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## PRELIMINARY COMMUNICATION

# Transportation of a microdroplet on an oriented liquid crystal surface

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Wetting phenomena play important roles in several technological applications and in many physical and biological thin-film phenomena, such as wetting, adhesion and friction. One of key issues of these studies is to control the surface energy (or wettability) dynamically for liquid transportation. We have developed a liquid crystal (LC) surface for use as a transport substrate since we expected that the surface energy of an LC surface can be controlled rapidly using an electric field. The rapid control of the polarisability (or wettability) of a liquid crystalline surface by an electric field has been demonstrated, together with the transportation of a liquid microdroplet.

**Keywords:** microdroplet transportation; surface energy; comb-type electrode

## 1. Introduction

Wetting phenomena play important roles in several technological applications (e.g. coatings, surface cleaning for electric devices) and in many physical and biological thin-film phenomena, such as wetting, adhesion and friction. Several experimental and theoretical studies have been devoted to understand the physics of wetting (*1–3*). One of key issues of these studies is to control the surface energy (or wettability) dynamically for liquid transportation. Ichimura *et al.* have shown that the surface energy of a substrate covered by an azobenzene monolayer can be controlled dynamically by irradiation with a UV lamp and have demonstrated liquid transportation on the substrate (*4*). Although this phenomenon is expected to be a new technology for bioscience or engineering applications, its applications are still limited since the speed of reaction of the surface energy change remains several seconds. To improve the response speed of the surface energy change, we have developed a liquid crystal (LC) surface for use as a transport substrate since we expected that surface energy of the LC can be controlled rapidly by an electric field. In this paper, we have report the rapid control of the polarisability (or wettability) of a liquid crystalline surface by an electric field and the transportation of a liquid microdroplet on it. The technique is expected become requisite technology not only for in engineering but for bioscience applications.

## 2. Experiment

All experiments were carried out at room temperature (23°C) and humidity was controlled to about 30% using an air conditioner. A brief explanation of the main tools used in our experiment is provided below.

### *Comb-type electrode*

Figure 1 illustrates schematically the top and cross-section views of the comb-type electrodes used. The electrodes on a glass substrate were made from Au with a thickness of 5 nm and a width of 7 μm. Each electrode was alternately arranged on the glass substrate and covered with a polyimide layer with a thickness of 10 nm.

### *Transportation substrate*

When 1 ml of liquid crystalline 4-cyano-4′-pentylbiphenyl (5CB) was put on the comb-type electrodes, it spread until its thickness reached an equilibrium value of ~0.5 mm. After equilibrium was reached, a voltage was applied in order to control the orientation of the 5CB. The degree of orientation was monitored by using birefringence microscopy. Figure 2 shows the normalised birefringence intensity as a function of the applied voltage. It was confirmed that when the applied voltage exceeds 2 V, birefringence intensity increases until 10 V, at which the orientation can be considered as being in an equilibrium state. The inset in Figure 2 shows polarising optical microscope images of 5CB under applied voltages of 10 V and 0 V.

### *Transportation medium*

Pure water was used as the transportation medium on the 5CB surface. The 5CB surface was misted with

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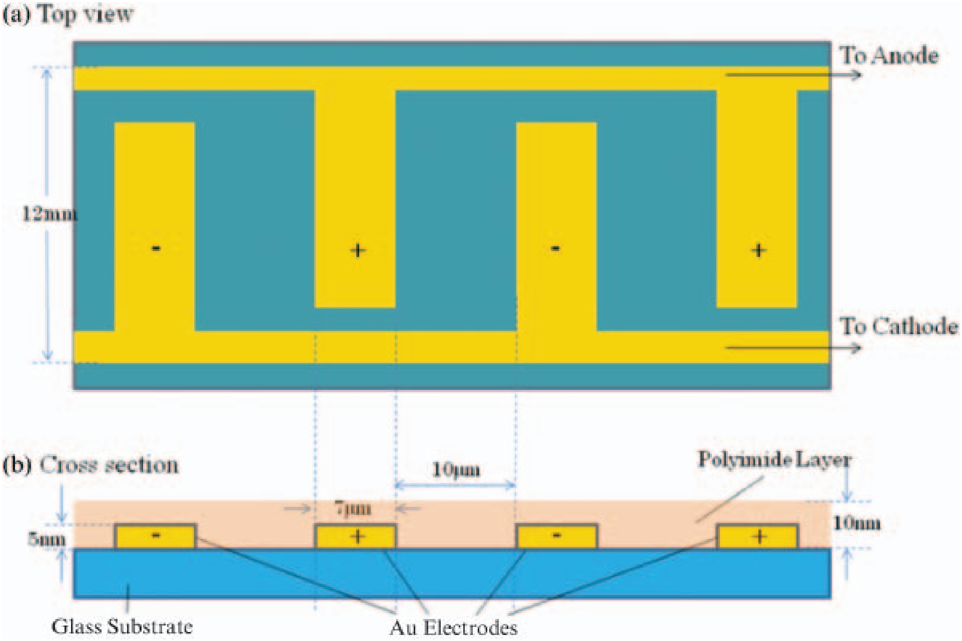

