Multi-element laser-diode array for high-speed, and high-resolution laser printer

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1. Introduction

Advances in digital information systems are increasing the need for high-speed, high-resolution printing technology. The laser-beam modulation speed is one of the main limiting factors in increasing printing speed and resolution. Figure 1 shows the relationship between the printing speed and the 1-dot pulse width for 1- to 4-beam lasers. Increasing the number of laser beams and reducing the 1-dot pulse width are methods of increasing the printing speed. In present systems, the 1-dot pulse width is limited to about 20 ns by the driving speed of the laser diodes. This limits the printing speed of single-beam systems less than 50 pages per minute (ppm). By increasing the number of beams from one to four, a printing speed of up to 200 ppm can be obtained with the present 1-dot pulse width.

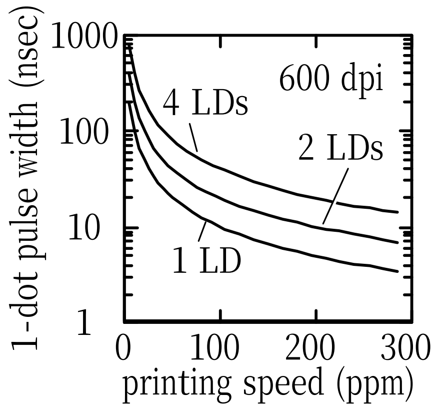

Fig. 1 Printing speed versus 1-dot pulse width.

The laser-diode array (LDA) which integrate multiple elements on a single laser diode-chip, is the simplest way to get multiple laser beams because if all the elements are placed with in a distance less than about 400 µm, the beams can be focused on a photoconductor drum with an accurate pitch using a single optical system.

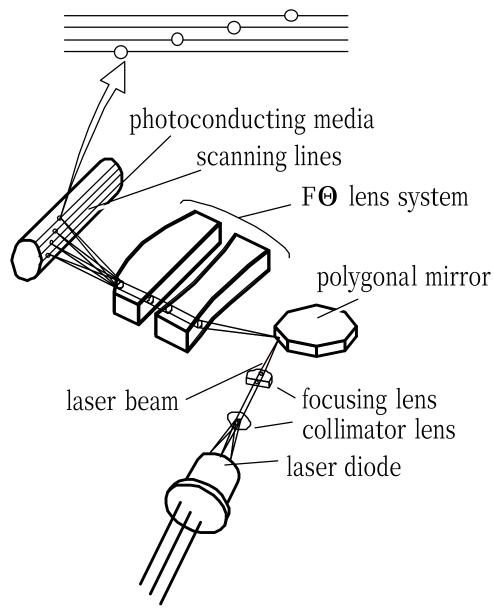

Fig. 2 Schematic of high-speed laser printer system.

However, integrating multiple elements on single chip causes problems with the output power stability, such as cross talk and droops caused by heat generation. These problems can be mitigated by using slant scanning [1], which reduces the spacing between the scanning lines without reducing the array-element spacing, as shown in Fig. 2. However, heat generation remains a problem because increasing the tilt angle makes it difficult to control the line spacing, as much as the limitation of the focal area. To obtain high-quality printed images, it is thus important to reduce the operating current and increase the thermal conductivity of laser chips.

2. Structure and fabrication of the laser diode

We fabricated a 680-nm LDA with four elements for use in laser printers. The active layer of the laser diode is a triple-quantum-well (TQW) structure consisting of GaInP well layers and two AlGaInP barrier layers. A ridged structure was formed by chemical etching in the upper p-type AlGaInP cladding layer, and selective growth of n-type GaAs was performed using an SiO2 mask, which was also used to chemically etch the ridged structure. Then, to obtain a low-resistance contact a p-type GaAs layer was grown after SiO2 film was removed.[2] The structure of the LDA is shown in Fig. 3.

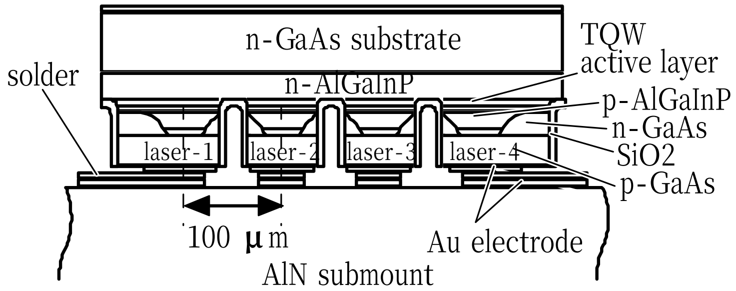

Fig. 3 Structure of laser-diode array.

A channel chemically etched into the n-GaAs layer isolates the array elements. To avoid thermal cross talk between the array elements and make laser printers easy to manufacture, we spaced the array elements at 100 μm.

