# The Development of LED Printheads

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Oki Electric offers highly original and innovative products in the field of electrophotographic printers using LED array light sources. We have been developing this type of printer for 25 years now, and our position in the printer market is currently assured. LED printheads have been achieved by overcoming a whole series of obstacles, including the initial development process, LED array production yields, optical transmission means, and mounting technology, amongst others. This article traces the evolution of LED printheads to the present day, focusing in particular on the early stages of development.

## LED array forming all-solid-state light source for optical printer

In and around 1977, Oki Electric was well known as a manufacturer of terminal devices, and we had a particularly solid position in the printer market. At that time, impact printers were the dominant technology, but the first steps towards the optical printer age were starting to be made, although this would take another 10 years to arrive in full. Optical printers using laser light sources were commonly known at the time. These devices comprised a helium neon gas laser as a light source, along with rotating mirrors for light scanning and lenses for projecting the laser light. Yet, these devices were not suitable for automated manufacture, and in the end the laser systems had to be discarded. However, the optical printers targeted by Oki incorporated LED technology and this was indeed a practicable system.

The dream of developers at the time was to achieve an all-solid-state device. This meant a completely solid-state head, with a solid-state light source and a solid-state scanning mechanism. Against the light scanning systems based on rotating mirrors used in laser printers, a single-line simultaneous-emission LED array provided a perfect device for realizing the developer's dreams.

## Existing core technology for LED heads

The development of the basic technology for achieving LED heads can be traced back to some 12 years earlier in 1965, when an Oki researcher was seconded to the Telecommunications Research Centre at Tohoku University under the leadership of Professor Junichi Nishizawa , in order to study LED technology. At the time, I was a student in Prof. Nishizawa's research team, and I never imagined then that I would end up spending many years involved in LED head development in the same company as that researcher. Anyway, the research into LEDs bore fruit in business terms, and Oki started to manufacture LED lamps and LED arrays. This technology also formed a vital foundation for semiconductor lasers, a key device in optical communications. Another core technology for LED heads was the thermal printer. Oki was the world's first manufacturer to develop a fax machine incorporating a thermal printer, and this machine became the industry standard in its market. In this way, the company was excellently placed in terms of printhead technology.

## The challenges of developing LED arrays

Our research and development of LED printers was based on joint investigation work made in collaboration with Telecommunications Research Centre at Yokosuka, Nippon Telegraph and Telephone Public Corporation (now called NTT). The Oki team leaders were still in their 40s and generally of section manager rank. Moreover, the idea of using LED arrays for light sources was proposed by the young research staff at the Yokosuka Centre.

The LED array technology of the time was in its infancy and a long way from maturity. One example of this technology is the 10 element per chip LED array we developed as a light source for frame-to-frame optical communications, but in attempting to restrict the light output fluctuation per chip to within ±15%, the chip production yield ended up at a meagre 1%. Expanding this chip to a 128 element per chip device for use as a printer light source, and maintaining a chip production yield of 30% or more, would have required massive orders of improvement, which seemed like a whole world away. However, just two years down the road, our LED engineers achieved just that.

## Achieving the right result by downgrading crystal quality

However large the power of the LED array, any significant variation in the power output will make the array unsuitable for use as a printer light source. However, if the power is reduced by a certain amount to achieve a more uniform output, then this application becomes feasible. With the very first LED arrays, there were massive differences between dots of high power and dots of low power. The cause of the fluctuating power in the LEDs was difference in the crystal defect density of the light emitting sections. Crystal defects were distributed unevenly within a wafer. Ideally, defects would be eliminated entirely from the wafer, but this was not possible. Therefore, the thinking went that even if