Figure 1. Schematic illustration of comb-type electrode: (a) top view; (b) cross-section. Note that each scale is exaggerated in the drawing.

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water using a mist generating apparatus (Ultrasonic Inhaler, Matsushita Electric Industrial Co., Ltd., Japan). After misting, an adequate microdroplet having a diameter of about 10 µm was obtained that could be observed under the microscope (with objective lens × 50).

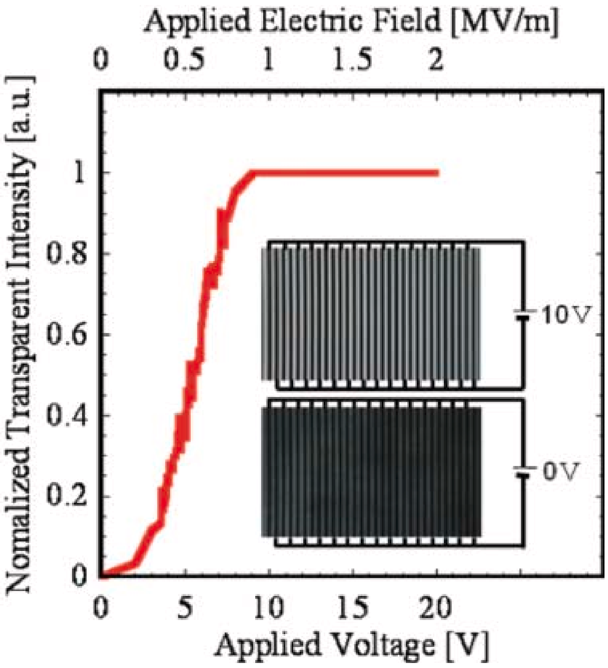

Figure 2. Normalised transparent intensity of 5CB over the comb-type electrodes. Inset: polarised optical microscopic image of 5CB under applied voltages of 10 V and 0 V.

## 3. Results

As described above, a liquid crystalline 4-cyano-4′-pentylbiphenyl (5CB) surface was prepared for use as a transportation substrate. After pure water was misted onto the 5CB substrate, the various sizes of the water droplets on the substrate were determined. The observations were focused on a water droplet with a diameter of about 10 µm.

Application of a voltage of 6 V, which is slightly above the Frederix transition voltage of about 5 V, caused the droplet to move towards the centre of the substrate between the electrodes (Figure 3).

When the applied voltage was 10 V, which is much higher than the Frederix transition voltage, the droplet moved from cathode to anode (data not shown).

## 4. Interpretation

At present, the driving force for such transportation is expected to result from three contributions.

First, there is the surface energy gradient due to application of the voltage. Wettability (or transportation ability) of the substrates can be defined by the spreading coefficient,

$$S=\gamma_{\mathrm{GS}}-(\gamma+\gamma_{\mathrm{LS}}), \tag{1}$$

where $\gamma_{\mathrm{GS}}$, $\gamma$ and $\gamma_{\mathrm{LS}}$ are, respectively, the interfacial tensions of the substrate/air, air/liquid and liquid/substrate interfaces. The spreading coefficient $S$ is well known as an indicator of wettability, i.e. if $S$ is

