Novel Display Method for Electronic Paper using Electro-Rheological Fluid

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Abstract

A novel display method using electro-rheological fluid is studied as a candidate technology for Electronic Paper. Electrorheological fluid has the remarkable characteristic that its liquidity can be locally controlled. This fluid form a chain structure in the presence of an electric field. This behavior can be used to form a pixel in a display system when the fluid occupies a cell with control electrodes. In this report, imaging characteristics are evaluated using various control electrode arrangement. The cyclic rewriting behavior confirmed in this study shows the potential of this method as an imaging technology for Electronic Paper.

Introduction

The amount of digital information continues to increase with the rapid adoption of the Internet. We can receive the information on printed papers or on displays. However, it is believed that working on displays tends to fatigue us; we generally like to read hardcopies rather than displays. Electronic Paper aims to be an ideal medium on which an increasing amount of digital information can be read comfortably.[1]

This study focuses on a novel display method that uses electro-rheological fluid. (ER-fluid) We expect this method can be used for Electronic Paper. The feasibility of this new method needs to be confirmed.

What is Electro-Rheological Fluid

An ER-fluid consists of fine particles suspended in a dielectric liquid. When an electric field is applied across the fluid the particles in the fluid line up to form chain structures that mirror the orientation of the electric field. Figure 1 shows a schematic drawing of the formation of a chain structure in an electro-rheological fluid.

Studies carried out on ER-fluids examined applications for mechanical components such as brakes and clutches. The mechanical binding force derived from the chain structures was the focus of attention in these studies.

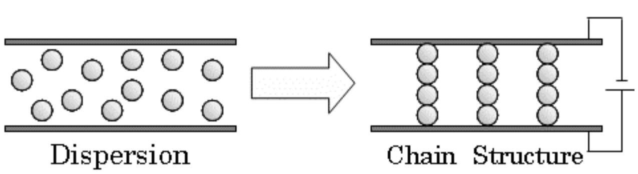


Figure 1. Phase change of Electro-Rheological Fluid

Imaging Principle

The principle of the electro-rhological fluid display is shown in Fig. 2. Rather than the mechanical properties the optical properties are utilized for realizing a display. Pixel control is expected as a result of controlling the cover area rate of particles in a fluid: the cover area is expected to fall due the formation of the chain structures. The persistence of dipole electric charges on the particles in ER-fluid is advantageous in a display method that uses particle migration as the display principle.

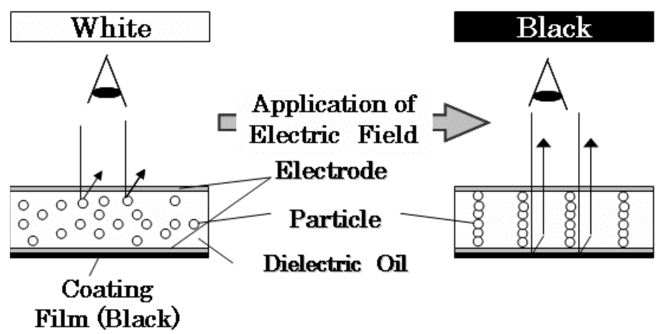


Figure 2. Principle of ER fluid display

Attributes to be Confirmed

Table 1 shows a list of the attributes that need to be confirmed to assure the feasibility of this new display method. The first experiment determined the appropriate electric fields and distances of the control electrodes (Experiment 1). The second experiment examined the impact of chain structure formation on the optical transmission rate (Experiment 2). Switching characteristics were evaluated as the final step in confirming the feasibility of the ER-liquid display method. (Experiment 3).

Table 1: Experiments for Confirming Attributes Necessary in Display Method

Items to be confirmed	Experiments
Requirement to Electric field	①
Improvement in contrast	②
Repeatable switching	③

Experiments

Evaluation of Required Density of Particles and Required Electric Field (Experiment 1)

Target

Tests were carried out in order to evaluate the effects of particle density and applied electric fields on the formation of chain structures in ER-fluid.[2]

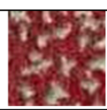
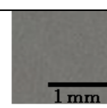
Methods

Experimental conditions are listed in Table 2. Five samples of ER-fluids of different densities, mixtures of particles and silicon oil, were prepared; weight percentage of particles were 0.3, 0.6, 1.3, 2.6, 5.4 wt% in whole liquid. Electric fields of 0 to 1000 V/m were applied to ER-fluids of each density in a test cell. Formation behavior of the chain structures was observed with a digital microscope set above the cell.

Table 2: Materials Used in for Experiments

Items	Condition
Electrode	ITO glass
Cell Gap	0.5, 1, 2, 3 mm
Electro rheological fluid weight percentage	0.3, 0.6, 1.3, 2.6, 5.4 wt%
Dielectric liquid (Silicone Oil)	TSF451-10 viscosity 10; Transparent and colorless

Table 3: Criteria Used for Evaluation of Chain Structure Formation

Appearance of sample			
Evaluation	○ (Good)	Δ (Halfway)	× (No chain)

Results

Results of the observations of the chain structures are shown in Tables 4, 5, and 6. Typical appearances of samples used as criteria for evaluation of chain structure formation are shown in Table 3. The 2.6 wt% sample could form a chain structure at a narrower control electrode gap (1 mm) than the other samples. No chain structure was observed in the 5.4 wt% sample; instead of chain structures network structures were formed. Expected formations of chain structures were recorded in the density range of 1.3 to 2.6 wt%.