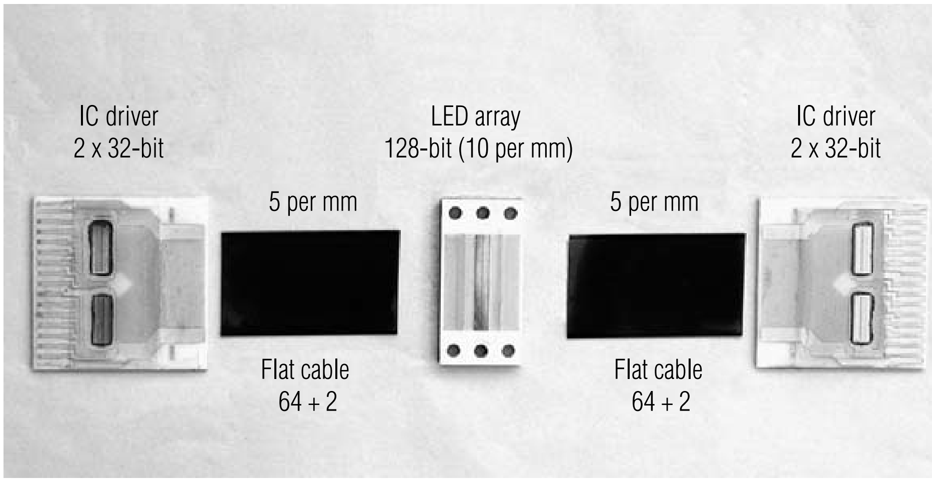


**Fig. 1 128-element LED array and IC driver set**

there was a certain ratio of defects, as long as these were evenly distributed, the resulting LED array would produce low variation in light emissions. Research started into ways of generating an even defect distribution.

An LED comprises a layer of gallium arsenide phosphorous (GaAsP) formed by epitaxial growth technology onto a gallium arsenide (GaAs) substrate, the light emitting region being formed in the GaAsP layer. Due to the slight difference between the lattice pitch of the GaAs crystals and that of the GaAsP crystals (lattice mismatch), a distortion of the crystals, in other words, a crystal defect occurs inside the GaAsP region. As a result of trial and error, we were able to propose a new structure for GaAsP crystals and a crystal growth program for achieving this structure, which made it possible to generate defects in an even fashion over the wafer surface. Consequently, we were able to build LED chips which, despite having a 100-fold increase in defect density and 1/10th of the previous power output, could be produced at a yield rate of 30% or above within a power uniformity range of ±15%. These did not display a deterioration of power characteristics due to crystal defects, and were confirmed to have suitable reliability. At that juncture, we were able to establish our basic policy towards LED array technology, as well as confirming the suitability of LED arrays for use as light sources in optical printers.[1) 2)]

Fig. 1 shows a 128-element chip, 10-element per mm LED array. IC drivers are connected to either side via flat cables.

## What about lenses?

Our first developments into methods for transferring the LED image to a photosensitive drum involved optical fibre plate systems. This was something like a shortened version of the optical fibre scope used in endoscopes. In other words, one end of the fibre-optic plate was positioned adjacently to the LED array, and the other end was placed by the photosensitive drum, onto which it transferred the LED image. Fig. 2 shows the first sample printed using the LED array in Fig. 1 combined with a fibre-optic plate.

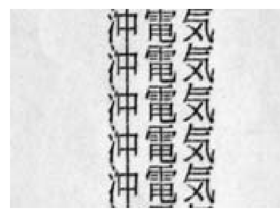


**Fig. 2 First print sample using LED array and fibre-optic plate**

However, this optical system involved a problem. The shorter the distance between the fibre-optic plate and the photosensitive drum, the clearer the image, but since the drum was rotating, a gap had to be left to stop it from touching the plate. Yet, if the gap was too narrow, then toner would stick to the ends of surface of the fibre-optic plate, rather than dispersing, and these toner particles would block the light and obstruct the printing process. Several solutions were considered, but in the end, this system had to be discarded.

At just about that time, the rod lens array having an image forming function had emerged in graded-index optical fibre applications used in optical communications transmission lines. This lens makes excellent use of the deflection of light caused by refractive index variation in glass, and rather than forming the LED image at its end face, as in the fibre-optic plate, instead, it forms an image in space, like a camera lens. For this reason, it is possible to leave gaps of several millimetres between the lens and the LEDs and between the lens and the photosensitive drum, and this solves the problem of toner adhesion mentioned above. What is more, the distance from the LED array to the photosensitive drum is generally several centimetres, which means that this type of lens is ideal for making the most of the compact design of the LED head. At the time, this system did not have adequate image resolution or damp-proofing characteristics, but now resolution as high as 1200 dpi is possible, and moisture does not present problems of any kind.

## The remaining hurdle : mounting technology

Thermal printers already existed as a model for ways of mounting the LED array and drive ICs, and the best option appeared to be to arrange the LED array in a single row, position the drivers in parallel, and then wire bond them to the array. However, it did not turn out to be so straightforward in practice. In a thermal printer, the light emitting sections are all formed together over the whole surface, but the LED chips generally had a length of about 10 mm. At that time, LED wafers were approximately 2 inches in diameter, and taking LED array yield into account, the LED chip size was limited to about 10 mm. Therefore, to print an A4 page would require around 20 chips, all positioned accurately in line on the substrate. Firstly, in order that the light emitting diodes at the ends of adjacent chips were spaced at an interval matching the printing pitch, the chips would have to be diced at positions very close to the light emitting cells, and no cracks or other defects could be allowed within the chip. The LED chips would also have to be dice bonded at a positional accuracy of several microns. Technology of this kind was not available.