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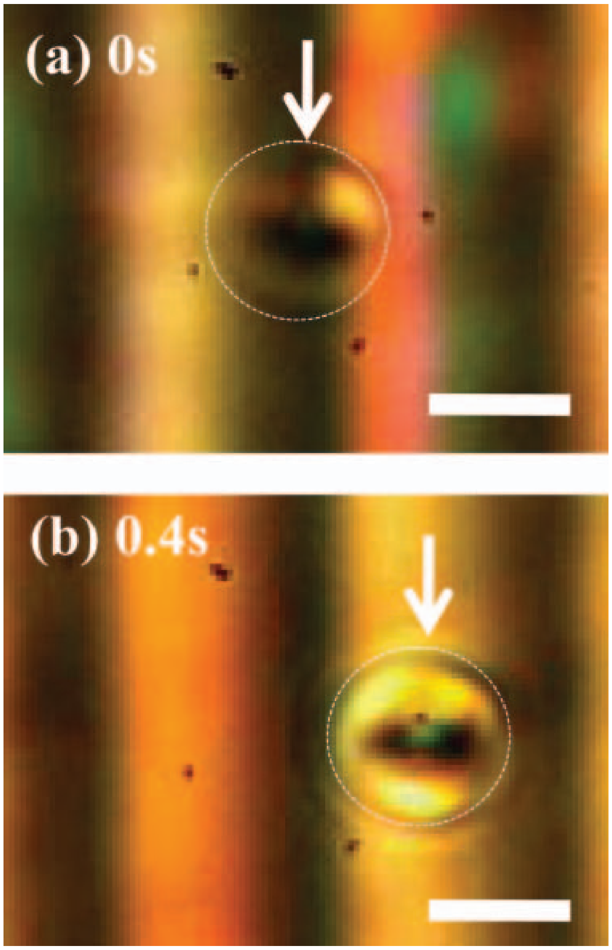

Figure 3. Snapshots of microdroplet movement under an applied dc voltage of 6 V, which is slightly above the Fledelix transition voltage (ca. 5 V): (a) before applying the voltage; (b) 0.4 s after applying the voltage. The diameter of droplet is ca. 7 µm. The scale bar denotes 10 µm and dotted curves are a guide.

positive liquid (or particles) on the substrate can wet (or cover the surface). Note that $S$ has energy dimensions per unit area. In general, an increase in $S$ tends to increase wettability (or transportation ability). The surface energy of a substrate is increased when the surface molecules of the substrates are polarised. Polarisability and spreading coefficient $S$ are correlated through the relation (*5*)

$$S = K\alpha_P(\alpha_S - \alpha_P), \tag{2}$$

where $K$ is an unknown coefficient and $\alpha_S$ and $\alpha_P$ are polarisabilities of the substrate and liquid, respectively. When an electric field is applied to the 5CB substrate, the polarisability of the 5CB substrate increases (*6*) by $u^2/3k_BT$, i.e.

$$\alpha_S = \alpha_0 + u^2/3k_BT = \alpha_0 + \alpha_{\mathrm{ind}}, \tag{3}$$

where $\alpha_0$ is the instinct polarisability, $u$ is the dipole moment, $T$ is the absolute temperature and $k_B$ is the Boltzmann constant. We denote the second term ($u^2/3k_BT$) of Equation (3) by $\alpha_{\mathrm{ind}}$. It is well known that $\alpha_{\mathrm{ind}}$ can be equivalent to $\alpha_0$ (*6*):

$$\alpha_0 \approx \alpha_{\mathrm{ind}}. \tag{4}$$

Since electric fluxes between the electrodes have curvatures except the minimal-length one, a polarisability gradient arises when the voltage is applied. The polarizability of the 5CB surface should be a function of θ, which is the angle between the 5CB molecules and horizontal level, as denoted in Figure 4. Therefore, the increase of the apparent surface polarisability of 5CB is expected to be

$$\alpha_{\mathrm{ind}} = \frac{u^2}{3k_BT}\cos\theta. \tag{5}$$

Using Equation (5), the surface polarisability difference, $\Delta\alpha_{\mathrm{surf}}$, between the centre of the electrodes ($\theta=0$) and the top of the electrodes ($\theta=\pi/2$) can be calculated:

$$\Delta\alpha_{\mathrm{surf}} = \alpha_{\mathrm{ind},\,\theta=0} - \alpha_{\mathrm{ind},\,\theta=\pi/2}. \tag{6}$$

From Equations (4)–(6), the order of $\Delta\alpha_{\mathrm{surf}}$ can be estimated as being of the the same order of magnitude as $\alpha_0$ (instant polarisability of the molecules).