Table 4: Evaluation of Chain Structure Formation (0.6 wt%)

Cell gap (mm)	Electric Field (V/mm)					
	50	100	200	400	750	1000
3.0	×	×	×	×	○	○
2.0	×	×	×	×	○	○
1.0	×	×	×	×	×	×
0.5	×	×	×	×	×	×

Table 5: Evaluation of Chain Structure Formation (1.3 wt%)

Cell gap (mm)	Electric Field (V/mm)					
	50	100	200	400	750	1000
3.0	Δ	Δ	○	○	○	○
2.0	Δ	Δ	○	○	○	○
1.0	×	×	×	×	×	×
0.5	×	×	×	×	×	×

Table 6: Evaluation of Chain Structure Formation (2.6 wt%)

Cell gap (mm)	Electric Field (V/mm)					
	50	100	200	400	750	1000
3.0	Δ	Δ	○	○	○	○
2.0	Δ	Δ	○	○	○	○
1.0	×	×	○	○	○	○
0.5	×	×	×	×	×	×

Improvement in Contrast (Experiment 2)

Target

We noticed that the contrast, or resolution, was insufficient if the simple structure of a cell constructed with a pair of solid electrodes was used. This is because the chain structures themselves reduce the transmission rate of the cell even when the control voltage is set for transmission state. A ring electrode structure was tested as a solution; the expectation was that the chain structures would gather in the neighborhood of the ring which would prevent the transmission rate from being reduced at the aperture area of the ring electrode. Appearances and transmission rates were examined using cells that had a ring electrode at their top.[3]

Methods

Structures and sizes of experimental cells are shown in Table 7. Four kinds of test cells were prepared in order to evaluate the improvement of transmission rate, and to evaluate the effect of aperture size. A test fluid of 2.6 wt% was placed in each test cell. Electric field applied ranged from 0 to 1000 V/mm. Transmission rate was measured with a transmission type density meter (Macbeth: TD932).

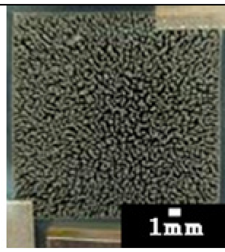
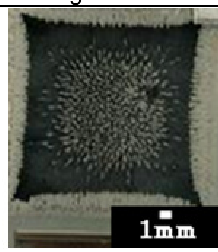
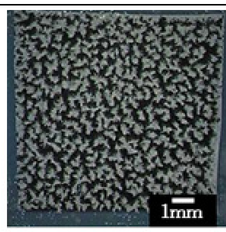
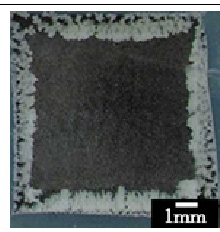
Table 7: Test Cells

Structure of Electrode	Cell size	Cell gap
Solid Electrode ①	25 mm x 25 mm	2 mm
Ring Electrode ②		
Solid Electrode ③	10 mm x 10 mm	
Ring Electrode ④		

Results

Appearances of the chain structure formed in each type of cell is shown in Table 8. We can see the concentration of the chain structures in the neighborhood of the ring electrode. Transmission rate of the aperture area surrounded by the ring electrode is improved as is expected. The relation between the electric field strength and the transmission rate of each cell is shown in Fig. 3. Ring electrode cells (2), (4) show higher transmission rates than the solid electrode cells (1), (3). Ring electrode (4), a smaller one, showed an improved transmission rate without residual particles in its aperture area, while ring electrode (2), a larger one, showed a lot of residual particles in its aperture area.

Table 8: Chain Structure Formation at various Electrode Sets

		Solid Electrode	Ring Electrode
Aperture	Large	 ①	 ②
	Small	 ③	 ④

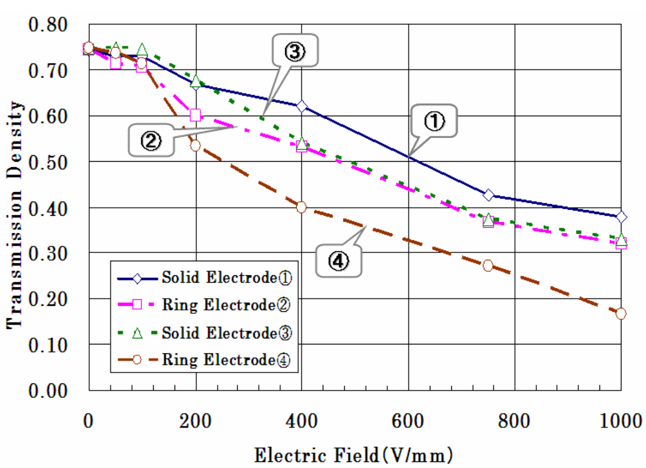


Figure 3. Optical density vs. Electric field

Switching Performance (Experiment 3)

