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Observation of Liquid-Liquid Micro Dynamics on Thin Oil Layer
油膜を利用した液–液間マイクロダイナミクスの観察

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1. Introduction

Inkjet apparatus generating microdroplets with a diameter of ~ 30 μm is adequate not only as a manufacturing system such as printed electronics, but also for investigation of micro fluid dynamics. While it is difficult to observe their rapid motion of microdroplets directly, the gravitational effect on the dynamics is negligibly small compared to surface and interfacial tension in a small spatial size. We are constructing systems for measuring mechanical properties of micro-liquid droplets, such as dynamic surface tension in midair or on the substrate. In our previous report,[1)] we succeeded in measuring the dynamic interfacial tension with high time resolution between hexadecane and water containing surfactant. In this work, we observed the shape of the microdroplet on the flat substrate coated with thin oil layer. We successfully measured the interfacial properties in the time range of 1 ms.

2. Principle

Under the condition of negligible gravity at the small size limit, the equilibrium shape of a microdroplet can be determined only by surface and interfacial tension. As is well known, the following Young's equation holds for a water droplet on the substrate without oil layer.

$$\sigma_{\mathrm{ws}} + \sigma_{\mathrm{w}} \cos\theta = \sigma_{\mathrm{s}} \qquad (1)$$

In this paper, subscripts w, o, and s represent water, oil and solid substrate respectively, and a pair of subscripts represents their interface, and θ represents the contact angle on the clean substrate.

Likewise, considering the Young's equation at each contact point of three-phase for a water droplet on the substrate with thin oil layer, the following equation is given:

$$\cos\theta - \cos\delta = \frac{\sigma_{\mathrm{s}} - \sigma_{\mathrm{os}} - \sigma_{\mathrm{o}}}{\sigma_{\mathrm{w}}} \qquad (2)$$

where δ represents the contact angle on the substrate with thin oil layer.

From this equation, the interfacial tension between oil and the substrate can be calculated. **Figure 1** shows a schematic diagram of a water microdroplet on the substrate with thin oil layer.

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3. Experiment

We used pure water, ethanol and Tween 20 aqueous solution (10 mM) as liquid samples of microdroplets, which were generated by our original inkjet system of on-demand type. As the substrates, we prepared acrylic or vinyl chloride disks with the diameter of 60 mm with and without the coating layer of oils, those are hexadecane and silicone oil with viscosity of 10cSt. The substrate was placed on the motorized rotation stage driven at constant speed to provide a fresh surface to the impinging spot of the droplet continuously. The shapes of the microdroplets were observed directly with a microscope using a stroboscopic technique. **Figure 2** shows a schematic diagram of the experimental apparatus. Also, **Figure 3** is a series of microscopic images taken immediately after a water microdroplet impinging on the clean substrate.

4. Results and Analysis

Figure 4 shows an image of a water microdroplet on a clean acrylic substrate at approximately 550 μs after impingement. From this image, the contact angle θ of the water droplet is determined to approximately 75 degrees. Until 2 ms after droplet impingement, there was little change in the contact angle θ.

Figure 5 shows an image on a thin hexadecane layer at approximately 550 μs after impingement. From this image, the contact angle δ of the water

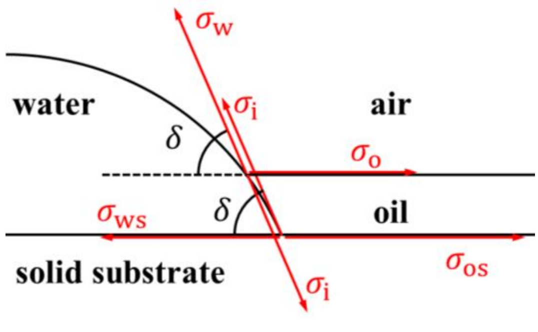

Fig. 1 Schematic diagram of water microdroplet on substrate coated with thin oil layer. It is assumed that oil surface is horizontal and a water droplet is part of a complete sphere.

droplet is approximately determined to 100 degrees. The contact angle obviously changes depending on whether the substrate is coated or not with thin hexadecane layer. The interfacial tension σ_{os} in acryl – hexadecane system calculated from the contact angles θ and δ becomes -15.5 mN/m under the condition of $\sigma_w = 71.9$ mN/m and $\sigma_o = 27.6$ mN/m (obtained by Wilhelmy method) and $\sigma_s = 43.2$ mN/m (obtained by literature).[2)] Since the interfacial tension should not be a negative value, the assumption that the surface of hexadecane layer is horizontal might not be exact. Or, the acrylic surface tension in literature might be largely different from the true value.

