

Light-Heat Conversion Material for Dye Thermal Transfer by Laser Heating

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Abstract

In a laser thermal transfer printing using dye sublimation type medium, a high definition and continuous tone image can be obtained easily because a laser light is focused to small spot and heat energy can be controlled by the pulse width modulation of laser light. The ink donor sheet is composed by the laser light absorbing layer and the ink donor layer. We have investigated light-heat conversion efficiency for several IR light absorbing materials in the ink donor sheets. Carbon black, metal-phthalocyanine pigment and dye, metal complex organic compound, and cyanine dye were used as light-heat conversion materials. As experimental results of dye transfer from ink donor layer to receiving sheet by laser heating, each sample exhibits different dye transfer characteristics according to kind of light-heat conversion materials. By the measurement of absorption spectra of laser light absorbing layers after laser heating, it became clear that the phenomena such as the decomposition reaction and the crystal phase transformation of light-heat conversion materials were caused by laser heating. We have concluded that it is necessary for a high heat generation efficiency to have no change of IR light absorption by laser heating.

Introduction

In a dye sublimation transfer printing by laser heating, it is possible to obtain a high definition and continuous tone image 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. A double layered ink donor sheet for laser dye thermal transfer printing is composed of a laser light absorbing layer that converts laser light into heat, and an ink donor layer that transfers dye to a receiving sheet.[1] In the previous paper, we studied the dye transfer mechanism from ink donor layer of double layered ink donor sheet.[2,3] In this report, we focus on the laser light absorbing layer of double layered ink donor sheet. Converting the light energy of laser light into the heat energy is requested to the laser light absorbing layer. In order to compare light-heat conversion efficiency for several IR light absorbing materials, we have discussed tone reproduction curves depending on changes of the light-heat conversion material in the laser light absorbing layer of the ink donor sheet. Absorption spectra of laser light absorbing layers before and after laser heating were measured because there were possibilities that physical properties of light-heat conversion materials were changed by laser heating under a condition of high exposure energy. Further, in order to clarify the difference of heat generation efficiency for the changes of the energy distribution of laser light spot among each light-heat conversion material, spot size dependences of optical density were measured.

Experimental

Principle of Laser Dye Thermal Transfer Printing

The principle of laser dye thermal transfer printing is shown in Figure 1. The ink donor sheet is composed of the laser light absorbing layer and color ink layer. The laser light absorbing layer is exposed to the laser light that is focused by a optical lens, and then the laser light energy is converted into heat energy and heats color dye ink layer. By this energy conversion process, a sublimation dye of ink layer is transferred to the receiving sheet, and dye image are formed on the receiving sheet.

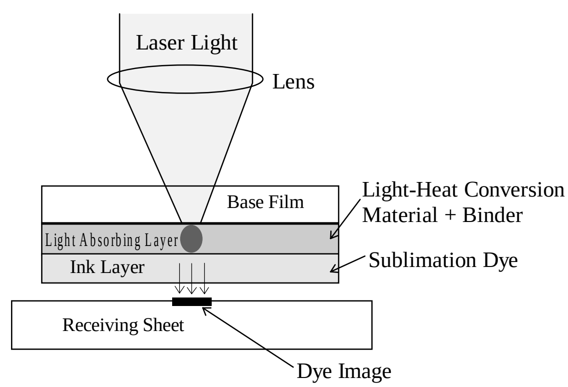


Figure 1. The principle of laser dye thermal transfer printing.

Preparation of Ink Sheet

Carbon black, titanyl phthalocyanine pigment (TiOPc), and three kinds of near-IR absorbing dyes: metal complex organic compound (Mitsui Chemical Co., Ltd., PA-1006), cyanine dye (Nippon Kankoh-Shikiso Kenkyusho Co., Ltd., NK-2204) and vanadyl phthalocyanine dye (VOPc(S-Naph)$_{16}$, Yamamoto Chemicals, Inc.), were used as light-heat conversion materials. These materials have a good optical absorption in the wavelength of laser light (825 nm).

Polycarbonate polymer (PC, Teijin Kasei Co., Ltd., Panlite K1300) was used as the binder polymer. The pigment was dispersed using an ultrasonic dispersion technique and near-IR dye was dissolved in PC polymer. The emulsion or solution was coated on the transparent polymer film by a wire bar coating. The construction of laser light absorbing layers is shown in Table 1.