Target

The simple cell structure consisting of a parallel pair of solid or ring electrodes has insufficient switching performance for display devices. This is because the formed chain structures cannot be expected to fully disperse when the applied voltage is cut off. A novel cell structure was studied in order to solve this problem. This structure consists of two pairs of electrodes: a vertical electrode pair and a horizontal electrode pair. Transmission state is realized by applying a voltage across the vertical electrodes, while dispersion state is realized by applying a voltage across the horizontal electrodes. The display principle of this electrode structure is shown in Fig. 4.[4]

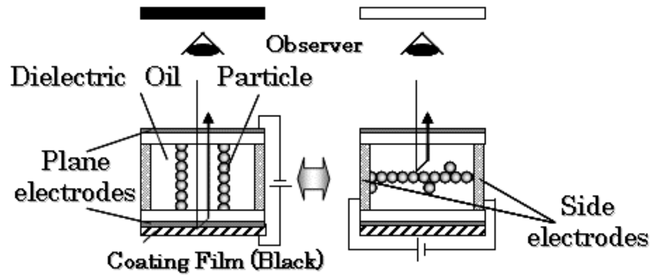


Figure 4. Display principle using pairs of plane electrodes and side electrodes

Methods

A 2.6 wt% sample was prepared. An experimental cell consisting of two pairs of electrodes was prepared: a vertical pair of a parallel set of top electrodes and a solid bottom electrode, and a horizontal pair of right and left electrodes. The distance between the vertical electrodes was 3 mm, and aperture area was 10mm×10mm (Fig. 5). Applied electric field was 1000 V/mm between the top and bottom electrodes, and 300 V/mm between the right and left electrodes. Switching voltages were applied alternatively to the electrode pairs. Transmission density was measured just after cutting the voltage that had been applied for five seconds.

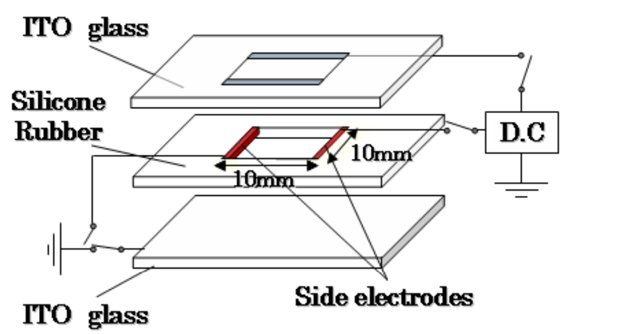


Figure 5. Test cell structure using parallel electrode set and side electrodes

Results

Measured results are shown in Fig. 6. The formation of chain structures perpendicular to the vertical electrodes was observed when a voltage was applied across the vertical electrodes, while chain structures perpendicular to the horizontal electrodes were observed when a voltage was applied across the horizontal electrodes. Expected switching performance between transmission state and dispersion state is shown by the two curves in Fig. 6. The tendency, common to both curves, a shift to a lower level of transmission density saturates after about 10 switching cycles as shown in Fig. 6.

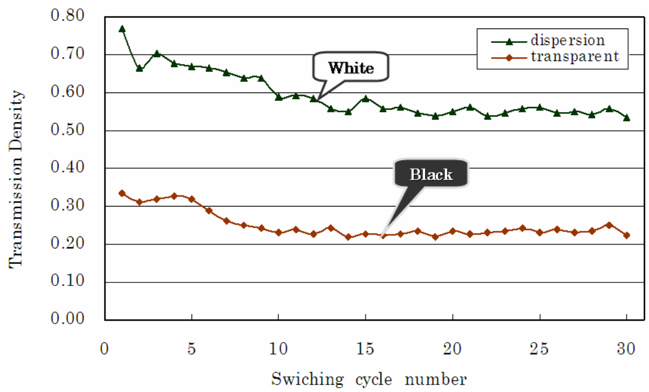


Figure 6. Switching characteristics

Summary

1. Relations between impressed electric field and optical transmission rate of ER-fluid were evaluated quantitatively for two cell structures: solid electrode type and ring electrode type.
2. Feasible switching characteristics were confirmed in the following integrated cell structure: a pair of a top service of parallel electrodes and a bottom solid electrode, and a horizontal pair of right and left electrodes.

References

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3. C. Asakawa, "Novel Display Method Using Electro Rheological Fluid －Improvement of Contrast－" Extended Abstracts (The 65th Autumn Meeting , 2004);The Japan Society of Applied Physics,p.880.
4. C. Asakawa, "Novel Display Method Using Electro Rheological Fluid－Switching Characteristic" Extended Abstracts (The 52nd Spring Meeting , 2005);The Japan Society of Applied Physics,p.1109.

Author Biography

Chiaki Asakawa was born in 1981. He received his B.S. degree in 2004 from Tokai University. He is expected to receive his M.S. degree from the graduate school of Tokai University in 2006. He is now engaged in the study of Electronic Paper, especially novel display methods based on ER-fluid.