PHOTORESPONSIVE OPTOFLUIDICS AND LIGHT-INDUCED MICROFLOW

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ABSTRACT

In this paper, we propose a novel concept of photoresponsive liquid and demonstrate its applications. The photoresponsive liquid is defined as liquid whose surface tension is controlled by light irradiation. By utilizing the photoresponsive liquid, various applications, such as photoresponsive liquid lens and light-driven pump, are expected. In order to realize the concept, we have synthesized new photo-degradative surfactants (PDS) and confirmed their photo-degradability and interfacial tension change during light irradiation. Then, we successfully demonstrated the concepts of photoresponsive liquid in its application to photoresponsive lens.

KEYWORDS: Optofluidics, Microfluidic actuation, Micropump

INTRODUCTION

Recently, various microfluidic actuation principles and components have been reported. Concerning to non-mechanical actuation, pumping with electrowetting [1, 2] and electro-osmosis [3] have been proposed. The non-mechanical actuation is expected to be effective for miniaturization of the micro systems.

In this paper, we report a novel method of non-mechanical liquid actuation and its applications to optofluidic actuation. In order to realize the actuation, new photo-degradative surfactants (PDS) were synthesized, and their solutions were named as 'photoresponsive liquids'. Upon UV irradiation, interfacial tension of the photoresponsive liquid decreases by degrading the surfactant (PDS). The interfacial tension change can be applied to the fluid actuation as presented in the following sections.

THEORY

Figure 1 illustrates PDS's photochemical reaction and its influence on surface tension. When PDS is irradiated with UV light, its hydrophilic group is removed to be less surface-active. Thus, surface tension of the photoresponsive liquid can be switched by UV irradiation (Figure 1b). During UV irradiation, degradation of PDS competes with adsorption of PDS from bulk solution to the liquid surface and, then, the interfacial tension increases. When UV light is turned off, the interfacial tension decreases again because of the adsorption.

Figure 2 shows possible applications of the photoresponsive liquid. Figure 2a illustrates a photoresponsive liquid lens. When the lens is irradiated with UV, the curvature (focal length) of the lens is changed and, the light intensity at the detector is spontaneously reduced. Figure 2b illustrates another example of PDS's applications, a light-driven pump. The height of the capillary rise is changed by UV irradiation and in order to balance surface tensions between two reservoirs, liquid is driven from one reservoir (right) to another (left).

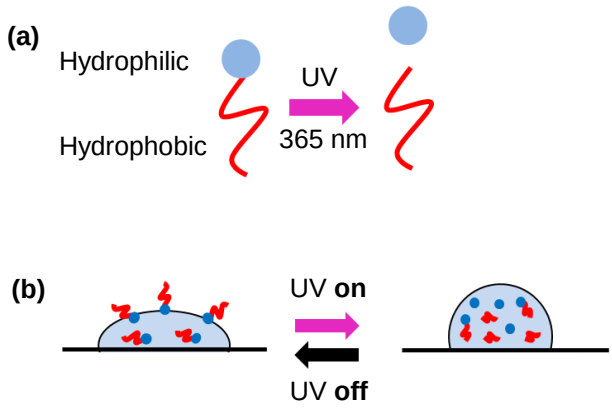

Figure 1: (a) Illustration of photo-degradative surfactant (PDS). (b) Illustration of the switching of the surface tension induced by UV irradiation. The surface tension of the droplet of the photoresponsive liquid is forced up during UV irradiation.

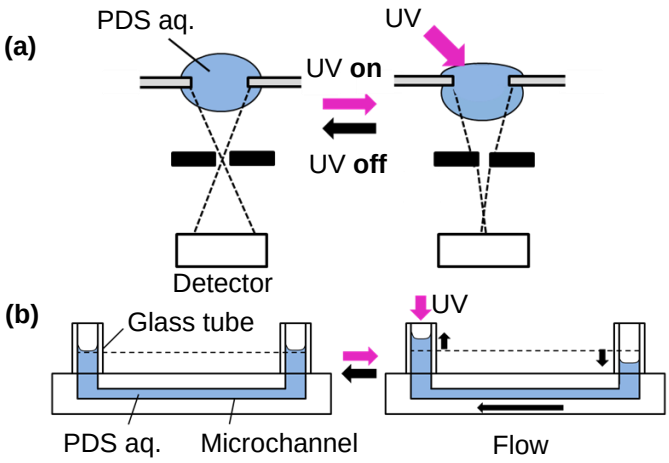

Figure 2: Applications of the photoresponsive liquid. (a) Illustration of a photoresponsive liquid lens. When the lens is irradiated by UV, the light intensity coming to the detector is spontaneously reduced by the change of the focal length. (b) Illustration of a light-driven pump. The interfacial tension of the photoresponsive liquid is changed by UV irradiation, and the water level is changed by capillary force. The change of the level caused the liquid transfer in the microchannel from right to left.

