

Laser Printing with Multiple Beams from Optical Fiber Array

Keiji Kataoka, Yasuyuki Shibayama*, and Koji Doi***
R&D Lab., Printer Div.**, Hitachi Koki Co., Ltd.*
Hitachinaka-City, Ibaraki-Pref. /Japan

Abstract

Simultaneous scanning of multiple beams is an effective method to realize high-speed and high-resolution laser printer. For producing multiple beams, we have been developing an optical fiber array method and recently we could successfully demonstrate a laser printing using the optical fiber array for five beams. The wavelength of diode lasers is 640nm at which the photoconductor drum has sensitivity. The fiber array has a spacing of 0.15mm and each fiber emits a circular Gaussian beam of 5μm in diameter. In the arrayed fibers, the alignment error vertical to the array direction is suppressed below 0.4μm. In the optics, the curve of scan lines and print position errors in scan direction caused by the wavelength differences among diode lasers are suppressed negligibly small due to the achromatized design.

Introduction

In laser printers of high-speed and high-resolution, the multiple beam scanning is going to be an essential technique because the transfer rate of print data and the rotation speed of the polygonal mirror would be over practical limits if one beam scanning is adopted. [1, 2] One method for generating multiple beams is to use a diode laser array in which diode laser elements are monolithically fabricated on a single semiconductor chip. The device is advantageous that it is compact and can be produced with low cost in mass-production. But there is a problem that the device is hard to be available if the specifications are special, for example, in the case that the large number of beams or newly developed diode lasers are required.

In this paper we propose an optical fiber array method for generating multiple beams. In the optical fiber array, plural diode lasers are coupled to single- mode optical fibers and the fibers are arranged in an array for generating an array of beams. Although this method requires precise fabrications, it has merits in that the number of beams are easily increased and newly developed diode lasers can be used such as lasers of short wavelength, 640nm in this case and in near future, blue diode lasers.

Necessity of Multiple Beam Scanning

In multiple beam scanning, the required specifications of the rotation speed of a polygonal mirror, R(rpm), the time duration to print one dot, t_p(ns), and the laser power, P(mW), of a diode laser are given by

$$1/t_p = (4\pi f/N)(VD^2/m) \quad (1)$$

$$R = 60VD/(Nm) \quad (2)$$

$$P = (4\pi f/N)(VS)/(\eta m) \quad (3)$$

where f(mm) is the focal length of a scanning lens, N is the number of mirror facets of a polygonal mirror, V(mm/sec) is the print velocity, D(dot/mm) is the print dot density, S(mJ/mm^2) is the sensitivity of a photoconductor drum, η is the light transmission efficiency from the diode laser to the photo-conductor drum, and m is the number of multiple beams. In these equations, it is noted that the time duration to print one dot becomes rapidly short in proportional to the square of the print dot density. The number of multiple beams effectively lowers the rotation speed of the polygonal mirror and the laser power of diode lasers, and increases the time duration to print one dot.

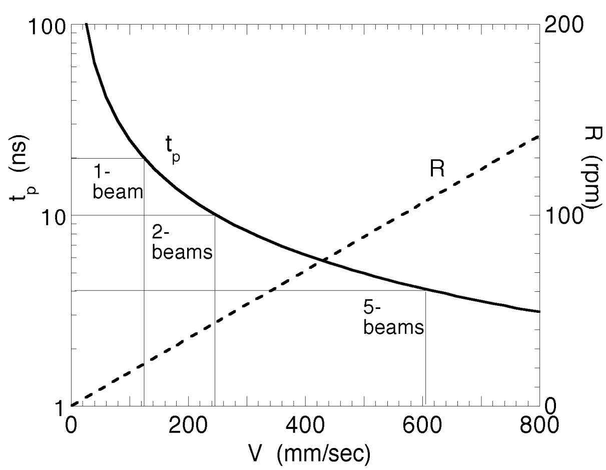

Figure 1. Specifications of a laser printer in the case of one beam scanning where the focal length of scanning lens is 460mm, the number of mirror facets is 8, and the dot density is 600dpi.

Figure 1 shows the plot of Eq. (1) and (2) where f= 460mm, N=8, D=23.6 dot/mm (i.e.600dpi). In the print speed greater than 240mm/sec, more than two beams would be required if the practical limit of the dot time is assumed to be 20ns.