The laser diodes are mounted on an AlN submount junction-side down. The submount has a Ti/Pt/Au electrode and PbSn solder pattern, as shown in Fig. 4. The arrangement of the submount, the laser chips, and the isolation channels was designed to avoid short-circuiting due to assenble aberration and movement of the solder in the conventional mechanical alignment and chip-cleaving techniques. None of the approximately 100 laser diodes we fabricated suffered from electrode short circuits.

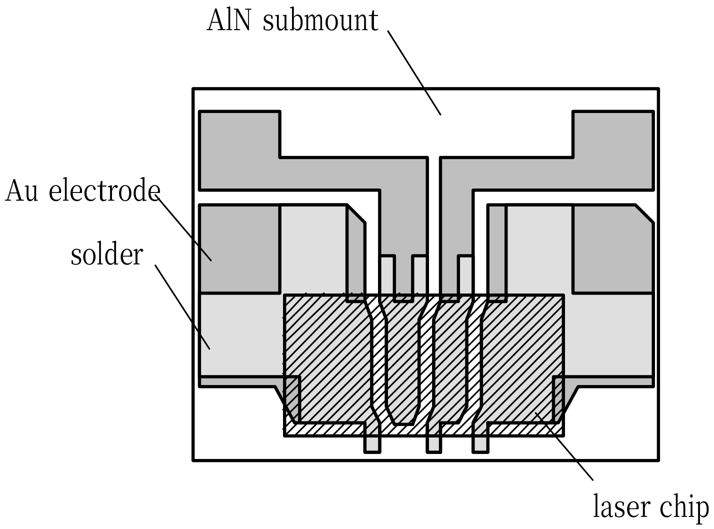

Fig. 4 Schematic of submount and bonded laser-diode chip.

3. Characteristics of the laser diode

The fabricated laser diodes were cleaved into a 300-μm bar and coated with 65%-refractivity SiO_2/SiN films on both cleaved facets. The average threshold current and slope efficiency of these laser diodes were 14.15 mA and 0.36 mW/mA, respectively. Figure 5 shows a typical light output power vs. current characteristics for a laser diode. In spite of the high refractivity coating on the laser facets, this laser diode could operate up to 26 mW. Although the maximum output power was limited by catastrophic facet damage. This output power is sufficient for a laser printer operating with an output power of up to 5 mW. The threshold current density was 943 A/cm2, which is comparable to that of the 680-nm high-power lasers used with magneto-optical disks. Because the threshold currents and threshold current densities of laser diodes are strongly related to heat generation and laser-diode lifetime [3], such a low threshold current would be beneficial for laser printers.

Because optical-pulse delays are longer when the operating power is low, we analyzed the optical-pulse response to the pulse current at an output power of 1 mW, which is the lowest power that can be used in laser printers. Figure 6 shows the optical output pulse generated by a 27-ns-pulse current. As shown in Fig. 6, the optical pulse was delayed by 2.5 ns and it had 1.5- and 2-ns transients at the start and end of the pulse, respectively.

Since the cut off frequency of buried ridge structure laser diodes is typically in the range of several hundred megahertz, the transients in the optical pulse can be explained based on the modulation frequency of the laser diode. Assuming that more than 90% of the power is needed to sufficiently control the printing dots, these results mean that these laser diodes can be used at 1-dot pulse intervals as short as 20 ns. Using this LDA, we can manufacture printers with a 200 ppm printing speed and a 600-dot-per-inch resolution (Fig. 1). If we reduce the device capacity to increase the cut-off frequency to more than 1 GHz, 1-dot pulse of less than 10 ns may be possible, printing speed of 400 ppm.

The cross talk between the array elements is shown in Fig. 7. One of the array elements (LD1) was operated as a continuous wave (CW), while the neighboring element (LD2) was operated at 50% duty with 2- s pulses. The operating power of each element was fixed at 1 mW. The power variation in the CW-operated element indicates the cross talk characteristics of the neighboring elements. As shown in Fig. 7, the thermal cross talk between array elements was less than 3%.

Figure 8 shows the droop characteristics of the 4-element laser diode. The output power of the array elements was fixed at 3 mA in CW operation. The four elements were then driven simultaneously with 200-μs pulses and the same peak currents. As shown in Fig. 8, the droop was less than 5% for all the tested elements.

4. Conclusion

We have developed a 680-nm-wavelength laser-diode array for high-speed, high-resolution laser printers. Reproducible junction-down bonding was performed by using a patterned AlN submount. The averaged threshold current of the laser diodes was 14.15 mA. The output power deviation due to heat generation, such as droop and thermal cross talk, was less than 5%.

