Wavefront Correction of Violet Laser Diode and Color Micro-marking on Plastic Surface

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The laser diode (LD) is a light source characterized by small size, light weight and high performance. Osaka University has been actively conducting research and development to precisely collect and directly process infrared LD light. Violet laser diode (VLD) light can be focused in a smaller spot because its wavelength is shorter than that of infrared LD light.
We report herein the development of a unit to precisely focus VLD light and the use of this unit, together with dyes and pigments, to create color micro-markings on a plastic plate. Concretely, we show corrections made to ensure that the single-mode VLD light can be changed to collimated light via a collimator lens and its wavefront aberration can be measured for precise light collection. The corrected light was precisely focused and used to irradiate a dye or pigment that was applied to a plastic surface. This resulted in markings on the part exposed to irradiation despite the fact that no absorption agent was used. We also achieved microscopic markings on a polyester (PET) plate by optimizing irradiation conditions, as well as 100-µm and 200-µm color markings.

Key Words: Violet Laser Diode, Color Micro-Marking, Wavefront Correction

1. Introduction

To promote the use of laser in the textile industry, we have developed a special fiber for laser marking and a microscopic marking technology to mark the fiber, and are actively conducting research and development to realize the practical use of this marking technology. These new developments have contributed to the improvement of YAG laser marking technology, which is now capable of clearly writing 0.06 mm letters on 0.1 mm monofilaments[1)]. However, there is a strong demand for color marking on a white background to broaden the range of applications because the current technology allows only white letters to be written on a black background, namely, it allows only white-on-black marking.

On the other hand, laser applications may become even more popular if laser diodes (LDs), which are characterized by high performance, small size and light weight[2)], are available as light source. However, multi-mode LDs cannot concentrate light to a single spot while single-mode LDs cannot be used for direct processing because they cannot ensure high output despite the ability to concentrate light. Taking these issues into consideration, we studied ways to precisely collect violet LD (VLD) light (wavelength: 405 nm) by means of wavefront correction technology[3)] and used it as a light source for direct processing with LD. We found that microscopic markings can be produced from three primary colors (blue, red and yellow) even in the absence of an absorption agent. In addition, microscopic color marking of 100 µm font size is possible on a monofilament even though the thickness is 300 µm.

2. Experimental

2.1 VLD Wavefront Correction

To realize wavefront correction of VLD light, we selected an approach by which VLD light is changed to collimated light via a collimator lens and the resulting light is collected via a focusing lens. Figure 1 depicts the positional relationship among the VLD, the collimator lens and the wavefront correction plate.

The VLD used for this experiment is a can-type package with an output of 60 mW and a wavelength of 405 nm. The

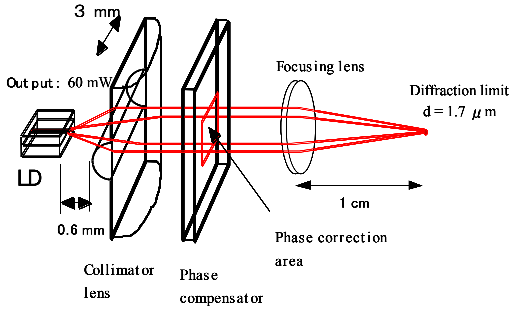

Fig.1 Optical layout of VLD unit and focusing lens

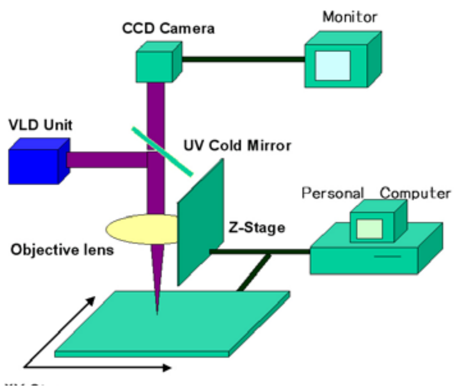

Fig.2 System configuration.

VLD and the collimator are combined to obtain laser as collimated light. A resin correction plate is set at the output end of this unit for correction. Light going out from this unit is measured with a Shack-Hartmann wavefront sensor to adjust LD position and angle in a way that the wavefront aberration of output light is minimized[4].

Next, wavefront aberration of output light is corrected by laser ablation shaping. A unit consisting of the VLD, the collimator lens and the correction plate is fixed on an XY stage and ArF laser light is irradiated in parallel with wavefront measurement[5]. Wavefront control is accomplished as follows: the amount of resin to be corrected or removed is calculated from the wavefront information collected by the Shack-Hartmann wavefront sensor and the number of required shots is calculated from the ablation rate for irradiation map creation to ensure that laser irradiation occurs sequentially in accordance with the created map[6].

