Estimation of TiO2 Particle Electrophoresis by Measuring Reflectance Response

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Abstract
A new rewritable printing media using electrophoresis and selective heating has been proposed to contribute to the reduction in paper consumption by printers. The mechanism is that when a heated part of the rewritable media is melted, white particles in that part of the media are able to move by electrophoresis. The media is initialized by heating its entire surface under the condition of voltage application and imaging is carried out by selective heating under the condition of an applied reversed-polarity voltage. In the media, the electrophoresis property of the white particle is important. So, the electrophoresis property of titanium oxide (TiO_2) in melted carnauba wax was estimated.

Introduction
Paper consumption due to printing using electronic printers, such as electrophotography and ink jet printers has increased very rapidly in accordance with the rapid progress of information technology. A considerable fraction of paper consumption corresponds to the checking of data or the preparation of documents. From an environmental viewpoint, a decrease in paper consumption is important. Rewritable paper technologies have recently attracted attention.[1] Rewritable paper is the approach from the viewpoint of printer technology and other approaches are carried out from the viewpoint of display technology. The approaches from both viewpoints are called electronic paper and several technologies, such as the reversible coloring reaction of leuco dyes,[2,3] dry toner motion,[4,5] thermal magnetophoresis[6] and gyricon[7] have been proposed.

Concerning electrophoresis, a segment-type display has been studied and its excellent visibility has been demonstrated.[8] An ion projection addressing display has been proposed[9] and its application to information boards has been reported.[10] Recently, the research and development of electrophoretic displays have again been extensively carried out by several groups to realize eye-friendly displays or paperlike displays.[11,12]

An electrophoretic display is considered to have the possibility of realizing an eye-friendly paperlike display, but an attempt to realize rewritable paper using electrophoresis has not yet been attempted. Novel rewritable printing media utilizing electrophoresis are currently studied.[13,14]

Proposed Rewritable Printing Media
The rewritable printing media is shown in Fig. 1.

1) Initialization: the media is melted by heating under the condition of voltage application, so that one side becomes colored and the other side becomes white.

2) Imaging: under a reversed-polarity voltage, the area of the media where the reflectivity is to be changed is melted by selective heating. Because of reversed-polarity voltage application, white particles move to the other side of the media only where the media is melted. Selective heating can be carried out using heating elements for thermal printing and is also considered to be possible by laser beam scanning. When conventional one-dimensionally arranged heating elements are used, the rewritable media is passed over a heating element and selective heating can be accomplished in the same way as in a thermal printer.

The rewritable printing media utilizes electrophoresis and the is media stable solid at its storage temperature, which is usually room temperature, so excellent visibility and stability are expected.

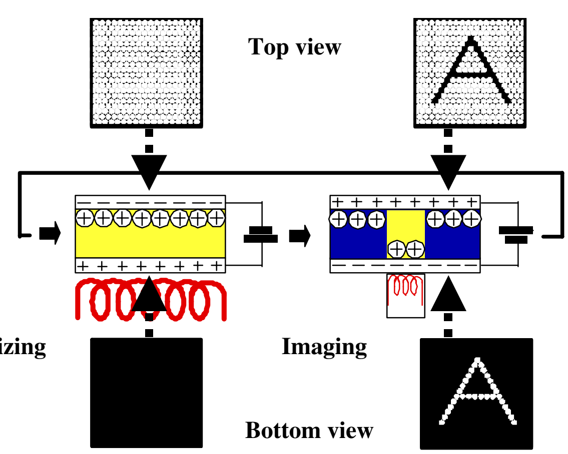

Figure 1. The rewritable printing media.

Experimental
The materials used to fabricate the rewritable media are carnauba wax, dye and TiO_2. Carnauba wax is used because its melting point is approximately 80°C, it exhibits a relatively sharp change from the solid to liquid states and it has the electrophoretic characteristics of TiO_2 particles. The wax is dyed by adding OIL

Black HBB (Orient Chemical Industries, Ltd., Japan) The materials are heated and mixed.

The rewritable media cell to be measured is fabricated by pinching the mixed materials between ITO (Indium Tin Oxide) glasses. The space between the ITO glasses is maintained by inserting an insulator stripe of 0.2 mm thickness. The sample is kept in a temperature-controlled box. The temperature is raised from room temperature to 100°C. Voltage pulses of positive and negative parity are applied to the sample. The three types of sample of different surfactant were prepared.

The time response of the reflectance of the cell is measured. Using two mirrors, the reflectance of both sides of the cell is monitored with a digital camera (Minolta: DiMAGE Z1) operating in the Motion JPEG mode, at 30 frames/s, with 640x480 dots, after the reversed-polarity voltage is applied. The Motion JPEG data are analyzed using a PC (Windows). The average reflectance of both sides of the cell is calculated.

The viscosity of wax is estimated from the free fall motion of ball. The experimental schematics is shown in Fig. 3. The ball is dropped into wax melted by heat and its motion is observed by digital camera. The falling speed of the ball is calculated from the image captured by the camera. The ball used is steel ball which diameter is 3.1 mm. It was observed the fall moved downward with constant speed 0.3 m/s. so the viscosity of the wax was estimated as 1.3 p.