[1] K. Kataoka et al., Appl. Opt. 36 6294 (1997)
[2] S. Nakatsuka et al., Jpn. J. Appl. Phys. 25 L498P (1986)
[3] S. Nakatsuka et al., Jpn. J. Appl. Phys. 30 493P (1991)

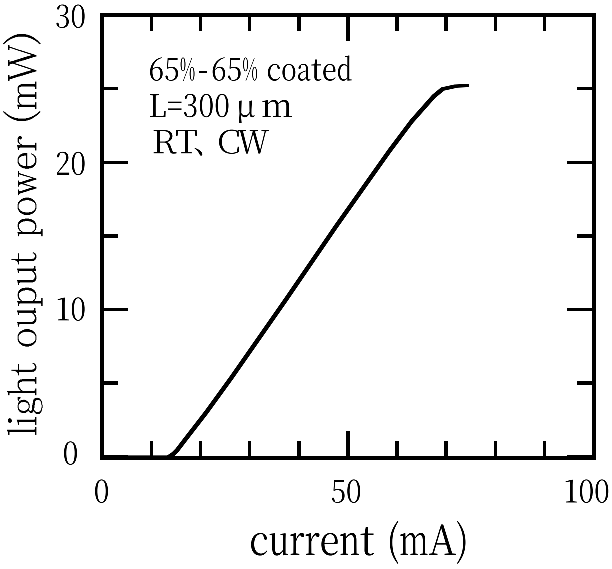

Fig. 5 Light output power vs. current.

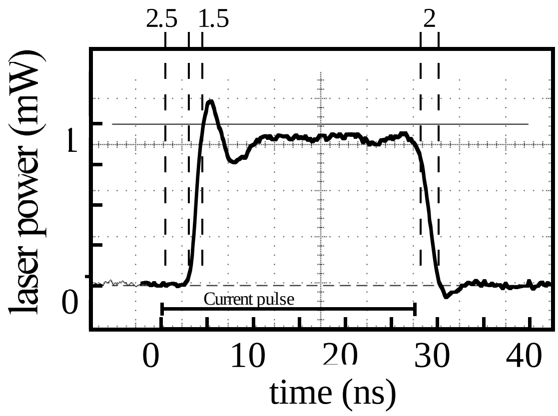

Fig. 6 Pulse operation of laser-diode array.

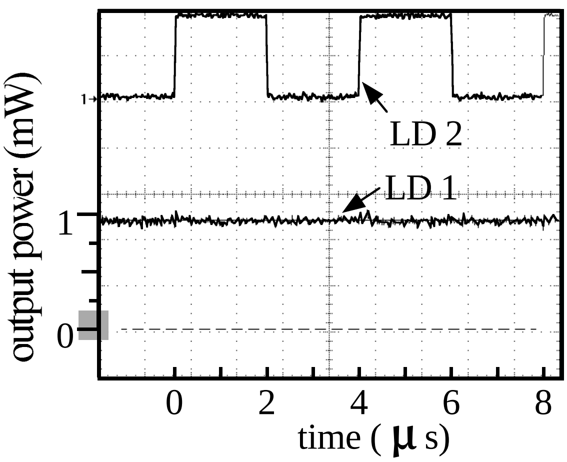

Fig .7 Cross talk in laser-diode array.

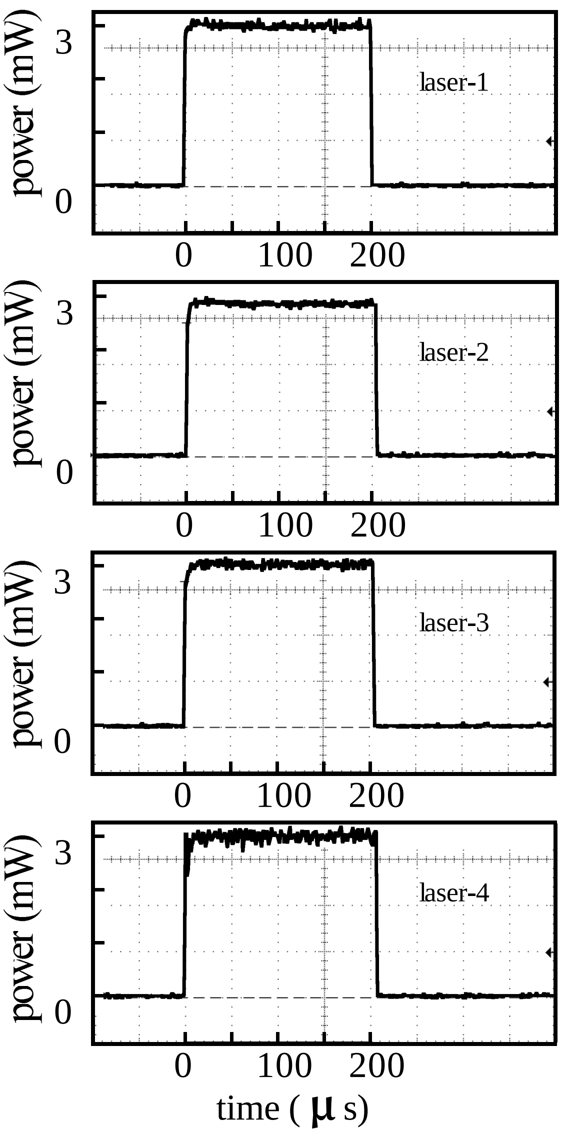

Fig. 8 Droop in 4-element laser-diode array.