Time-Resolved Microscopy of the Surface of Ink Layer in Laser Dye Thermal Transfer

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Abstract

In laser thermal transfer printing using a dye sublimation type medium, a high definition and continuous tone image can be easily obtained because a laser light focuses on a small spot, and its heat energy can be controlled by pulse width modulation. On the other hand, the physical phenomena occurring at an ink donor sheet during or just after the laser heating are unknown. In this report, the surface of the ink layer consisting of sublimation color dye heated by microseconds laser pulse irradiation was observed using time-resolved optical microscopy. The ink layer was deformed during and after laser pulse irradiation. The diameter of the hole formed by laser heating at the ink layer increased rapidly after the threshold time during the laser pulse, and its increasing rate became slowly according as approach to the pulse end. The Gaussian distribution of laser light intensity and the diffusion of the heat energy by thermal conduction seem to be important factors to explain the thermal response of the ink layer in microseconds order.

Introduction

In a dye sublimation transfer printing by laser heating, it is possible to obtain a continuous tone image with a high resolution of more than 2,540dpi easily because a focused laser light is used as heat source and transfer amount of dye can be controlled by changing the energy of laser light.[1] In the previous report, we have reported the dye transfer mechanism from ink donor layer of double layered ink donor sheet to understand the tone reproduction of transferred image.[2-4] However, it is necessary for essential understanding of the dye transfer mechanism to observe the surface of the ink layer during laser pulse irradiation. In this report, we have the experimental setup for time-resolved optical microscopy which can observe a response of the imaging medium for laser irradiation by setting the imaging optical head under the sample stage of the optical microscope and introducing a dye laser as an illumination source. The time-resolved microscopy is demonstrated using a double layered sample similar to the ink donor sheet, and the thermal response of the ink layer is discussed.

Experimental

Experimental apparatus

The experimental setup using the optical microscope is shown in Figure 1. A distance between the sample and the optical head is variable as the optical head under the sample stage is set on the z-axis stage, and its distance can be read relatively with a micrometer. Therefore, an optical spot size on the imaging medium can be changed by a movement of the z-axis stage. A wavelength of the laser diode is 830nm, and a maximum laser power on the imaging medium is 70mW.

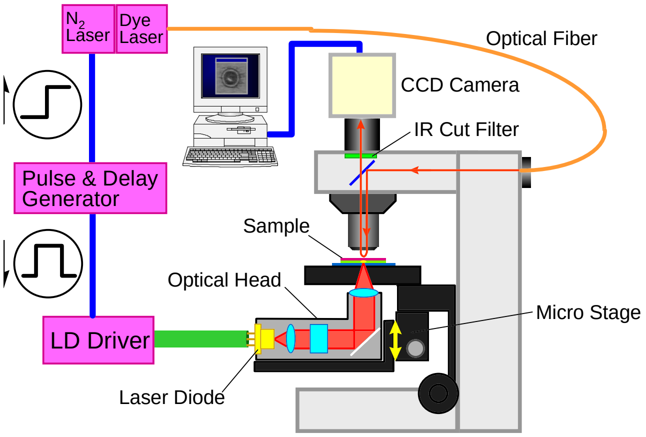

Figure 1. Experimental setup for time-resolved microscopy.

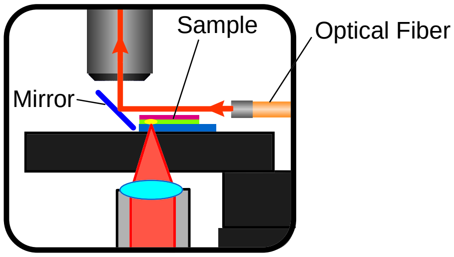

Figure 2. Setup for side-view observation.

Time-resolved microscopy was made as follows. An imaging laser irradiation is started by sending an imaging pulse from a pulse generator to a LD driver. After a certain delay time, an illumination pulse is sent to a N_2 pumped dye laser (600nm, 3ns), and then a surface of the sample is illuminated instantaneously with 3ns dye laser pulse. An observation image was shot by a CCD camera and captured into a personal computer. A series of time-resolved images was obtained by repeating the observations with changing the delay time.

