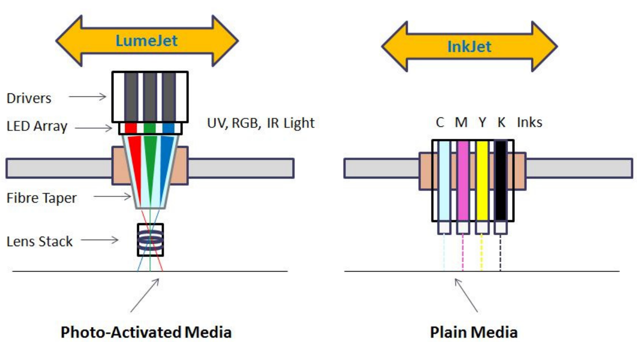

***Figure1**. LumeJet compared to Ink Jet (moving head version)*

In its first commercial application (launching summer 2013) for ultra high quality, short-run image intensive document printing, LumeJet leverages the continuous tone quality and archival properties of silver-halide (AgX) media. It allows, for the first time, pin sharp text and graphics (<1pt colored text) to be imaged together with superb contone images. This is due to the print head optics and electronics design, together with the micron-accurate media delivery and calibration systems, as will be explained in this paper.

Digital Print Head

The LumeJet® Digital Print Head (DPH) for commercial printing applications comprises a custom designed LED array with unique drawn fiber taper reduction optics (5:1) and 1:1 projection lens (Figure 2) .

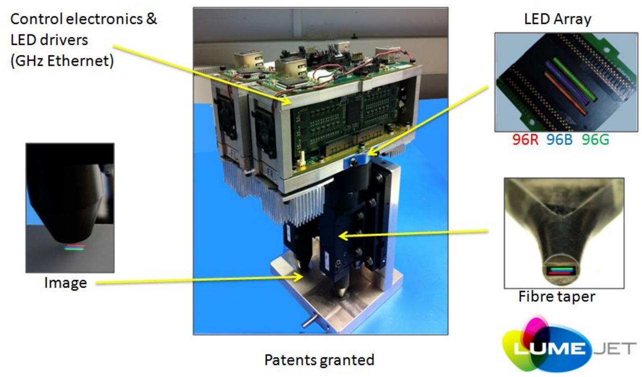

***Figure2**. LumeJet Digital Print Head components.*

The LED array comprises 288 individual, 0.33x0.33mm dies robotically placed and wire-bonded (to better than 0.020mm) on a thermally conductive ceramic substrate. There are 96Red (695nm), 96Green (535nm) and 96Blue (465nm) dies arranged in 6 parallel rows, 2 rows per color i.e. RR GG BB. The dies (48 per row) are placed in an odd/even staggered offset to allow for some Gaussian overlap between adjacent pixels to reduce micro-banding. The dies are top-bin selected from single wafers to ensure closely matched wavelengths and powers. In front of the LED array is an accurately plotted black mask, with 0.4x0.4mm apertures, to minimize cross talk between the LEDs. In front of the mask are custom selected neutral density and band-pass filters to match the spectral response curves of the media and reduce inter-color impurities (Figure 3).

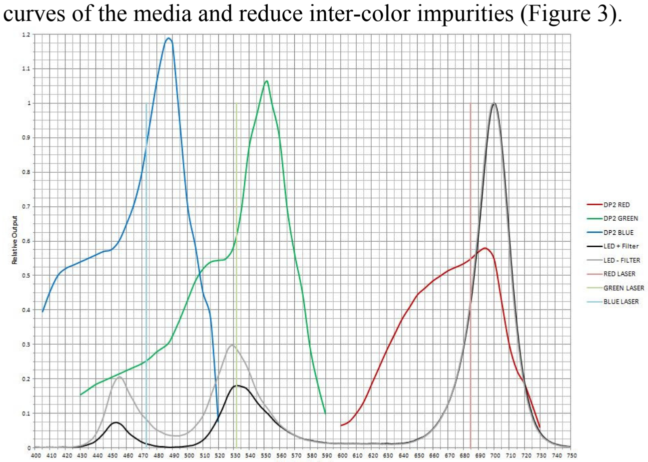

***Figure3**. Spectral response curve of AgX media, LEDs and filters*

The LED array, mask and filter 'sandwich' is mounted on top of a drawn fiber taper, made to LumeJet's design, with a proprietary mix of clear and interstitial fibers. This acts as a spatially coherent reduction lens, with individual bundles of c. 0.020mm fibers drawn to c. 0.004mm at the output end (5:1 reduction). Light from each LED passes through approximately a 300 fiber bundle, creating highly collimated and separate 'light funnels'.