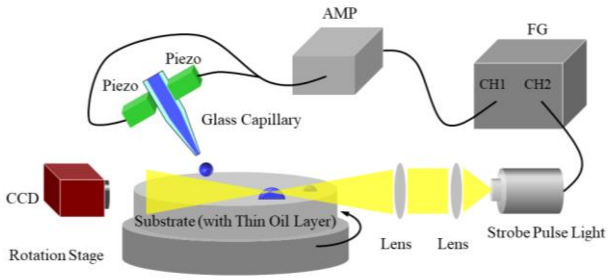

Fig. 2 Schematic diagram of the experimental apparatus. In fact, microdroplets are injected directly downward.

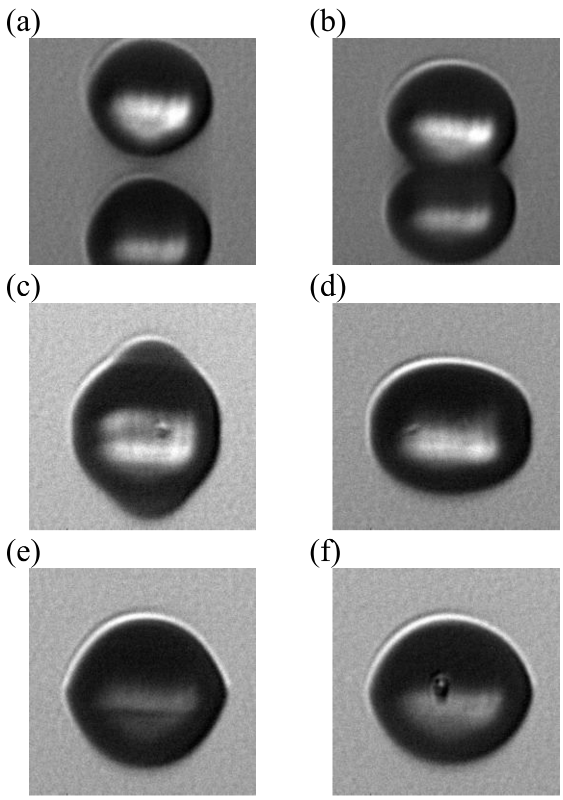

Fig. 3 A series of images of droplets after the moment when a water microdroplet impinged on the clean acrylic substrate, (a) 0 µs, (b) 4 µs, (c) 8 µs, (d) 12 µs, (e) 16 µs and (f) 20 µs.

5. Conclusion

We devised a method to measure the interfacial tension in solid – oil system by water microdroplets impinging on the substrate with thin oil layer. This method can be used even if oil and solid satisfy completely-wetting condition. Also, the experiment was carried out for a system of water, hexadecane and acrylic. It was confirmed that the contact angle obviously changed depending on whether oil layer coated or not, while the interfacial tension result became a negative value.

Acknowledgment

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References

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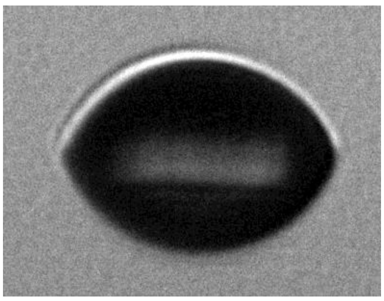

Fig. 4 An image of a water microdroplet on the clean acrylic substrate at approximately 550 µs after impingement.

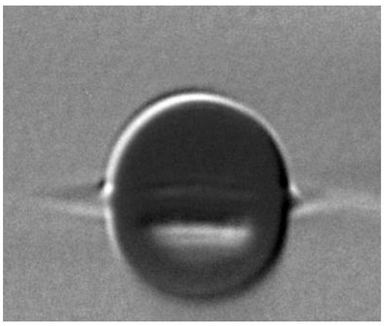

Fig. 5 An image of a water microdroplet on the acrylic substrate with thin hexadecane layer at approximately 550 µs after impingement.