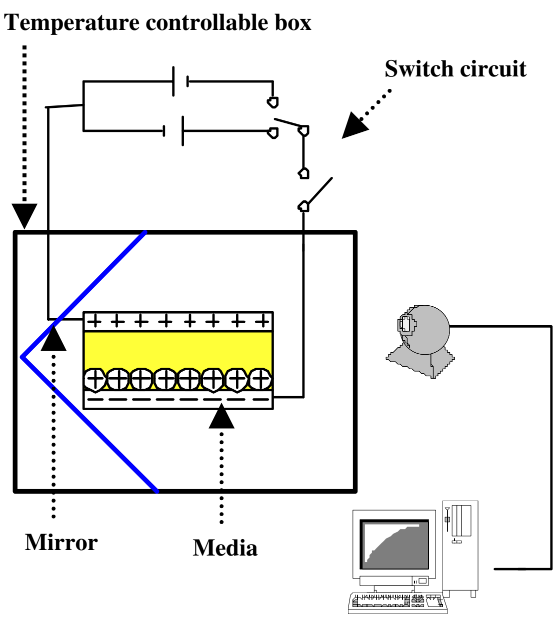

Figure 2. Schematic diagram of experiment.

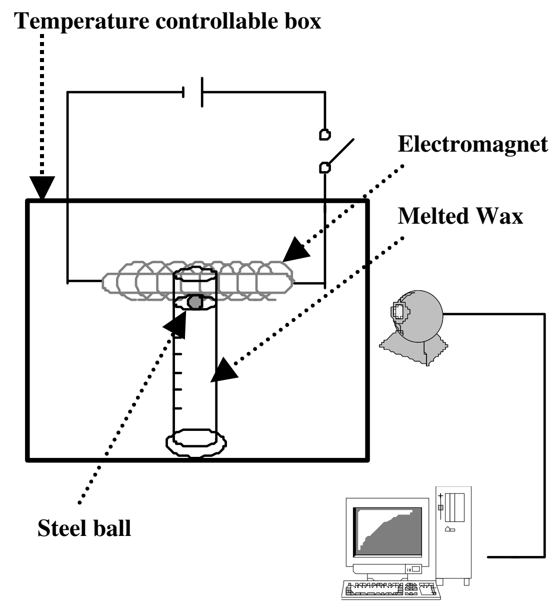

Figure 3. Schematic diagram of viscosity estimation.

Results and Discussion

The reflection change by voltage application is shown in Fig. 4. It is observed that the reflection of one side increases and the reflection of other side decreases by the application of the voltage. The increase and the decrease are reversed when the voltage polarity is reversed.

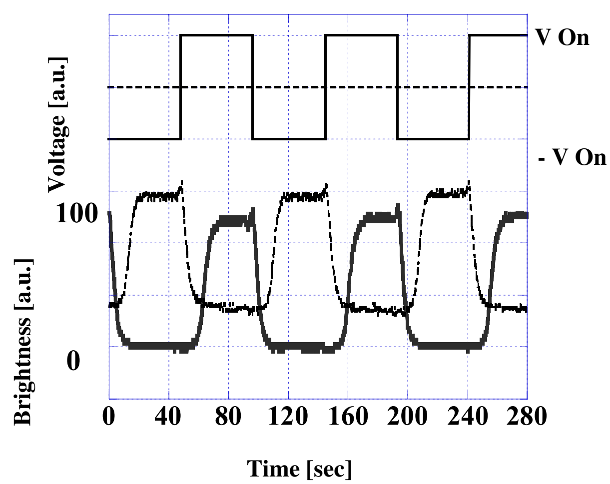

Figure 4. Reflection response against voltage pulse.

The response time of reflection change is defined as shown in Fig. 5. This definition means the time needed for half change after the voltage application. The inverse of the half change time is plotted as the applied voltage. It is found that the difference between TiO_2 moving upward time and moving downward time. The difference is possibly because of gravity force.

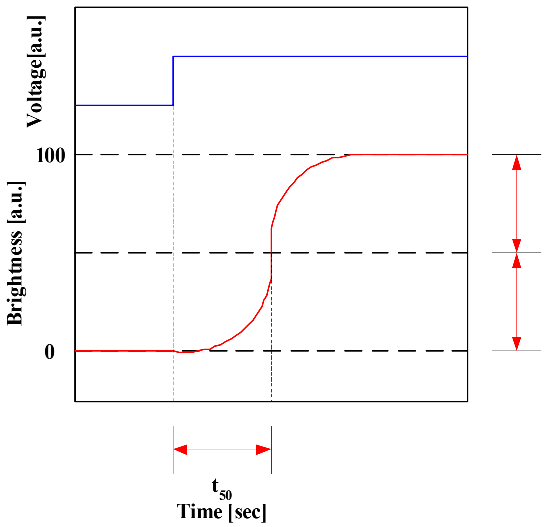

Figure 5. The response time of reflection change.