Finally a 1:1 lens stack projects the light from the output end of the taper, onto the media, to allow for a c. 1cm working distance. The printed 'swathe' is c. 6mm wide and the individual pixel size on the media is 0.063mm, which is equivalent to 400ppi (note: in continuous tone printing ppi ≡ dpi as there is no need to make a halftone screen, which will be explained later). 400ppi is both the MTF maximum of the AgX coating and also the maximum that can be resolved by the average human eye for prints held at 14" distance.

LED Array Design and Optical Modeling

A third generation LED array and DPH design has been in development during 2012, building on the learning points of the past 3 years. A micrograph of the Blue dies in the new array is shown in Figure 4. This is planned for integration with a new photonics digital printer, the LS200S, for later in 2013.

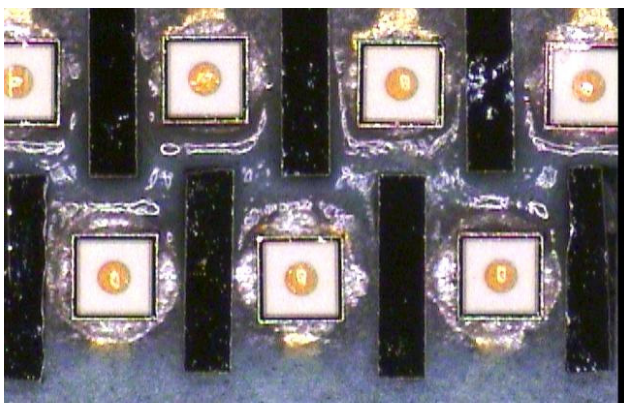

***Figure4**. Gen 3 LED array with improved cross-talk and optical alignment*

The new array will incorporate advanced cross-talk compensation, including Si-Blocks between LED dies, as well as improved optical alignment and thermal management. This has been the result of detailed optical modeling, as shown in Figure 5.

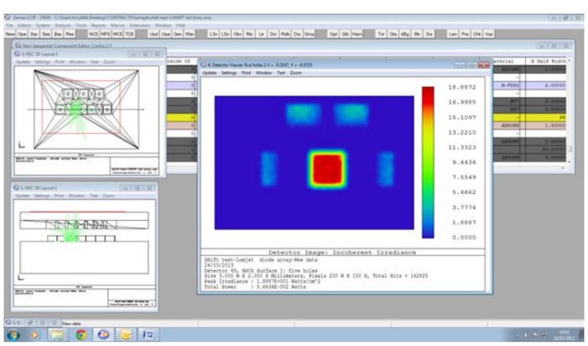

***Figure5**. Optical model of cross talk in nearest neighbor dies (Zemax)*

LED and Media Control and Color Calibration

The LED array is controlled by custom designed driver boards (one per color), which are mounted directly on top of the DPH and addressed via a Gigabit bus structure. The DPH are configured as a Master and 'N' Slaves, so that more than one head can be ganged together for faster printing, each DPH adding 6mm to the swathe width. Figure 2 shows a dual DPH, with one Master and one Slave, producing a 12mm swathe.

The driver boards feature individually addressable constant current controllers (one per LED), together with dot correction compensation. The power delivered by each LED is controlled by pulse width modulation (PWM) of the constant current source.

The PWM system allows for 11-bit Red and Green (2048 levels each) and 10-bit Blue (1024 levels). Thus we have 32-bit (11+11+10) tone control per LED. LumeJet has developed its own algorithms to interpolate from standard 24-bit (Bitmap) color into the final 32-bit output. This maximizes the full contone range of the AgX media, especially the subtle transitions in the highlight and shadow regions (where much detail is often lost in half-tone printing technologies) and ensures smooth graduations in vignettes and blends.