2.2 System Configuration

We used the wavefront-corrected VLD unit as light source to configure the experimental system shown in Fig. 2. This system has a feature for reflecting light outgoing from the VLD unit to the lower side via a UV cold mirror and collecting it on the surface of a processing object via a collecting lens. We employed this system to observe the state of processing by means of a CCD camera. This system is effective for specimens having uneven surfaces, such as fiber, because auto focus is possible during laser irradiation. This system also shows much promise for marking microscopic areas because it has easy-to-use features, such as material surface observation and auto focus.

Table 1 Disperse dyes used in experiment.

Color	
Blue	Dianix Blue S-BG (DyStar)
Red	Dianix Red A-CE (DyStar)
Yellow	Dianix Yellow GFS (DyStar)
Fluorescent	UNITEX ERN-250*

*Chiba Specialty Chemicals

Table 2 Pigments used in experiment.

Color	
Blue	HICOLOR BLUE NB*
Red	HICOLOR PINK NG*
Yellow	HICOLOR YELLOW NG*

*HAYASHI-KAGAKU-KOUGYO

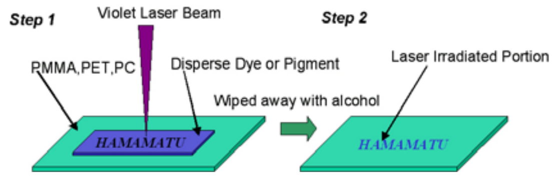

Fig.3 Processing of color marking on plastic surface.

2.3 Disperse Dyes and Pigments

Table 1 shows the disperse dyes and Table 2, the pigments used. The disperse dyes (powder) and pigments (liquid) were evenly mixed at concentrations of 10% and 20%, respectively, with emulsion print paste. This color paste was thinly applied to plastic plate material, such as polyester (PET), polycarbonate (PC) and acrylic (PMMA) as shown in Fig.2, and then dried. After completing laser irradiation, unfixed dyes and pigments were wiped off with an alcohol-soaked cloth.

2.4 Miniaturized Letters

Although micro-marking with a conventional YAG laser has enabled printing of white letters on a black background, there is an increasing demand for color marking on white strings because it covers a broader range of applications. To meet this demand, we conducted miniaturization tests using dyes and pigments of three primary colors, which were used for adhesion tests on PET plate materials. We designed an experimental system that uses the VLD unit as light source to study the possibility of micro-marking. In this experiment, we used burn-paper to confirm that 100 μm letters are written clearly. Next, we thinly applied color paste prepared in the same way as that described in section 2.3 to a PET plate material and irradiated the plate with VLD light after confirming that the paste had dried. In addition, we evenly arranged PET monofilaments of approximately 10 cm in size on a board art, applied color paste thinly on the monofilaments, and irradiated the monofilaments with VLD light to confirm that miniaturized letters are written.

3. Results and Discussion

3.1 Wavefront Correction Technology

We corrected the wavefront aberration of VLD light by laser ablation shaping after incorporating the VLD and the collimator lens into an aluminum tool and adjusting its position. Figure 4 shows the state of a wavefront before and after correction. We found that the wavefront after correction has reduced aberration in comparison with that prior to correction. Although the ideal wavefront aberration is 0.25λ, we conducted the following processing experiment using existing light (0.75λ). Figure 5 shows the external view of the wavefront-corrected VLD unit. Considering that this unit is equal to the thumb (approximate dimensions: 2 x 2 x 3 cm) in size and can be used with a smaller and less expensive laser light source than a YAG laser light source, we have successfully fabricated a unit capable of making microscopic markings by combining this light source and the XY stage.

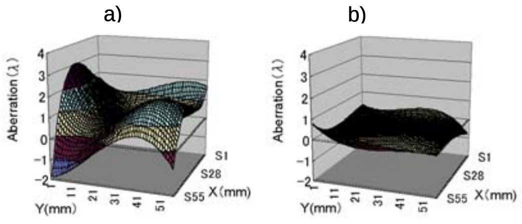

Fig.6 Wavefront of output beam.

(a) Before Correction. (b) After Correction.