As shown in Figure 1, the surface of the sample was usually observed from above. We also observed a side-view of the sample by placing a mirror on the stage and illuminating a side of the sample as shown in Figure 2.

Preparation of Sample

A construction of double layered sample used for the time-resolved microscopy is shown in Figure 3. A mixture of IR absorbing dye and binder polymer was coated onto a transparent acrylic plate by a spin coating. In the next, a magenta sublimation dye was coated onto the laser light absorbing layer by vacuum evaporation. The sample is similar to a double layered ink donor sheet. The thicknesses of the laser light absorbing layer and the ink layer are 1.8μm and 1.5μm, respectively.

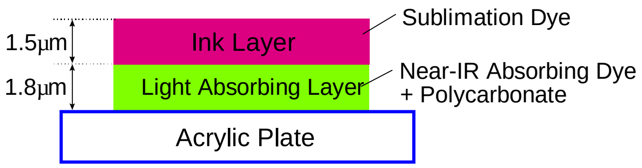

Figure 3. The construction of double layered sample.

Results and Discussion

Time-Resolved Microscopy

Figure 4 shows the top view photographs of the ink layer in series by the time-resolved microscopy during and after laser pulse irradiation. The laser power and the pulse width were 60mW and 200μs, respectively. The optical spot size was 25μm in diameter. At 12μs duration, the central region of the ink surface corresponding to the beam center begins to rise up. It is considered that this physical change of the ink layer is caused by an expansion of IR absorbing layer and a melting of magenta dye. Then the region of rising and melting continues to extend circularly. At 36μs duration, the center of the rising region begins to sink and the rim is formed. The formation of complete hole is observed at 75μs duration. The diameters of the rim and the hole increase until the end of the laser pulse of 200μs.

