The Trends in LED Printheads

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The market for colour printers based on electrophotographic systems is growing steadily. The sector exceeded 690,000 units in 2001 and is forecast to reach some 1.5 million units by 2005. The printer expected to be the main driving force behind this market expansion is the tandem type colour printer.

The tandem colour printer has separate processes and recording systems for cyan, magenta, yellow and black, and is able to form a toner image in a single pass of the printing paper. This means that the printer has a simple structure and is suitable for high-speed printing, as well as achieving compact design and lower prices.

The recording light source in a tandem colour printer uses either an LED printhead or a laser scanner head. The LED printhead has several advantages - being a solid-state light source, it is easy to handle, and its compact design allows for reduction in the printer size. These make it the ideal choice for tandem colour printers, a situation which has led to pressure for further price reductions in LED printheads, whilst maintaining performance factors, such as high print density and high speed.

Oki Digital Imaging Corp. started operations in October 1999, with its aim to become the world's leading supplier of LED printheads through a comprehensive approach combining R&D, design, manufacture and marketing. The company is developing LED printhead technology, in parallel with the development of colour printers, and has already managed to devise the compact and inexpensive high-density, high-speed technologies required in light sources for electrophotographic colour printers.

This paper compares the structure of LED printheads with that of laser scanner heads, discussing the issues involved with head design, and introducing the technology that has been developed by Oki Digital Imaging.

Comparing printhead structures

Fig. 1 is a general view of an LED printhead. This printhead consists of a wiring substrate on which an LED (Light Emitting Diode) array and driver IC are mounted, and a rod lens array. The LED array is a compound semiconductor chip in which a large number of light emitting sections are integrated, and the driver IC is a semiconductor chip integrating driver elements for controlling the switching operations of the respective light emitters in the LED array. The rod lens array is a lens formed by graded index fibres fixed in an array fashion, and it produces a real upright 1:1 image.

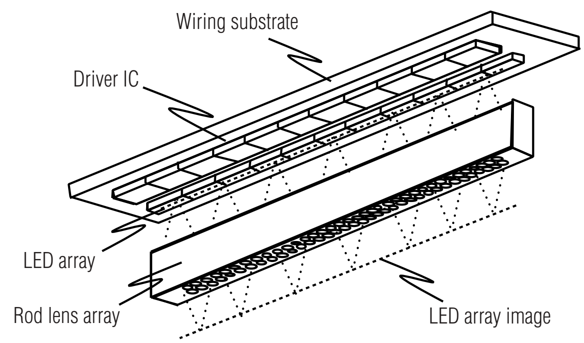

Fig. 1 General structure of LED printhead

The LED printhead is constructed by die-bond mounting a number of LED arrays onto the wiring substrate in a straight line, so that it complies with the width of the printing paper, such as A4. Each light emitting section is connected electrically to a driver element on the driver IC, via metal wires, or the like, and is switched on and off in accordance with a print signal. The light output by the light emitters is focussed onto a photosensitive drum by the rod lens array. In this image forming process, the light emitters of the LED array on the wiring substrate are projected onto the drum at a magnification of 1:1, so the width of the printing paper is respected. Based on this structure, the LED printhead has the following features:

- It is a solid-state light source formed by several thousands of light emitting sections, which create an electronic light scanning system.
- It has simple optics, a short light path, and a compact size.

Fig. 2 is a general view of a laser scanner head. The laser scanner head comprises a laser diode, collimating lens, polygon scanner, f-θ lens, cylindrical mirror, and the like. The light output by the laser diode is converted to parallel light by the collimating lens and the laser light is then scanned across the printing width by rotating the polygon scanner. The scanned laser light forms an image on a photosensitive drum via the f-θ lens. The laser scanner head has the following characteristics:

- The light source involves a single laser diode and is based on a mechanical scanning system.
- The head has a complex optics system, long light path, and is relatively bulky.

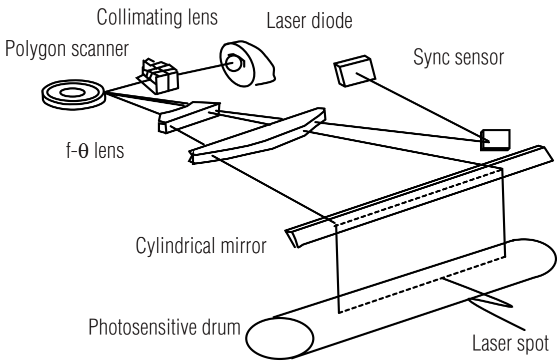

Fig. 2 General structure of laser diode head

Issues in printhead design

Here, we look at the technical issues involved in adapting LED printheads and laser scanner heads for colour printing, focusing on the themes of high resolution, high speed, and the light source applications in tandem colour printers.