Laser Printer Optics Using Optical Fiber Array

The laser printer optics using the optical fiber array device is shown in Fig. 2. The optical fiber array device is composed of plural diode laser modules and an optical fiber array part. In the diode laser module, a diode laser of a 640nm wavelength is coupled to a single-mode optical fiber. The optical fiber has a core diameter of 4μm and transmits a Gaussian beam of 5μm in diameter. The fibers from the modules are bundled in an array with a period of 150μm.

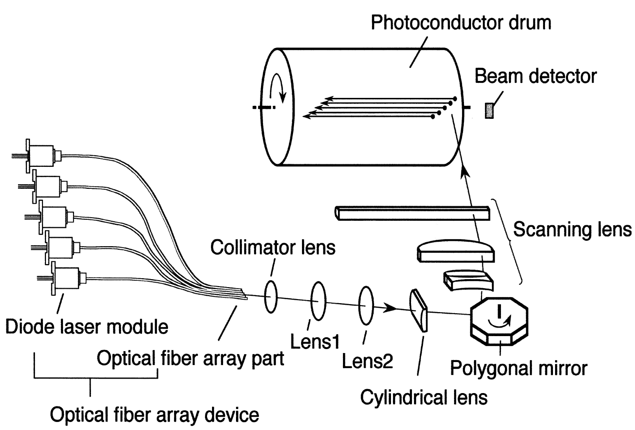

Figure 2. Laser printer optics using optical fiber array device.

The arrayed beams from the optical fiber array device are converted to parallel beams by a collimator lens. Two lenses with a telescopic arrangement expand the beam width and cause the multiple beams to cross at the polygonal mirror so that the mirror size of the polygonal mirror may not become larger than what is required for one beam. A cylindrical lens in front of the polygonal mirror is used for correcting pitch irregularities of scan lines caused by wobble of the polygonal mirror during rotation. The polygonal mirror deflects the incident multiple beams simultaneously and the scanning lens focuses the beams into arrayed spots on a photoconductor drum. The arrayed spots have a spacing 30 times larger than the spot diameter on the photoconductor drum. Therefore in order to obtain consecutive scan lines we adopted the slant scanning method where the arrayed spots are arranged in a slant angle to the scanning direction. The slant angle is adjusted by rotating a combined mount of the optical fiber array part and the coupling lens around the optical axis.

Optical Fiber Array Device

The optical structure of the diode laser module, which we call as LD module below, is shown in Fig.3 (a). A diode laser in the module has a wavelength of 640nm, and the beam spread angles of 8 degree in parallel and 31 degree in vertical to the radiant active layer at full width-half maximum. The beam from the diode laser is coupled to an optical fiber of a 4μm core and a 125μm clad in diameter by two lenses of numerical apertures of 0.45 and 0.24. The incident surface of the optical fiber is polished with an angle of 8 degree so that the reflected light may not return to the diode laser. The alignment tolerances of the fiber, ΔX, ΔZ, shown in Fig.3 (b) are calculated ±0.2μm and ±17μm respectively if the coupling efficiency to the optical fiber is tolerated to 20% down from the maximum. Therefore the optics of the module has to be set up precisely and stable even in ambient temperature change, especially in transverse directions. To achieve this, the optics in the module is set up in the mount of Invar material, which has a very low thermal expansion coefficient. And for two lenses we used bi-aspheric molded glass lenses because the aberrations are highly corrected, the sizes are small, and the thermal variations of optical characteristics are small. The fabricated light transmission efficiency from the diode laser to the fiber output end was 40%.

In the optical fiber array part, the bared fibers of a 125μm diameter were arranged in an array on V-shaped grooves which are made of anisotropic etching of silicon crystal with a period of 150μm, and bonded with UV cured resin. Finally, the end face of the array was polished and a glass plate was pasted on it to minimize influences of dust particles and the light power reflected back to the diode laser. Figure 4 shows a photograph of the end face of the arrayed fibers.

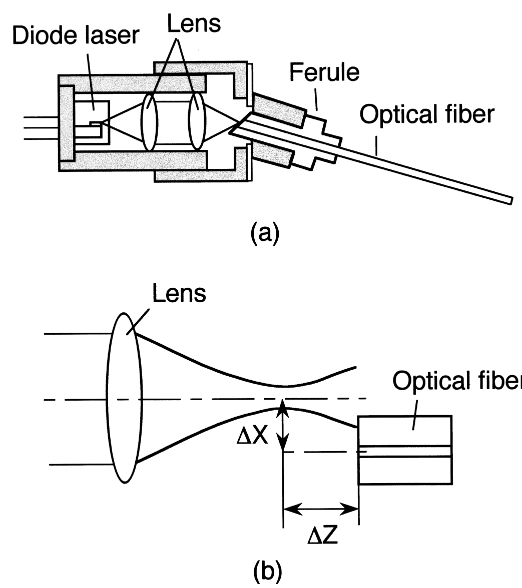

Figure 3. Structure of diode laser module: (a) structure of diode laser module, (b) situation of alignment errors.