Therefore, as shown in Fig. 3, a design was adopted in which LED arrays were arranged in two staggered rows to avoid spatial contact between the arrays, and rod lens arrays were positioned corresponding to each of the rows of LED arrays. In this way, an LED image could be projected continuously onto the photosensitive drum in an accurate linear fashion. Product development started out on the basis of this design, although subsequent developments in high-precision dice-bonding technology and dicing techniques which avoid damage to the LED chips have meant that, today, LED arrays are arranged in a single row.

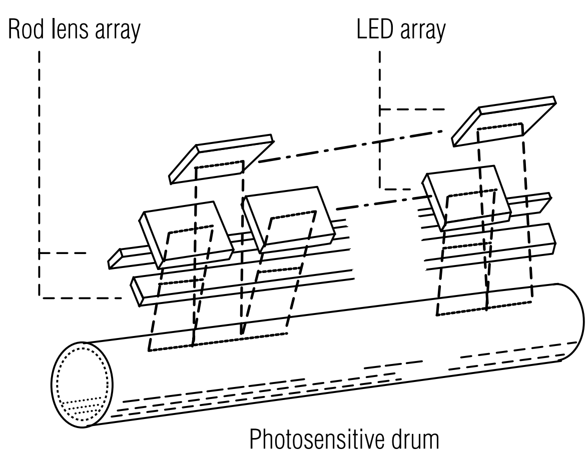


**Fig. 3 LED head using two rod lens arrays**

## The birth of printers using LED array light sources

Printing speed is governed not only by the light output power of the LEDs, but also by the sensitivity of the photosensitive drum. The development of high-sensitivity selenium drums, allied with increases in LED output, allowed 10-fold-plus improvements in the product of optical sensitivity and optical power.

The LED array light source electrophotographic printer unveiled in 1979 was a table-top printer capable of producing 20 A4 pages per minute at a print density of 10 dots per mm.[3) 4) 5) 6)] Following this, 1981 saw the start of the LED printer market.

## Advances in LED head technology

LED printheads involve a combination of technologies relating to LED elements, drive circuits, optics, and mounting techniques,[7)] and remarkable progress has been made in all of these areas. Here, I would like to look at the advances made in both density and power output in LED arrays.

### (1) Achieving 1200 dpi density

The first step in improving printing density was from 300 dpi to 600 dpi, followed by the development of the world's first 1200 dpi printer in a table-top format. The existing method for forming the light emitting sections in LEDs, in other words, the PN junctions, is known as vapor-phase diffusion, which involves depositing an impurity in gaseous form onto the crystal surfaces and then diffusing them into the crystals by applying heat. This method requires a long period of heating to achieve high-density doping of the impurity, and if the impurity travels laterally, as well as in the depth direction during this process, and if the dots are spaced very closely together, then adjacent dots can merge together. At 1200 dpi resolution, the pitch between the light emitting cells is 20 micron, and since the light emitting elements are 10 micron in size, which is close to the diffusion distance of the impurity, then it is very hard to control this diffusion technique adequately. This is caused by the fact that the impurity is a gas of very low density.

As an alternative method, we developed proprietary technology capable of diffusing an impurity to a high density, but in a shallow area. In this technique, a solid containing a high density of the impurity is grown directly onto the diffusion point, and is then heated for a short time. This method is called solid-phase diffusion technology[8) 9)], and as well as 1200 dpi heads, it opens up the possibility of ultra-high-density heads going well beyond this.

1200 dpi print density is difficult to achieve in rival laser printers. More specifically, the laser systems require special mechanisms for focussing the light spot in a small area. Firstly, lasers need to move towards shorter light emission wavelengths, in other words, from the infrared region currently used, to blue wavelengths. This advance would be achieved with the advent of high-density optical disks, but the technology still remains very expensive. Then there is also the issue of lenses. Current low-cost extruded plastic lenses have limited resolution and must therefore be used in combination with glass lenses, which require polishing and push costs upwards. An even more difficult issue is the need to increase the size of the scanning mirror, and its speed of rotation, in line with the increased print density, which in turn leads to problems of mirror damage, increased motor size, and noise, etc. The LED system, on the other hand, controls light emission electrically, and therefore has none of these limitations.

**(2) Ten-fold increase in light output power**

One of the technological advances made has been a 10-times increase in light emission power compared to conventional LED arrays. This high-power LED design is known as a double heterojunction, and using this as a basic structure and then incorporating special electrode design and techniques involving solid phase diffusion methods, we have been able to reach our target [10].