(1) High-resolution printing

The lens used in an LED printhead produces a same-size upright real image. Therefore, the printing resolution of the head is determined by the density of the light emitting sections in the LED array, and hence the key to achieving high printing resolution is the development of high-density LED arrays.

In a laser scanner head, on the other hand, resolution is affected by the modulation frequency of the laser diodes, and the optical characteristics of the collimating lens and f-θ lens. With the inexpensive plastic lenses currently in general use, it is difficult to achieve very small spot diameters of the order of 1200 dpi, for instance, and therefore it is crucial to develop technologies for reducing the laser diode wavelength. What is more, in order to double the resolution at the same printing speed, it is necessary to increase the rotational speed of the polygon scanner by a factor of 2, and the laser diode modulation rate, by a factor of 4. This means that in laser scanner head systems, the problems relating to high resolution overlap with issues relating to operational speed.

(2) High-speed printing

In seeking to achieve faster LED printheads, the main issue is that of the heat generated by the head when it is driven at high speed. Here, the solution has been to develop technology which increases the light emission efficiency of the LED array.

The printing speed of laser scanner heads, meanwhile, is governed by the rotational speed of the polygon mirror and the number of faces on the mirror, but there are mechanical constraints which limit the speed at which this type of head can operate. Therefore, the key to achieving faster laser scanner heads lies in developing multi-beam technology for the laser diodes.

(3) Light source applications in tandem colour printers

As stated previously, a tandem colour printer comprises four independent processes and light sources, which allow it to form a toner image in a single pass of the printing paper. Consequently, the main technical issue is how to align the four light sources in position. Any significant divergence from this alignment will result in colour blurring in the printed image and a subsequent decline in print quality.

The LED printhead has the advantage of being a small, solid-state light source, which allows compact printer design. It also allows relatively straightforward alignment control, and does not require the positional adjustment mechanisms needed in laser scanner systems. However, LED printheads do involve their own intrinsic problems, due to the fact that they are made up of thousands of individual light emitting sections. These problems, and the technological developments for resolving them, are listed below.

- Fluctuation in light quantity : Light quantity correction technology
- Degradation of light quantity : Light emission efficiency enhancement technology
- Positional accuracy of LED array image : Die-bond positional accuracy technology and lens array assembly technology
- Positional variation due to thermal expansion : Light emission efficiency enhancement technology

If, on the other hand, a tandem colour printer is built using a laser scanner head, then it is necessary to adjust the laser spot on the drum surface for each head, and this requires position correcting and adjusting means for each optical system. Moreover, a variety of correctional measures are required to offset the optical variations caused by heat, and the like, during the printing operation. A laser scanner head also requires a long light path, which means that if simply four laser scanner heads are used, then the resulting printer will be bulky. New optical developments incorporating a whole range of features are needed before laser scanner heads can be applied successfully as light sources for tandem colour printers.

Our involvement

Oki was the first Japanese manufacturer to announce the development of an LED printhead, in 1979, and since then we have continued to lead the world in technology and product development. With recent moves towards colour printing, in particular, we have made constant strides in achieving high-density, high-speed technologies which are inexpensive and compact, and we have been able to implement an optimum head for use as a tandem colour printer light source.

Below, we look at the steps made by Oki towards LED heads with colour printing capability.