We have evaluated the laser light absorbing layers based on the absorbance at the wavelength of laser light, and considered that higher absorbance at 825 nm showed higher heat generation. However, in case of comparing among different materials, the heat generation isn't always equal even if measured absorbance is equal. Therefore, we have prepared laser light absorbing layers to have an almost similar absorbance and thickness by adjusting the mixture ratio of light-heat conversion materials to PC polymer in order to compare laser light absorbing layers under the same condition apparently (Table 1).

A magenta sublimation dye was coated as an ink donor layer on the laser light absorbing layers by vacuum evaporation. The thickness of ink donor layer is 1.5 μm.

Table 1. The construction of laser light absorbing layers.

Mixture Ratio to Binder	Absorbance (825 nm)	Thickness
Carbon Black : PC = 1 : 4 wt.	1.14	1.28 μm
TiOPc Pigment : PC = 1 : 4 wt.	1.32	1.25 μm
Metal Complex Dye : PC = 1 : 1 wt.	1.30	1.55 μm
Cyanine Dye : PC = 1 : 9 wt.	1.40	1.10 μm
VOPc Dye : PC = 1 : 2 wt.	1.32	1.30 μm

(PC : Polycarbonate)

Printing and Measurement

The ink donor sheets in contact with the receiving sheet were set on the printing drum, and continuous tone images (grayscale data) with resolution of 2540 dpi were recorded by modulating pulse width of laser light under the recording condition which a laser power is 40 mW and recording speed is 156 mm/s. A spot size of laser light is selected on 3 μm which is a possible minimum spot size at this printing system. The characteristics of continuous tone reproduction were obtained by the measurement of average optical density at each pulse width using optical densitometer.

To observe the change of physical properties of light-heat conversion materials by laser irradiation, absorption spectra of laser light absorbing layers (without ink donor layer) before and after laser irradiation were measured by a spectrophotometer using a integrating sphere attachment.

In the next, the ink donor sheets in contact with the receiving sheet were irradiated with the pulse width of 32 μs under the condition of changing the spot size by controlling a distance between the optical head and the printing drum.

Results and Discussion

Tone Reproduction Curves

Figure 2 shows the relationship between pulse width of laser light and optical density of transferred dye using 3 μm spot size of laser beam. The sublimation dye was transferred in response to pulse width from the range of short pulse width for all light-heat conversion materials. However, the optical density for carbon black and VOPc dye samples is clearly higher than that for the other materials, and goes to the saturated optical density quickly. After all, the experimental result indicates that the laser light absorbing layers using carbon black and VOPc dye have a high heat generation efficiency.

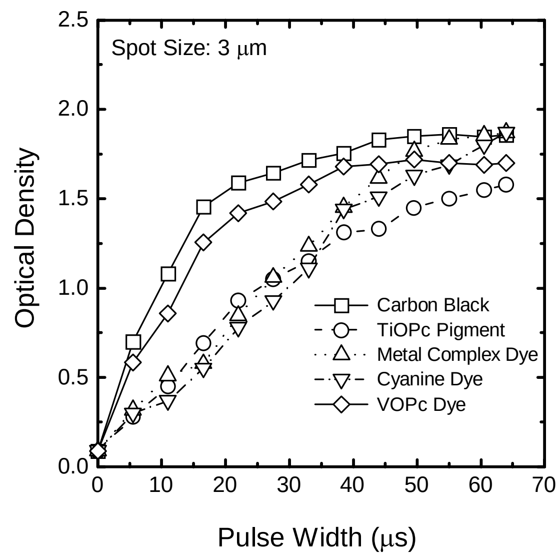
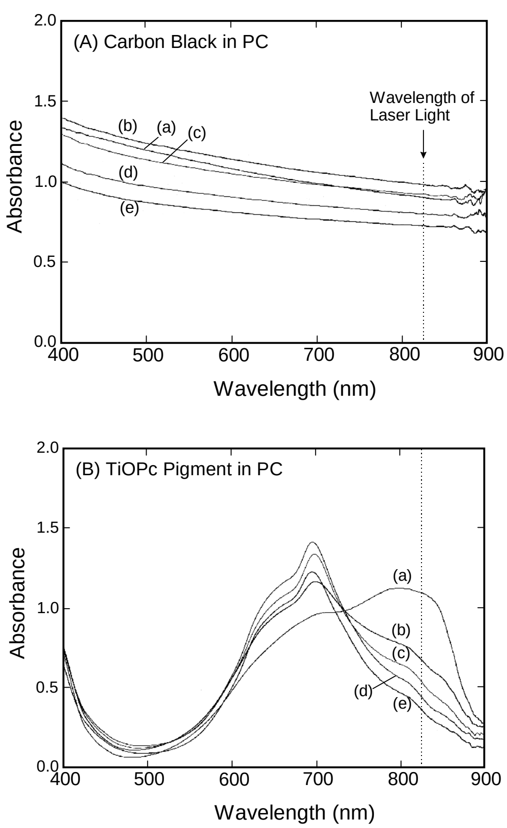