Modern LEDs are very stable, with narrow spectrums and life times measured in 10,000s hrs, so are ideal for light-based printing systems with low maintenance requirements. However, they typically have temperature coefficients of -0.5%/C so a print head with nearly 300 LEDs needs very precise thermal management, to better than 0.1C, to ensure the LED outputs do not drift and cause visual banding. LumeJet's thermal management system has required innovation in both the DPH itself, using heat fins with forced air cooling and feedback system to achieve better than 0.1C (as measured on the array and driver pcbs), as well as in the print chamber to better than 1C (Figure 6).

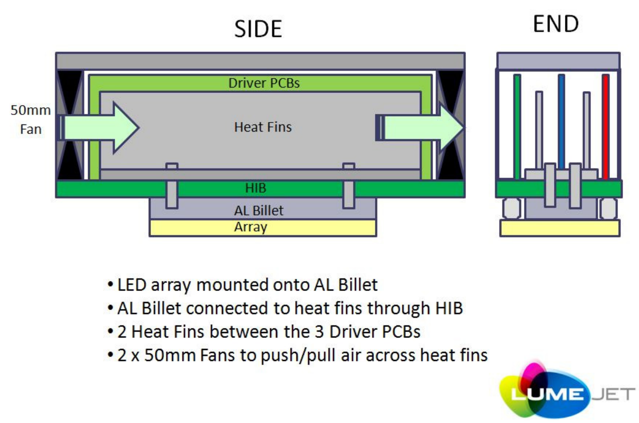

***Figure6**. Thermal management system for new LED array and DPH.*

Once the LEDs are held thermally stable it is then necessary to calibrate each LED for precise power output relative to its neighbor, to ensure a flat and even response on the media across the print swathe. This is a two stage process, the first on the DPH itself and the second once the DPH is mounted in the printer.

In stage one, the 1st step is to trim the LEDs to each other using an integrating spectrophotometer, to adjust the spectral output per LED and produce a dot correction table (note: from a single wafer containing many 1000's dies each LED may vary by

10-20% in power and wavelength due to doping variations). This does not precisely balance the LEDs for printing, as the exposure curve and spectral response of the media will vary and are non-linear, but provides a first level 'course' setting to bring the LEDs approximately into balance.

The 2nd step uses an optical alignment jig with a CCD camera and accurate grid to check and adjust for any misalignment of the LEDs due to distortion in the taper and projection optics. This can then be taken out by varying the PWM timing per LED. The alignment jig is also used to adjust the offset between the Master DPH and the Slave(s), so that the end pixels are set exactly on pitch to ensure there is no gap (overlap or underlap) between the two heads, and their resultant combined swathe can be treated as just one in the printer.

To guarantee band free printing in a moving head photonic printer it is important that the media is held flat and stationary during printing, and that the print heads are transported very accurately across the media width (X), parallel to the media height (Z) and perpendicular to the direction of media travel (Y). It is also critical that the media can be advanced to precisely the swathe width, so that successive swathes abut accurately without visible banding (note: it is impossible in practice to produce a mechanism with zero error, so LumeJet has evolved proprietary algorithms to take account of these errors by slightly overlapped and blending swathes by a small number of pixels).

LumeJet's next generation photonic printer, the LJ200S, is aimed at the very demanding commercial digital print sector requiring ultra high quality text, graphics and images for short run, image intensive documents. This has required the design and engineering of micron-accurate printing mechanisms and motion control systems in all three axes, resulting in significant knowhow.

The LJ200S features a roll-feed, cut-sheet design with 12" (30cm) wide media that can be cut to any length up to 39" (100cm) long. The paper advance (Y) is accurate to +/- 5microns and the pixel placement (X) to better than +/- 0.5microns. The media flatness is to +/-5 microns and can be adjusted for different media thicknesses (150-300 microns), in increments of 1 micron, without hysteresis. Media slew is better than 0.1mm over 1meter.

Provided the media transport and motion control are micron accurate, and the DPH have been aligned and coarse calibrated offline, it is then possible to complete the LED calibration in the printer using just software. LumeJet has developed its own calibration routines and algorithms using accurate 12-level grey density charts, with target marks denoting the position of each LED. These are printed on the media and then scanned at 1600dpi, using a flatbed scanner, to measure each LEDs print density in CMY. The charts contain fiducial marks, used to de-rotate the print image if not placed square to the scanner.

The calibration initially requires a number of iterations (perhaps 5-10) to balance the LEDs at all densities levels on a new media, which are then saved with the media profile. Subsequent calibrations can be done in 1 or 2 passes as a daily setup, provided the DPH are at print temperature and the process control of the media is well maintained.