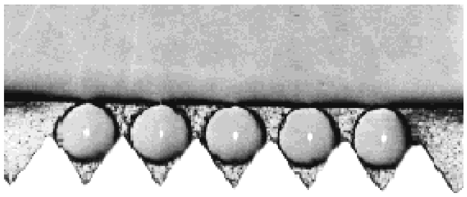

Figure 4. Photograph of the end face of the arrayed fiber.

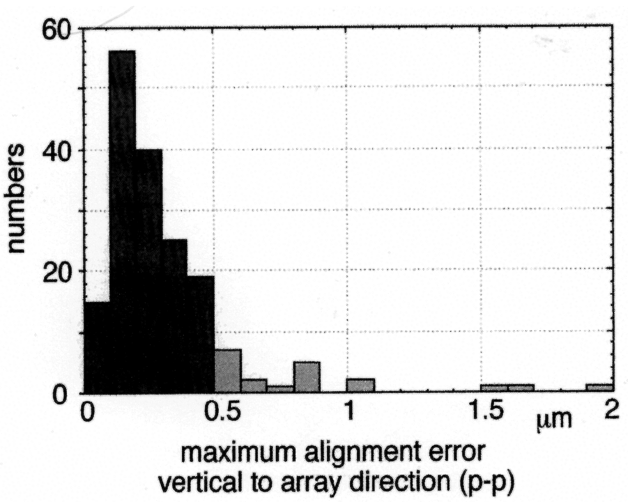

Figure 5. Maximum alignment errors in the optical fiber array parts. The alignment error is defined by the deviation from the ideal array line.

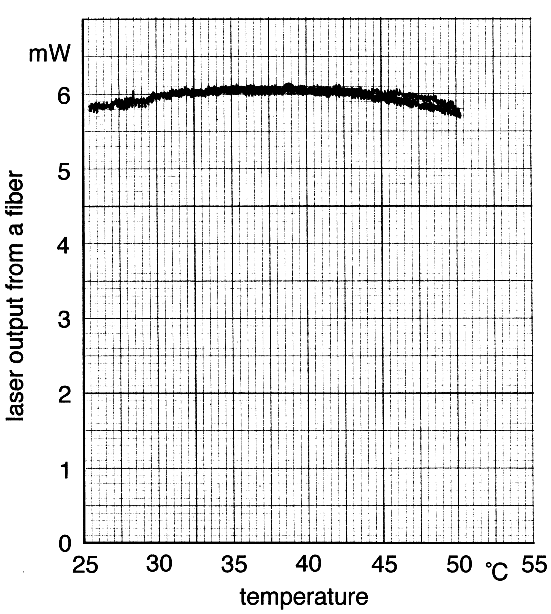

Figure 6. Output laser power variation due to ambient temperature change.

In the optical fiber array part, the alignment accuracy vertical to the array direction is important because it relates to the period irregularities of scan lines in the slant scanning method. The alignment error is partly caused by the structures of the optical fibers themselves, such as variations of outer diameters and eccentricities of the core regions. The catalogues of optical fibers only describe these fiber parameters roughly, but the actual measurements showed they were within allowable ranges in some maker's fibers. Figure 5 shows an experimental result about the alignment accuracy obtained by fabrication of the arrayed fibers. The alignment errors in most of arrayed fibers were suppressed below 0.4µm.

Figure 6 shows a typical output laser power variation of a fabricated fiber array device when the ambient temperature is changed. Although the laser power of the diode laser was held constant with an automatic power control circuit, slight light power variation of ±1.7% arose due to thermal deformations of the LD module. If more stabilized laser power were required, an external light power monitor and feedback control system would work effectively for it.

Scanning Lens

In the scanning optics utilizing multiple beams, we have to pay attention to the curve of scan lines because the multiple beams pass the scanning lens with different angles in sub-scanning direction (i.e. sagittal direction). The curve of scan lines would cause pitch irregularities of scan lines and deteriorate the print quality. Besides this, chromatic aberrations, especially lateral chromatic aberration, have to be considered because diode lasers usually have a wavelength variation of a few nano-meters. The lateral chromatic aberration would cause the different deviations of scan positions in the scan direction among multiple beams of different wavelengths.