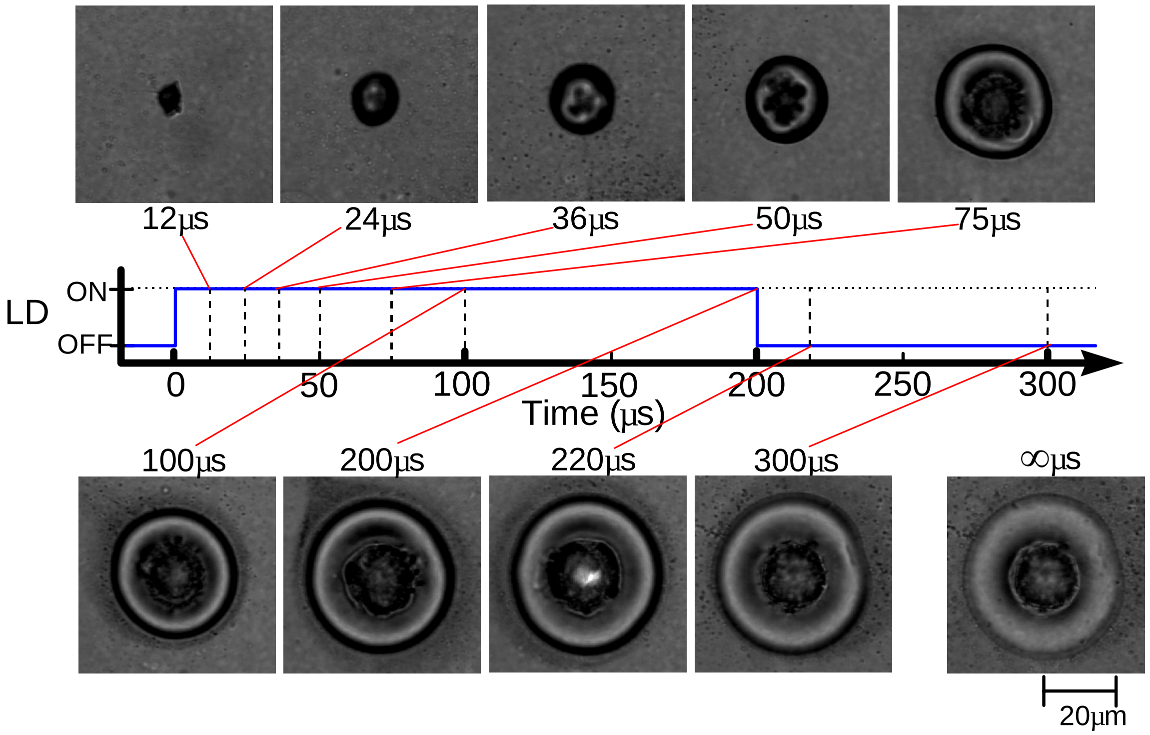

Figure 4. A series of time-resolved microphotographs of ink surface. Laser power and spot size are 60mW and 25μm, respectively.

Because the surface of the acrylic plate is exposed to air at the inside region of the hole, the hole is also formed through the laser light absorbing layer. After a few seconds of laser pulse irradiation, the melting and rising dye is changed to solid by cooling, and the deformation with the rim and the hole remained permanently.

Radiuses of Rim and Hole

The rim radius which is the distance between the outside of rim and center of hole, and the hole radius during laser pulse irradiation were measured using the time-resolved images. Figures 6 and 7 show the timely variation of the rim and the hole radius, respectively. The solid line in the figures is fitted to the data using Equation 1. Since the energy density of the laser spot has a Gaussian spatial distribution (Figure 5), the rim radius or the hole radius $r(t)$ at the laser pulse duration time t(μs) is given by

$$r(t) = \sqrt{\frac{W^2}{2}\ln\left(\frac{2\times10^{-3}\cdot P\cdot t}{J_{th}\cdot\pi W^2}\right)} \qquad (1)$$

where W(μm) is the radius of the laser spot, and P(mW) is the laser power.[5] J_{th} is the threshold energy density in order to form the rim or the hole (Figure 5). In Figures 6 and 7, the standing up point of the smooth curve corresponds to that of the plotted data by determining $J_{th}=3.0\times10^3 \text{J/m}^2$ and $7.2\times10^3 \text{J/m}^2$, respectively.

The rim radius increases rapidly after the threshold value of J_{th} as is shown in Figure 6. However, the plots are larger than the predicted curve in the latter half of the laser pulse. One of the reasons of this failure is due to the diffusion of the energy distribution by a thermal conduction at the latter half. The factor of the thermal conduction is not included in Equation 1. The effect of the thermal conduction on the melting of dye in the time scale of microsecond order will be considered. Another reason is that the melting dye is moved around by a change of the surface tension and a high pressure caused by the hole formation.

Figure 7 shows good fitting except for a little failure at the latter half of the pulse. This agreement is caused by an ablation of the laser light absorbing layer and a balance of the thermal conduction to the acrylic plate and the thermal diffusion to the plane of ink layer. As described above, we must consider the effect of thermal conduction. However, in both of Figures 6 and 7, the fundamental characteristics such as the rapid standing up and the slow increasing of hole radius at the latter half of the pulse agree with Equation 1, and so it is confirmed that the thermal response of the imaging medium corresponds to the change of the energy density in microsecond order.

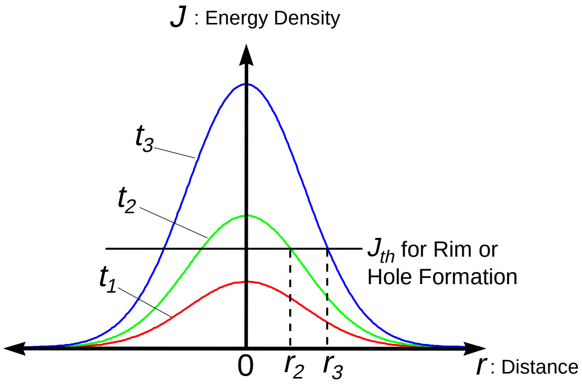

Figure 5. Distribution of energy density of laser spot.