3.2 Adhesion of Disperse Dyes and Pigments

Although PET filaments are generally dyed with disperse dyes that show good compatibility with the filaments, color fastness to light of pigments is usually higher than that of disperse dyes. For this reason, pigments are said to be more desirable for use with plastics than disperse dyes. As a prior step to conducting microscopic color marking experiments on PET filaments, we performed color macro marking experiments on a PET plate surface. Figure 6 shows marking results obtained by using a blue disperse dye and a pigment. Figure 6(a) shows a planar photograph of a PET plate marked with the disperse dye and Fig. 6(b), its cross-sectional image. Figure 6(c) shows a planar photograph of the plate marked with the pigment and Fig. 6(d), its cross-sectional image. The cross-sectional images indicate that the dye and the pigment have infiltrated the PET plate, resulting in marking. When the disperse dye having good compatibility with the PET plate is a thermo-sol dye, it infiltrates the non-crystalline part of the filament when heated at a temperature of 170℃ to 180℃. On the other hand, a pigment having poor compatibility with the PET plate does not dye the plate even when heated. According to the general dye principle, the reason why pigments adhere even though they are not dyes is that the pigments absorb laser energy at the center of the marking to generate heat that melts the base material, and the melted material mixes with the pigments to result in a marking. Furthermore, a comparison of Fig. 6(b) and Fig. 6(d) revealed that the width of the line using the disperse dye is larger than that using the pigment. The reason for this is assumed to be that the PET material is melted by the power of the laser beam and both the dye and pigment are mixed with the PET material, but in the region in which the temperature is not raised high enough to melt the material, the PET material is dyed by the affinity which the disperse dye has, and at the center portion where the energy density is high a part of the disperse dye may be sublimated and the dye concentration may be diluted. In conclusion, we found that determining the optimal conditions for dyeing is necessary to devise a marking method that does not require melting the surface of the PET material.

3.3 Microscopic Marking

Not only have we developed a method for making 0.06 mm micro markings on 0.1 mm filaments with the YAG laser to counter imitation, we have also continued our efforts to make this technology practical. Because the YAG laser allows for only white-on-black marking, there is a demand for color marking on a white background to extend the range of applications. We legibly marked 200 μm letters using three primary colors (red, blue and yellow) on a PET plate surface by changing the irradiation method from continuous laser light (CW) to pulsed laser light (cyclic frequency: 30 Hz, duty ratio 1/6) and reducing conventional dye thickness to approximately half. Figure 7 shows how 100 μm letters written legibly on

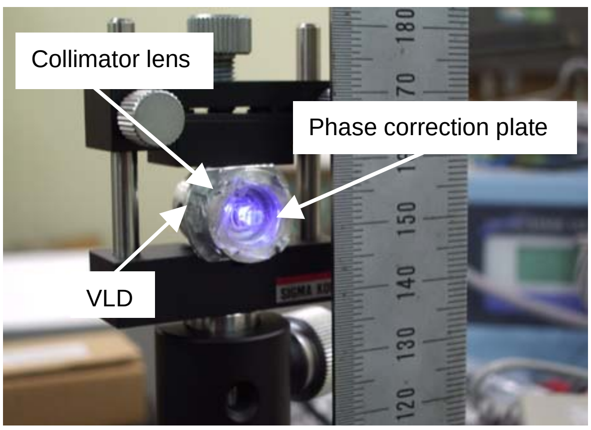

Fig.5 Photograph of VLD-lens unit.

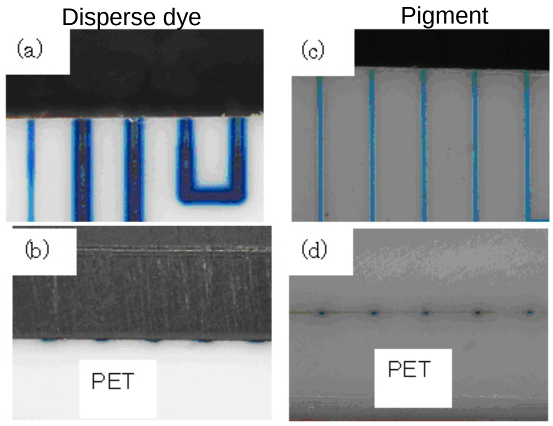

Fig.6 Photograph of color marking (planar photo and cross-sectional photo).