After the LED balance it is then possible to use conventional Grey Balance and ICC profile tools to calibrate the media to international standards. LumeJet has partnered with German color management experts ColorGATE to develop these tools, which are embedded in their RIP systems. Independent trade bodies and industry experts have confirmed that LumeJet has one of the highest levels of print quality and color fidelity of any print technology, outperforming offset litho, inkjet and toner systems.

LumeBar, page-wide photonic print heads.

The DPH print heads use a moving head, moving media principle similar in concept to inkjet. The DPH has been designed as a Master head and 'N' Slave heads, each head contributing 6mm to the image swathe. Printing is bi-directional. The DPH traverses the media at c.1.5m/s to produce a swathe of 12mm, then the paper advances 12mm in c. 0.25s during which the DPH ramps down, reverses direction and prints a second 12mm swathe abutting the first. This process continues until the image is completed. This equates to approximately a linear speed of 40m/s, which is comparable to inkjet. Clearly we can use more print heads, as do large format flatbed inkjet plotters, but this increases inertia, complexity and cost which, beyond 3-4 heads, can be prohibitive.

During the past 2 years LumeJet has been conducting a technical feasibility study on micro-LED arrays and their potential use as an imaging source for a high speed photonic printing bar. This is similar in concept to page-wide inkjet print heads, being developed by the likes of MemJet and ToneJet for the next generation of inkjet press.

However unlike inkjet bars, with many thousands of nozzles often requiring mass redundancy of ejectors, a micro-LED bar would contain many thousands of micro-emitters of light i.e. no nozzles to block. We have termed this page-wide photonic print head – LumeBar (Figure 7).

Figure7. *LumeBar concept, with 20µm LED clusters and parabolic reflectors*

In June 2013 LumeJet secured a $375,000 UK government grant towards the development of a LumeBar prototype. A project consortium has been formed including InfiniLED in Ireland, a spin out from research at the Tyndall Institute at Cork University, who are experts in the fabrication of clustered, parabolic micro-LED arrays with individually addressable micro-pixels of the order of 20microns and cone angles of +/- 30 degrees.

The basic building block for LumeBars are separate micro-LED arrays, which we are terming LumeChips, each with 128 µLEDs per chip in a 4-row staggered offset array. These will be fabricated by flip-chip bonding methods, each µLED comprising clusters of 9 micro-pixels with parabolic reflectors fabricated to produce intense collimated beams. LumeJet will produce the ASIC drivers and bus structure for each LumeChip, as well as the methods to align 'N' LumeChips into the final LumeBar. Other consortium members will be working on the focusing optics (micro-LENs or FOCAL lens) and the thermal management.

The key deliverables from the project, due to run for 24 months, will be 3 prototype 12", 400ppi LumeBars, one in each of the primary colors Red, Green and Blue, matched to the spectral response of the AgX media. If successful, LumeBar could provide printing speeds in the 1-10m/s range to challenge toner and inkjet digital presses.

At other wavelengths, particularly IR and UV, LumeBars could also have potential applications in electrophotographic printers, inkless printing and printed electronics, as discussed in the final section.

What makes LumeJet quality so different?

Colour negative (CN) media has had over 100 years of continuous development and is coated around the globe by the millions of square meter each year. It still represents the benchmark for image quality, longevity, cost (about 1/3rd inkjet of equivalent bit depth and resolution) and faithful colour reproduction.

CN papers are multilayer coatings, where the primary image forming layers contain AgX grains sensitized to Red, Green and Blue wavelengths. Following exposure and processing these layers form Cyan, Magenta and Yellow dyes respectively, in direct proportion to the RGB exposure, and the silver grains are recovered – leaving just spectrally pure dyes in a three layer stack, one on top of each other, as shown in Figure 8.