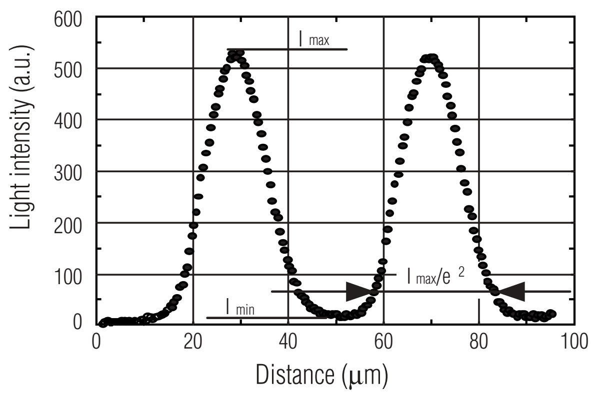

Fig. 3 Resolution characteristics of 1200 dpi LED head

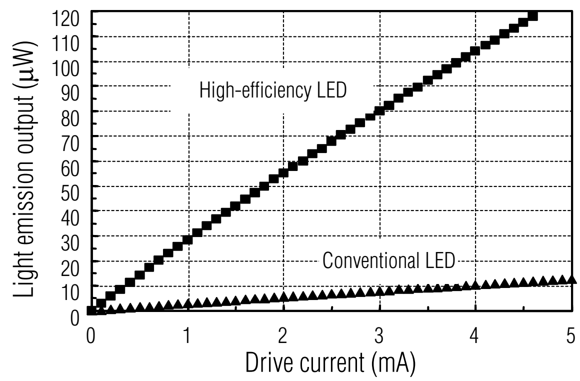

Fig. 4 Light output characteristics of 1200 dpi LED

(1) Achieving high density [1)]

Producing excellent images of near-photograph quality with a DTP (Desktop Publishing) system or colour printer requires a high-resolution printhead of at least 1200 dpi. With this issue in mind, Oki has been working on microfabrication technologies for light emitting diodes, and we were able to develop a new LED array manufacturing technique based on solid-phase diffusion. Using this LED array, we produced the world's first 1200 dpi LED printhead in 1996.

Fig. 3 shows the resolution characteristics of the LED printhead. In order to evaluate the resolution of the head, we measured the LED light intensity distribution formed by the rod lens array. This measurement was taken by switching on alternate light emitters of the LED array, using a rod lens array of 20°. The light spot diameter defined by I_{max}/e^2 was approximately 30 μm, and the MTF (Modulation Transfer Function) which is an index of resolution, was 80% or above, thus demonstrating suitably high resolution.

(2) Enhancing light emission efficiency [2)]

The individual LEDs in the LED printhead can be switched on and off electrically, making it an ideal light source for high-speed operation. However, because each head contains thousands of LEDs, then although the current supplied to each LED dot is low at several milliamps, the current fed to the head as a whole reaches several amps in total. For this reason, heat generation in the head and increase in the drive current are major obstacles to achieving faster printing speeds. In tandem colour printers, in particular, the expansion of the respective heads due to the heat created in them causes a decline in print quality. To resolve this problem, the light emission efficiency of the LED array must be improved. In response to this issue, in 1998, Oki unveiled a new and different LED element structure, which successfully improved light emission efficiency by a factor of 10 over conventional LEDs. The new LED element is manufactured by forming aluminium gallium arsenide in a double hetero structure, and then selectively diffusing zinc by solid-phase diffusion, and forming p-n junction regions inside the active layer.

Fig. 4 compares the light emission characteristics of this high-efficiency LED with those of a conventional LED. As this graph reveals, the new high-efficiency design achieves a 10 fold-plus improvement in light emission efficiency over conventional designs. In this way, the high-efficiency LED can produce 10 times the light output of a conventional LED when supplied with the same drive current, or in other words, it requires only 1/10 of the drive current to achieve the same light output.

This development has enabled us to resolve the problems of power consumption and heat generation, which were barriers to higher operating speeds.

(3) Price reduction [3)]

The high-efficiency LED makes it possible to ensure that sufficient exposure energy is supplied to the photosensitive drum in a short emission time, without having to increase the current supplied to the LED. Oki has applied this high-efficiency light emission technology to the issue of reducing printhead prices, and in this way, we were able to lower the price of our 1200 dpi LED printhead in 2001. We have also been able to reduce prices by adopting time division driving in the head drive system, and developing LED array chips which are compatible with this type of drive system.

Fig. 5 is an illustrative diagram of a 1/8 matrix drive developed by Oki. A1, 2, ... 8 are anode electrodes, and C1, 2 ... 8 are cathode electrodes. Each anode is connected via an 8 x 8 multi-layer wiring matrix to 8 LEDs situated at 8-dot intervals. The cathodes, meanwhile, are connected to 8 consecutively positioned LEDs. Light emission is driven by supplying a drive current corresponding to the print data to the anodes, from a driver IC, and then switching the cathodes to turn the LED dots on and off, in cathode units. This development has reduced the number of driver IC chips to 1/2, compared to a conventional head, and the number of wires, to 1/4. What is more, the fact that the electrodes can be arranged along one side of the LED array has