At the same time, we have successfully converted from GaAsP to AlGaAs with the objective of simplifying our LED forming processes.

The principal upshot of this is the ability to print at ultra-fast speeds outstripping those of laser printers. In particular, this change has had the effect of reducing the current load on the driver ICs and lowering costs by allowing more compact chip design.

**(3) Future possibilities**

The LED printhead has many different features – its all-solid-state structure, ultra-compact size, and high-density, high-speed printing capabilities – and we can expect a massive surge in high-speed colour printers and ultra-high-speed large-scale printers which make full use of these characteristics.[11] We also hope that these developments will bring more people around to LED printers. LED head technology is still in the process of evolution, and additional new possibilities are likely to emerge in this field, leading us to expect further expansion of the LED printer and LED head markets in the future.

**Table. 1 The development history of LED printheads**

| Year | Development |
|---|---|
| 1965 | LED technology acquired under guidance of Prof. Junichi Nishizawa at Tohoku University. LED device research started by Oki in 1966. |
| 1977 | Start of joint research into optical printers<br>- LED array light source electrophotographic printer initiative - |
| 1979 | Successful trial manufacture of 10 dot/mm, 128 dot/ chip LED array with 7 μW light output and ±15% power variation<br>- Suitability of LED array technology policy confirmed - |
| 1979 | 12-fold improvements achieved in the product of photosensitive drums light sensitivity and LED light output. The first printing executed by using optical plate systems. Successful printing by using focusing rod lens array. |
| 1979 | Printer with LED array light source achieves 20 ppm print speed on A4 paper at 10 dot/mm resolution.<br>- World first - |
| 1981 | Launch of LED array light source printer product<br>OPP6100 (240 dpi)<br>1986 : Launch of 300 dpi printer<br>1988 : Launch of common paper FAX device with LED print system<br>1991 : Launch of 600 dpi printer |
| 1996 | 1200 dpi LED array developed<br>1997 : Launch of 1200 dpi printer |
| 1998 | Development of ultra-high-power LED array |
| 1998 | Launch of 600 dpi colour printer |

## Conclusion

Table 1 summarizes the development history of LED printheads, and this article has focused principally on the early stages in this process. This is a tale of hurdle after hurdle being overcome through sheer determination. Here, I would like to pay tribute to the team managers involved in the early stages – the real creating force behind this sector – both for their leadership and their intelligence and foresight in the field of LED technology, something which I, as an inheritor of this technology, appreciate very deeply.

The fact that we have managed to come this far is down to the many people who developed the LED printer business, convinced that LED printers had a real future, as well as the great number of engineers who have nurtured our LED printhead technology through their constant input of ideas.

## References


1) “Development of new light-emitting diode array for printer”, Nikkei Electronics, 17th Sept. 1979, pp. 61-64
2) Tateishi, Nakaya: “Investigation into LED array light source for optical printer”, IEICE Communications Dept., Proceedings of National Conference, 592, p. 1 - 211, Sept. 1980
3) Tateishi, Ikeda, Kotani: “LED Printers”, IEICE Technical Digest (Image Engineering), IE80-71, Oct. 1980
4) Tateishi, Hoshino, Abiko: “Optical printheads using LED array light sources”, IEICE Technical Digest (Image Engineering), IE81-4, April 1981,
5) “Unveiling a third optical printer: The Light-emitting diode printer”, Nikkei Electronics, May 25th 1981, pp. 114-128
6) K.Tateishi, Y.Ikeda, S.Kotani and S.Nakaya: “Optical Printer Using LED Array”, SID 81 Digest, pp.66-67
7) Abiko: “Handbook of recording and storage technology for LED array printer”, Maruzen, pp. 293 - 298
8) M.Ogihara, M.Taninaka and Y.Nakamura: “Open tube zinc diffusion into GaAs0. 8P0. 2 using AlN and SiNx cap films”, J. Appl. Phys. Vol. 79, pp.2995-3002, 1996
9) T. Shimizu, M. Ogihara, M. Taninaka and Y. Nakamura: “1200dpi LED Printhead”, Proceedings of Japan Hard Copy, pp.125-128, 1996
10) M. Ogihara, H. Hamano, M. Taninaka, H. Kikuchi and Y. Nakamura: “High Speed 1200 dpi LED Print-head” Proceedings of PPIC/JP, pp.257-260, 1998
11) Abiko: “LEDs for tandem colour printers: Basic Technology and Tendencies”, 51st Symposium of the Imaging Society of Japan, July 18-19th 2001


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