EXPERIMENTAL

Here, only one PDS will be shown although some PDS were synthesized and their properties have been investigated. Figure 3 shows chemical structure and photoreaction of the PDS. It has a hydrophobic alkyl-chain group (hexadecyl group) and a hydrophilic ionic part (quaternary ammonium group attached to *o*-nitrobenzyl part). When the *o*-nitrobenzyl compound is irradiated with a wavelength around 365 nm, the benzyl group is degraded. In case of our surfactant, the quaternary ammonium part is separated from the main part to be less hydrophilic and less surface-active.

We have synthesized the proposed surfactant and verified its chemical structure. The interfacial tension between the photoresponsive liquid and hexadecane was measured by a pendant drop method.

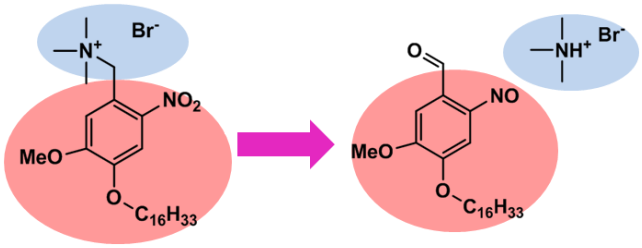

Figure 3: Newly synthesized photo-degradative surfactant.

RESULTS AND DISCUSSION

First, temporal interfacial tension change under 365-nm-light irradiation was measured. Figure 4 shows the interfacial tension with the irradiation times of 10, 20, 50, 100, 200 and 1,000 s, where the interfacial tension was increase from 25 to 45 mN/m. The degradation of PDS was also confirmed by UV-Vis spectra.

Using the photoresponsive liquid, a liquid lens structure was configured as shown in Figure 5a, where the photoresponsive liquid was suspended through a hole on a glass substrate modified by octadecyltrichlorosilane (OTS). Figure 5b shows the liquid lens before (left) and during (right) UV irradiation. The curvature radius (*R* and *R'*, respectively) of the liquid lens was changed from 1.52 mm to 1.65 mm, which means the focal length of the lens can be modified by UV irradiation. In addition to the curvature change, liquid flow was also observed. From the pictures, the actuated liquid volume during the irradiation (700 s) was estimated to be 200 nL. The flow rate under the present condition was 0.02 µL/min. We can increase and decrease the rate by changing radius of the reservoir and/or resistance of the fluidic channel.

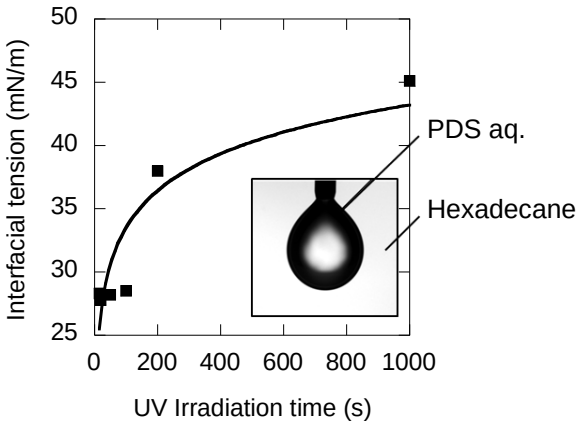

Figure 4: Interfacial tension change induced by UV irradiation. The interfacial tension of the photoresponsive liquid and hexadecane was measured by pendant drop method.

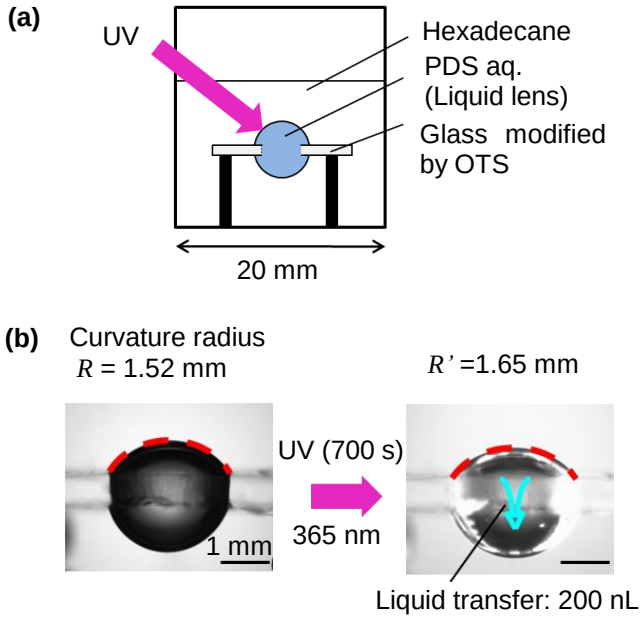

Figure 5: (a) Illustration of UV irradiation to the liquid lens of the photoresponsive liquid. (b) Micrograph of the liquid lens before (left) and during (right) UV irradiation. The curvature radius(R and R') of the liquid lens was changed by UV irradiation. At the same time, the liquid was transferred downward.

CONCLUSION

Using newly synthesized PDS, we successfully demonstrated the concepts of photoresponsive liquid and its applications to photoresponsive optofluidics and light-induced microflow. This technology will open novel applications of microfluidic and optofluidic devices.

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