Figure 2. Relationship between optical density and pulse width. Spot size of laser light is 3 μm.[5]

Absorption Spectra for Laser Light Absorbing Layers

Figure 3 shows absorption spectra of laser light absorbing layers (without ink donor layer) before and after laser irradiation. As the comparison with the absorption spectra among five kinds of light-heat conversion materials, spectra changes by laser irradiation are little for carbon black and VOPc dye. It is considered that absorbed laser light is converted into heat efficiently with little damage by laser irradiation due to the high heat stability of carbon black. The phthalocyanine dye exceeds the cyanine dye in heat and light stabilities, and can convert light into heat with a situation that a damage such as a decomposition is little in comparison with the other dyes under the printing condition of high exposure energy using focused laser light. For the TiOPc pigment, the crystal phase transformation by laser irradiation was observed as shown in Figure 3 (B), though the phthalocyanine has high heat and light stabilities, and an absorbance at the wavelength of laser light was decreased. Figure 4 shows a DSC curve of TiOPc pigment used here. An exothermic peak ascribed to the crystal phase transformation was observed at 250ºC. In our temperature estimation of laser light absorbing layer during laser irradiation based on that the absorbed laser light was completely converted into heat energy, the temperature of laser light absorbing layer rose to 250ºC within 1 μs from the beginning of laser irradiation. Therefore, it is reasonable that the crystal phase formation is already observed at the irradiation time of 16 μs as shown in Figure 3 (B)-(b). On the other hand, there was no problem of the crystal phase transformation for the VOPc dye because of the dye molecule was dissolved in the polymer matrix compared with that existed in the crystal state for the TiOPc pigment. If a speed of the dye decomposition or crystal phase transformation is faster than the pulse width of laser light, the absorbance at the wavelength of laser light will be decreased during the pulse duration, and so a decrease of heat generation will be expected.



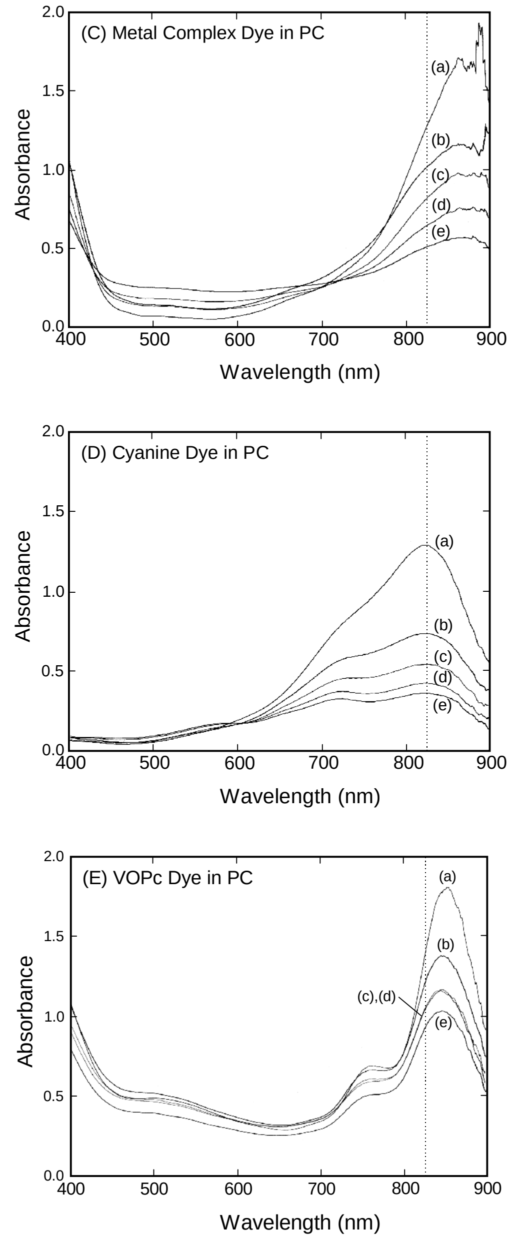


Figure 3. Absorption spectra for laser light absorbing layers at different irradiation times (a) 0 μs [non-irradiation], (b) 16 μs, (c) 32 μs, (d) 48 μs and (e) 64 μs. Spot size of laser light is 3μm.[5]