Figure 7(a) and (b) show characteristics of a scanning lens that we used in the experiments. The magnification variation in sub-scan direction or sagittal direction is suppressed below 0.25% over the scanned area. This corresponds to the maximum deviation of scan lines among five beams of 0.2µm on the photoconductor drum. Concerning the lateral chromatic aberration, the scanning lens was achromatized by introducing glass materials of different wavelength dispersions. Due to this the maximum deviation of the scan position is suppressed to 2.7µm for a wavelength change of 1nm as shown in Fig. 7(b).

Print Experiments

Print experiments were carried out using the optics shown in Fig. 2. The simultaneous slant scanning of five beams from the optical fiber array device was adopted. The printer is for continuous form paper of 18" width, and has a print speed of 400mm/sec and a dot density of 600dpi. A photoconductor drum of As_2Se_3 material is used because it has high durability and sensitivity at the wavelength of diode lasers. A print example is shown in Fig. 8.

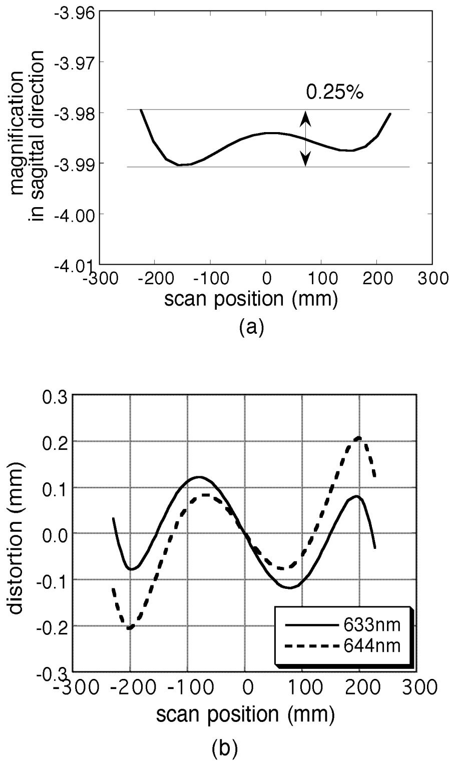

Figure 7. Characteristics of scanning lens: (a) magnification variation in sagittal direction, (b) Distortions in case of two wavelengths.

Conclusion

We have developed the optical fiber array device for laser printers utilizing multiple beam scanning. The optical fiber array device generates five beams which have a spot diameter of 5μm and a spacing of 150μm. The light transmission efficiency was 40% from the diode laser to the fiber output end. In the optical fiber array part, the alignment accuracy vertical to the array direction was suppressed below 0.4μm.

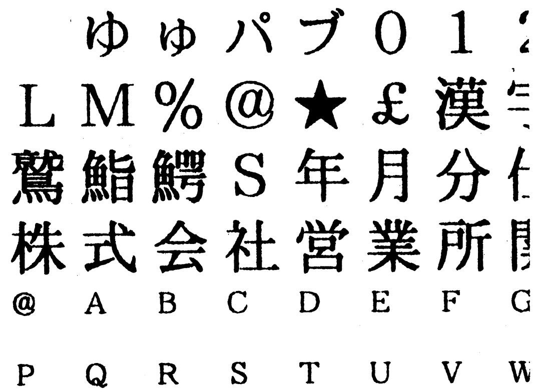

Figure 8. Enlarged photograph of print sample. The characters are printed with a period of 4.2mm.

In the design of scanning optics, the maximum deviation of scan lines caused by the curve of scan lines was suppressed below 0.2μm among five beams and the maximum deviation of the scan position was to 2.7μm for a wavelength change of 1nm due to the achromatized optics.

In print experiments, we demonstrated a high-performance printing with a print speed of 400mm/sec, a print dot density of 23.6dot/mm (i.e. 600dpi), and a print width of 431.8mm(i.e.17 in.).

References

1. K. Kataoka et.al.,*Appl. Opt*. 36., 6294-6307(1997).
2. K. Kataoka et.al., *Proc. SPIE* **3482**, 540-549 (1998).

Biography

Keiji Kataoka received his B.S. and M.S. degrees in Physics from Osaka University, Japan, in 1969 and 1971, respectively. From 1971 to 1990, he worked at C.R.L of Hitachi Co., Ltd. Since 1990 his work has focused on the development of optical systems and optical devices for laser printers at R&D Lab. in Hitachi Koki Co., Ltd. He is a member of the Japan Society of Applied Physics, the Optical Society of Japan, and the Imaging Society of Japan.