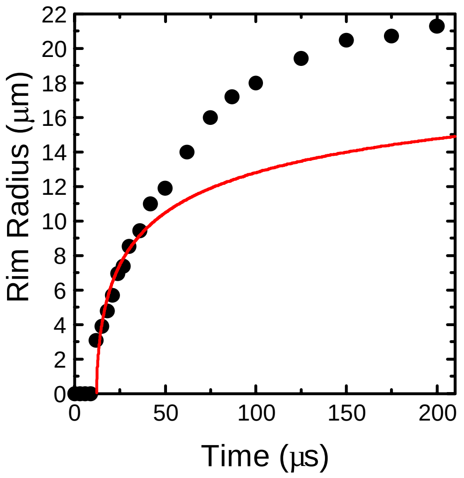

Figure 6. Plots of rim radius versus irradiation time. The smooth curve is fitted to the data using Equation 1.

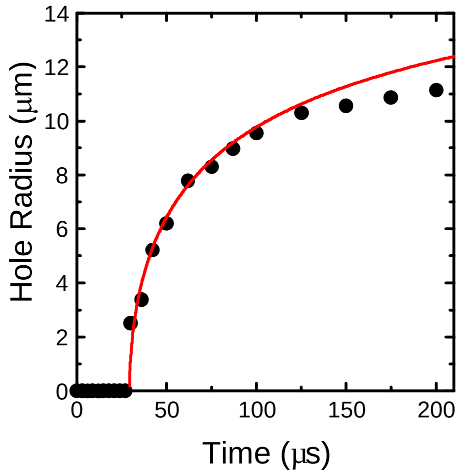

Figure 7. Plots of hole radius versus irradiation time. The smooth curve is fitted to the data using Equation 1.

Side-View Observation

Figure 8 shows the time-resolved images of the side-view of the ink surface during and after laser pulse irradiation. At 24µs duration, the surface of the ink layer rises up largely. The height of the rising is 4.5µm, and a sum of the thicknesses of the ink layer and the laser light absorbing layer swells by a factor of 2.3. While the region of the rising then continues to increase, the height decreases slightly and is 3.0µm at the end of the laser pulse of 200µs. After a cooling, the permanent rim with the height of 2.0µm remains around the hole. The large rising at the first half of the pulse is owing to the effective thermal energy with little loss until the hole formation at the beam center. The laser dye thermal transfer printing is capable of a stable imaging due to the rising of the ink surface observed here, though there is usually no pressure on the ink and receiving sheets.

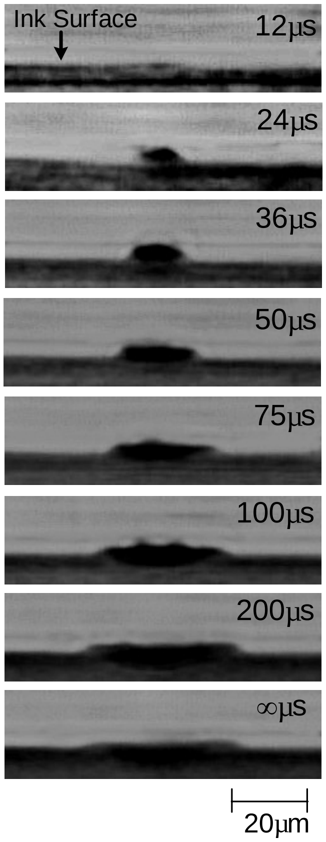

Figure 8. A series of time-resolved microphotographs of the side-view of sample. Laser power and spot size are 60mW and 25µm, respectively.

Conclusion

The setup for the time-resolved microscopy was constructed in order to investigate the dye thermal transfer mechanism by laser heating in the laser dye transfer printing. The experimental results using the double layered sample similar to the ink sheet indicate that the deformation and hole formation in the imaging medium occur during the laser irradiation, and these transient responses correspond to the change of the distribution of energy density.

References

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Biography

Masaru Kinoshita received his B.S. and M.S. degrees in image science from Chiba University in 1996 and 1998, respectively. He is a student in a doctor course in Graduate School of Science and Technology, Chiba University. His research interest is in Laser Thermal Transfer Technology. He is a member of the IS&T.