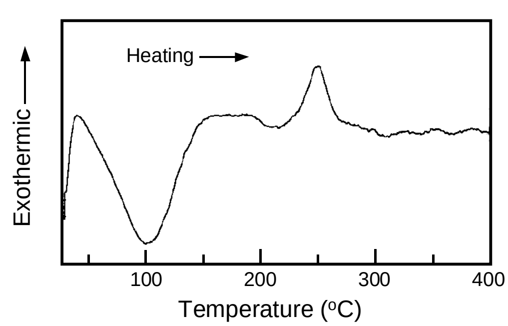


Figure 4. DSC curve of TiOPc Pigment.

Spot Size Dependence

Figure 5 shows relationship between spot size and optical density for each light-heat conversion material. The spot size on the laser light absorbing layer is varied by the change of distance from the optical head to ink donor sheet. The spot size of 3 μm is corresponding to just focus and the spot size increases with the increasing distance from the optical head. The optical density decreases after peak value for all materials. Though these characteristics have already reported,[4] they are different according to kind of light-heat conversion materials. Especially, there are large difference between optical values at around just focus position due to the durability of the materials. Figure 6 shows relationship between decomposition temperature of near-IR dyes measured by DSC and optical density of transferred dye at the spot size of 3 μm. There is a correlation between decomposition temperature and amount of transferred dye, and the near-IR dye having high decomposition temperature shows high heat generation. On the other hand, each material shows the similar optical density at the spot size of 50 μm as shown in Figure 5, because the energy density distribution of laser light spot is extremely flat compared with just focus and so there is no damage in the laser light absorbing layers.

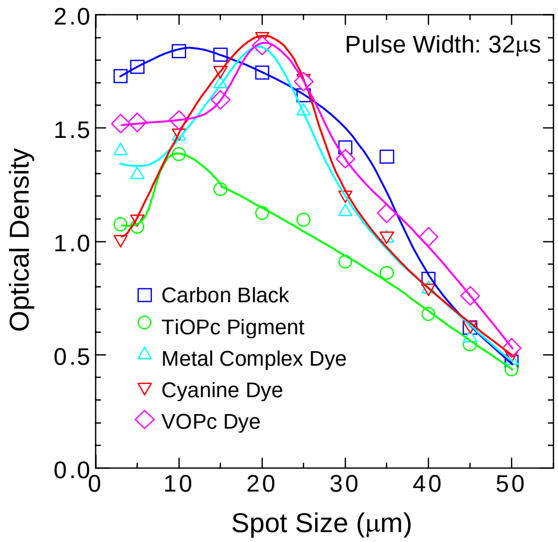


Figure 5. Relationship between optical density and spot size of laser light. Laser power is 40 mW.

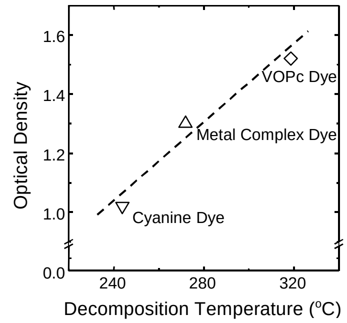


Figure 6. Relationship between decomposition temperature of near-IR dyes and optical density of transferred dye at the spot size of 3 μm.

Conclusion

The heat generation of several light-heat conversion materials for the laser light absorbing layers was discussed on the basis of the amount of dye transferred from the ink donor sheet and the absorption spectra of laser light absorbing layers after laser irradiation. Each light-heat conversion material showed the similar heat generation under the printing condition of low energy distribution. On the other hand, the heat generation was different according to kind of light-heat conversion materials under the printing condition of high exposure energy. It was confirmed that the different heat generation was affected with the decrease level of laser light absorption by the decomposition reaction or the crystal phase transformation of the materials during laser irradiation.

References

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Biography

Masaru Kinoshita received the B.S. and M.S. degrees in image science from Chiba University in 1996 and 1998, respectively. I am a student in a doctor course in Graduate School of Science and Technology, Chiba University. My research interest is in Laser Thermal Transfer Technology.