The motion of charged particle is expressed as, when the particle moves upward,

$$QE_{up} = 6\pi\eta a v_{up} + (m - m_{wax})g \tag{1}$$

when the particle moves downward,

$$QE_{down} + (m - m_{wax})g = 6\pi\eta a v_{down} \tag{2}$$

where Q is the charge amount of the particle, E_{suffix} is the electric field: when suffix is 'up', is when the particle moves up, and suffix is 'down', is when the particle moves down, η is the viscosity of the melted wax, a is the radius of the particle, v_{suffix} is the velocity the particle (suffix is the same meaning of the suffix of the E), m is the mass of the particle and m_{wax} is the mass of melted wax of same volume of the particle, and g is the gravity acceleration constant. The velocity has the following relation;

$$\frac{l}{T_r} = v_{suffix} \tag{3}$$

where l is the distance between the electrodes and Tr is the time for the particle across the electrodes. The inverse of the half change time is plotted as the function the applied voltage in Figs. 6-8. Using the Eqs.(1)-(3) we can get the relations between the charge and diameter of the particle and the slope of electric field dependence and distance between lines. For three cases, the following values are obtained as shown in Table 1.

Table 1: Obtained Results of Size and Charge of the Particle

Sample number	Radius of particle (10^{-6}m)	Charge amount/particle (10^{-16}C)
1	5.5	6.5
2	4.5	1.4
3	8.0	9.8

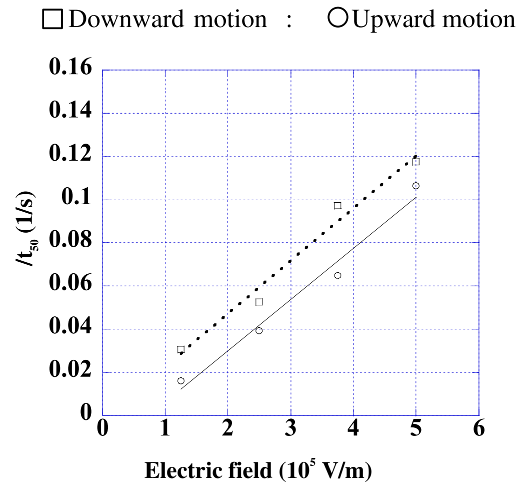

Figure 6. Inverse of response time dependence on electric field (Sample 1 : surfactant 1).

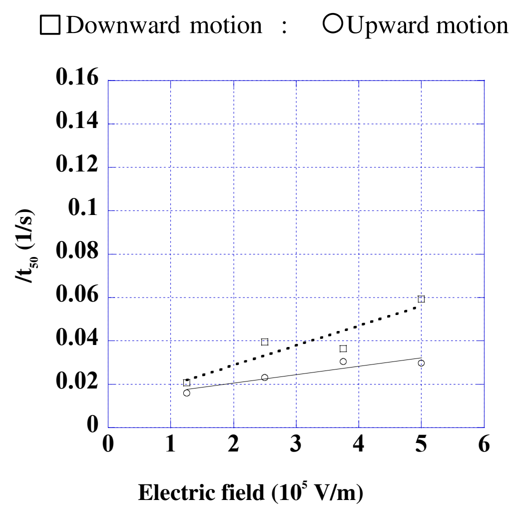

Figure 7. Inverse of response time dependence on electric field (Sample 2 : surfactant 2).

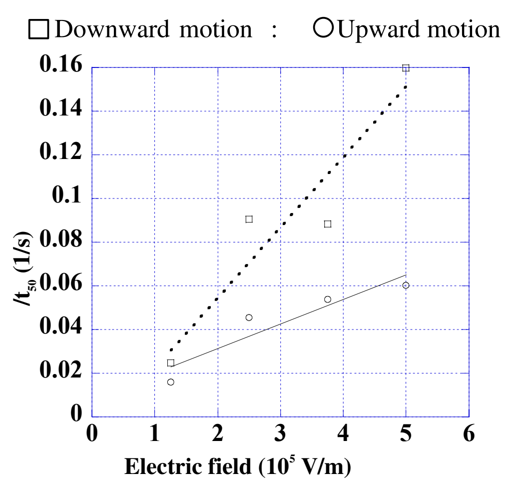

Figure 8. Inverse of response time dependence on electric field (Sample 3: surfactant 3).

Concerning the estimated diameters of the TiO_2 particle, its values are seems to be big. This is considered due to the aggregation of the TiO_2 particles. In these samples, the charge amount is less than conventional toner charge and also charge of liquid developer in melted wax.[15] It is considered that there is possibility of increasing the toner charge.

Conclusions

The electrophoresis characteristics of TiO_2 in melted wax are estimated. The characteristics are estimated from the time response of the reflectance change by voltage application. The time response shows the difference between when TiO_2 moving upward and downward. The difference is assumed from the gravity force and the TiO_2 particle charge and diameter are estimated.

Acknowledgements

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