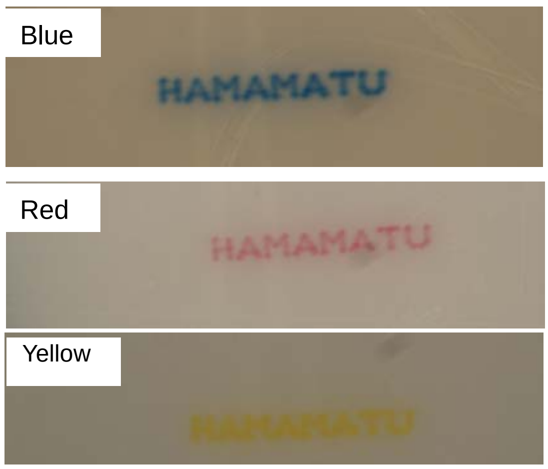

Fig.7 Color-micro-marking of 100 μ m font size on PET plate.

burn paper can be marked on the PET plate. We found that the line thickness of each letter on the PET plate is slightly larger than that on burn paper, and more legible marking can be achieved on the PET plate than on barn paper. We also found that yellow marking is less legible than red and blue markings because violet light is more strongly absorbed in the former marking. However, this can be improved by optimizing irradiation conditions, such as light power and pulse conditions. Such letters cannot be recognized by the naked eye. Even such a small letter becomes available as a marking for traceability if it can be marked on plastic products. We believe that this approach would benefit enterprises that manufacture products for distribution overseas and want to ensure traceability of their products.

We attempted to mark 200 μm and 100 μm letters on a 300 μm filament under the same conditions as those used for marking 100 μm letters on the PET plate. Microscopic color marking of 100 μm font size was realized on a monofilament shown in Fig.8 as even though the thickness of 300 μm is slightly large.

3.4 Application to macro marking and micro marking

Markings on electronic or optical components are classified into two types. One is macro marking, which can be recognized by the naked eye, and the other is micro marking, which cannot be recognized by the naked eye. Although macro markings are effective for applications requiring user confirmation, there are many markings that require no user confirmation. Typical are markings to protect brand-name goods against imitations and management markings to ensure traceability in the production process. As for traceable markings, the date manufactured, manufacturing line, the lot number, ID number, materials used and treatment process parameters are written in a predetermined area of each component so that if a fault occurs, the corresponding information can be used to locate the reason. For this reason, the above information is recorded in dots (size: a few μm) in an area that cannot be deleted by the user and is used for process management or recovery from faults. This information needs to be recorded in the manufacturing line (production site) or immediately after the process, and laser markers are required depending on the number of manufacturing processes or lines. However, conventional laser markers are expensive and it is usually difficult to procure the desired number of markers. If LD were available as light source, marking system would cost less and procurement of system would be facilitated. We believe that traceable marking is a fundamental technology for the development of high value-added industries in Japan.

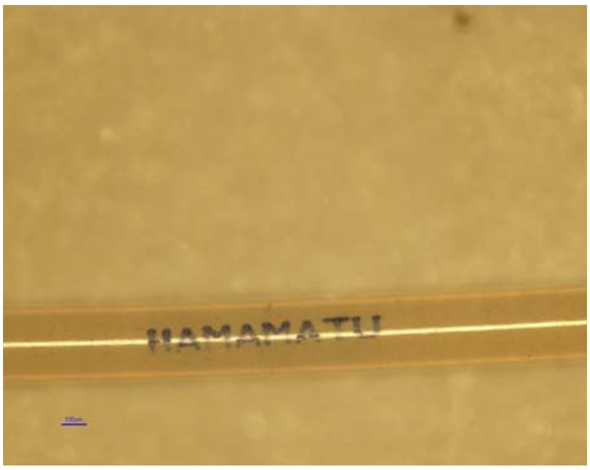

Fig.8 Color-micro-marking of 100 μm font size on monofilament.

3. Conclusion

We have fabricated a small LD unit whose size equals that of a thumb by modifying the wavefront aberration of VLD light through laser ablation shaping after incorporating a VLD and a collimator lens into an aluminum tool and adjusting the position of the tool. Using this unit as light source, we easily accomplished adhesion of a dye and a pigment on the surface of a PET plate. In addition, we confirmed that the combination of the LD unit and the XY stage worked successfully as a simplified microscopic marking unit, making 100 μm microscopic color markings clearly on plastic surfaces. We found that thermal damage of fiber surface can be reduced by optimizing process conditions, such as irradiation of pulsed laser light and thinning of dyes to be applied. Consequently, use of a disperse dye enabled 100 μm microscopic color markings of PET fiber surface. This string of letters, which cannot be recognized by the naked eye, can be used as a concealed mark.

Once wavefront correction is initially made in the prototype fabricated this time, adjustment is hardly necessary and the prototype would serve as a simple, robust unit. This unit is capable of making markings immediately after a microscopic part production process or a semiconductor device treatment process. In addition, a simple processing system can be configured because total unit weight is low and target processing position can be directly moved without having to transmit laser light via a fiber or a galvanomirror.

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