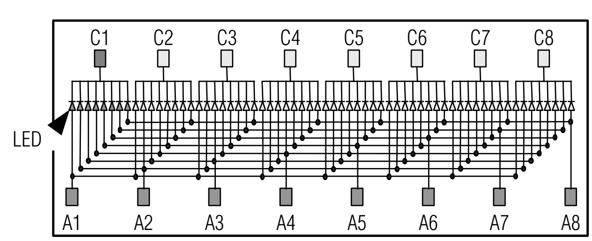

Fig. 5 Schematic view of 1/8 matrix drive system

made it possible to shrink the LED array chips to 1/2 of their previous width. The drive current is also reduced in comparison to conventional LEDs, allowing the use of smaller driver IC chips. With all this, cuts have been made in the number of components and their material costs, as well as processing costs, resulting in the appearance of significantly cheaper printheads. These price reduction technologies have also been extended to our 600 dpi LED printhead, and we have started mass production of a light source for tandem colour printers.

(4) Application to light sources for tandem colour printers

- **Light quantity correction technology**

The fact that LED printheads are made up of individual LEDs has always been an inherent cause of non-uniformity in the light output. If printing is conducted with a head that has uneven light output, then variations in print contrast will occur. The key to resolving this problem lies in the development of light quantity correction technology.

The light quantity correction technology developed by Oki homogenizes the light output after it has passed through the lens, by controlling the current supplied to each LED dot. The system comprises 4-bit correction for the current supplied to each chip unit, within a 3% margin, and a 6-bit correction function for the current to each dot, within a 1% margin. The development of this correction system means that even if there is a light output variation of ±10% before correction, this can be reduced to ±1% or less after correction. This effectively resolves the problem of non-uniform light quantity, which has been a major stumbling block in LED printheads.

- **Lifespan**

The LED printhead has also presented durability problems, in terms of light degradation in individual dots. The lifespan of an LED is generally proportional to the square of the current supplied: the greater the current supplied, the faster the degradation in the light output. However, the LEDs used by Oki in its printheads are based on high-efficiency light emission technology, and because the current supplied to each LED is low, the LEDs can be expected to last longer.

Fig. 6 shows the lifespan characteristics of a 1200 dpi LED printhead. Under the operating conditions for this test, all the dots were switched on by supplying a current of 1 mA to each LED dot. The black points on the graph indicate the change in the average light output of the head. The vertical axis indicates the rate of change from the initially measured light output value, and the horizontal axis represents the cumulative time for which the LEDs were switched on. As the measurement results demonstrate, the average light output after 2,000 hours showed virtually no change. If these results are converted to a print number, assuming a print duty using normal use of 10%, then they represent a total of some 3 million pages, thus proving that stable images can be output over the long term.

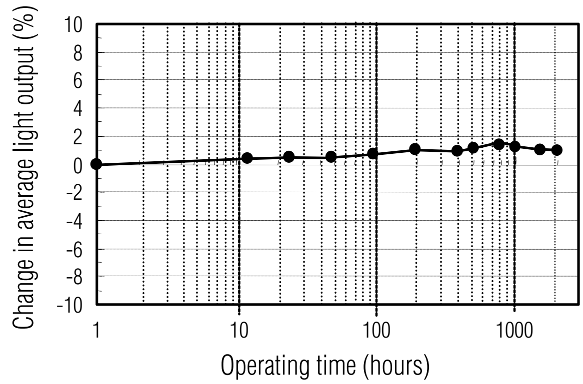

Fig. 6 Lifespan characteristics of 1200 dpi LED printhead

- **Compact design**

In order to reduce the size of a tandem colour printer, it is necessary to achieve a more compact head. At Oki, in developing the low-cost 600 dpi LED printhead, we adopted the use of high-efficiency LEDs which enabled us to achieve further size reductions. The head consists of a wiring substrate mounted with an LED array and driver IC, a rod lens array, and a lens holder. It does not require a large heat sink. The dimensions of the head are: width 14 mm, length 280 mm, and height 17 mm, and with a weight of 100g, it is light as well as compact.

Conclusion

Oki has been developing LED printhead technology in parallel with the development of colour printing capabilities, and has been able to achieve the small and inexpensive high-density, high-speed technology that is required in recording light sources for electrophotographic colour printers. With these developments, our LED printheads now outstrip laser scanner heads in terms of performance and quality. In the future, we can expect further significant advances in the area of LED printheads, as the market for colour printers continues to grow.

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