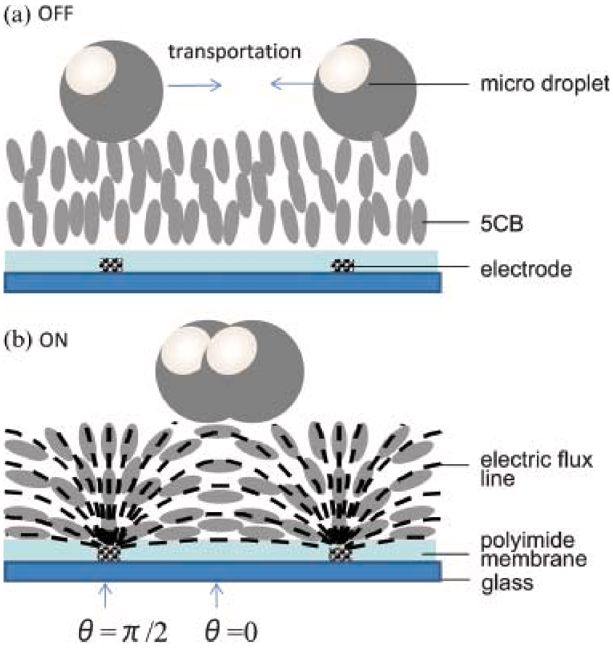

Figure 4. Schematic illustration of microdroplet transportation system: (a) voltage off; (b) voltage on state. Symbol θ indicates the angle of 5CB molecules to the horizontal level.

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Therefore, the increase of surface energy, $\Delta S$, induced by an electric field is

$$S \approx K\alpha_{\mathrm{P}}\alpha_{\mathrm{ind}} \approx 10^{-2}\,\mathrm{J\,m^{-2}}, \qquad (7)$$

providing the change of polarisability of the microdroplet is neglected for the order of magnitude calculation.

The second effect resulting in microdroplet transportation is the electric force acting on the microdroplet. Since the water/5CB interface forms an electric double layer, a water droplet can be positively charged at water/5CB interface with a certain electric charge density, $+\sigma$. Therefore, the electrostatic force per unit area acting on the microdroplet can be estimated as $+\sigma E$. This effect causes the movement of the microdroplet from cathode to anode. When the applied voltage exceeded about 10 V, the microdroplet moved from anode to cathode without staying at the centre of electrodes where surface energy should be maximum (data not shown). This result indicates that the effect of electrostatic force became dominant when the applied voltage exceeded 10 V.

The third contribution for microdroplet transportation is the increase of the surface free energy, $\Delta F$, due to a decrease of the surface entropy when the electric field is applied. In order to simplify the discussion, consider that the mesogenic structure, having long and short axes $a$ and $b$, respectively, lies in a two-dimensional plain. The lateral side turns towards the surface (at the centre between the electrodes, state A) and the head region turns towards the surface (at the top of the electrode, state B). In the state A case, the number of mesogens per unit area is $1/\pi ab$, whereas that of the state B case is $1/\pi b^2$. These lead to the difference of surface free energy $\Delta F$ per unit area:

$$\Delta F \approx -k_B T\left[\ln\left(\frac{1}{\pi ab}!\right) - \ln\left(\frac{1}{\pi b^2}!\right)\right] \sim 10^{-21}\,\mathrm{J\,m^{-2}}. \qquad (8)$$

$\Delta F$ is always positive, which means that a particle tends to move from state B to state A in order to reduce the surface free energy. Although this can lead to transportation, the order of $\Delta F$ is found to be $10^{-21}\,\mathrm{J\,m^{-2}}$, which is much smaller than the polarisability effect of Equation (7) and thus it should be negligible.

## 5. Summary

We have constructed a spontaneous microdroplet transportation system using a liquid crystal surface. The driving force for microdroplet transportation contains the following contributions:

1. a surface energy gradient due to the polarisation gradient of the liquid crystal;
2. an electric force acting on the microdroplet;
3. an entropy gradient due to mesogen molecule realignment.

We think the effect of 3 is negligible and that 1 and 2 are comparable since we can change the microdroplet position by changing the intensity of the applied voltage.

## Acknowledgement

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## References

(1) Hoffman R.L. *J. Colloid Interface Sci.* **1974**, *50*, 228–241.
(2) Joos P.; Pintens J. *J. Colloid Interface Sci.* **1976**, *60*, 507–513.
(3) de Gennes P.G. *Rev. Mod. Phys.* **1985**, *57*, 827–863.
(4) Ichimura K.; Oh S.; Nakagawa M. *Science* **2000**, *288*, 1624–1626.
(5) de Gennes P.G.; Brochard-Wyart F.; Quéré D. *Capillarity and Wetting Phenomena*; Springer: 2003.
(6) Israelachvil J.N. *Intermolecular and Surface Forces*, 2nd ed.; Academic Press: 1992.