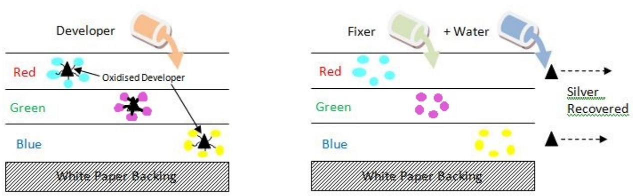

***Figure8**. Exposure and processing of CN media.*

The LumeJet process is about as spectrally pure and spatially precise as it is possible to reproduce an original RGB color image with just CMY dyes. Owing to the LumeJet micron-accurate, dot-on-dot structure the CMY dyes act like little filter stacks that produce ultra sharp edges, full tonal range and dense blacks, in one pass. Unlike half-tone systems it does not require a separate black (K) layer, or tight registration, to trick the eye into seeing 'pseudo' color reproduction.

Precise analysis of the structure and comparable quality of LumeJet and various halftone systems is beyond the scope of this paper, as they all use very different principles. Figure 9 shows enlargements of LumeJet and a top-end Digital Press system of the same image detail, at 40 and 400x.

With LumeJet the pixel cell is generated such that the image pixels per inch (ppi) is directly equivalent to the printer dots per inch (dpi), and works at the maximum resolution of the media and human eye (c. 400ppi). The pixel cell is completely filled and contains continuous tones of cyan, magenta and yellow dyes (2048 levels C&M, 1024 levels Y), rather than screened dots.

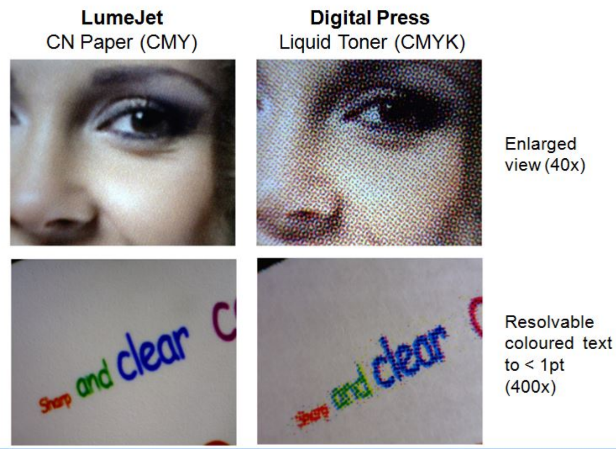

***Figure9**. Comparison of LumeJet and Digital Press output at 40 and 400x.*

To give a perception of a comparable quality, halftone systems require of the order of 10x more resolution. This is needed to create the finer, dot-beside-dot FM screen patterning within the pixel cell to fill in the gaps to make the image 'appear' smooth. It has been estimated that to produce close to LumeJet quality would require 8-colours and over 4000dpi for an FM screened inkjet systems. Think of this when you next use your home inkjet printer for holiday snaps and you will realize why you are always replacing the cartridge. Retail or commercial printers – don't even go there!

Other Applications

LumeJet technology may have wider applications than just high quality digital printing. Discussions are taking place with the FMCG community regarding the use of LumeBars for printing onto a new class of color change photopolymers for inkless printing and packaging applications. This will require further developments of µLED or Laser Diode arrays in IR and UV wavelengths.

There is significant interest in being able to print variable data, at inline production speed, directly into predefined areas of pre-printed labels for localized information e.g. nutrient content, tracking data, marketing promotions. Current inkjet and laser systems, used mainly for coding and marking, are not considered suitable especially for fine text and graphics. The ultimate step is to be able to produce the whole label, digitally, in color and on demand at production speed, but this may be several years away yet. LumeJet is working with key materials suppliers who may have the answer to the coatings required to fulfill this vision.

LumeJet has also spotlighted the needs of the plastic electronics community for high resolution patterning for backplanes and TFT's for flexible and transparent displays, OLED lighting and OPV. Currently patterning is typically performed by photolithographic processes using fixed area masks and UV resists. For an OLED display this may require up to 10 masks, each costing several $100k. This is a significant barrier for developers of new printed electronics technologies.

LumeJet has identified the need for a direct-write, UV LumeBar print head and micron-accurate plotter for maskless lithography and is in discussion with key partners and potential customers.

Author Biography

Trevor Elworthy received his BSc (Hons) in physics from the University of Bath UK, and studied for a PhD in geophysics at the University of Witswatersrand, Johannesburg S.A.

Since 1983 Trevor has founded 4 companies developing digital technology for the printing and photographic markets. The most recent, LumeJet , was spun out from research he initiated at Warwick University. Trevor holds a number of industry awards and patents and was appointed a Fellow of the Royal Society of Arts (FRSA) in 2011.