論文の内容の要旨

Abstract

論文題目 Interaction Force on the Contact Area during the Sliding and Vibration of Droplets
(液滴の滑りと振動における接触面での力)

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1. Introduction

The objective of this study is to directly measure the interaction force distribution on the contact area during the sliding and vibration of liquid droplets using MEMS-based force sensors. Conventional methods to study the dynamical behaviors of liquid droplets mainly rely on observations using a high speed camera, a microscope or an SEM. However, since it is difficult to visualize the inner region the contact area, the interaction force distribution on the contact area of remains unclarified. In this study, a measurement method using MEMS force sensors is proposed to study the dynamical interactions between the droplet and a rigid substrate. Using these MEMS sensors, the distribution of the interaction force on the contact area of the droplet during sliding and vibration is directly measured.

2. Sensor design and sensing principle

Two axis force sensor and cantilever type one axis force sensor were used for measuring the force distribution during the sliding and vibration of the droplets, respectively. Both of the sensor types consist of a 300 nm-thick Si structure on which piezoresistors are formed, and a micropillar attached to the Si structure. By monitoring the fractional resistance change of the piezoresistors, the forces acting on the micropillar can be detected.

3. Experimental results on droplet sliding

From the measurement results, the contact mechanism of the droplet during the sliding can be interpreted as followed. First when the droplet starts to contact with the micropillar at its advancing edge, the micropillar is pulled backward and upward by the surface tension. Inside the contact area, the micropillar is pushed downward and the shear force becomes almost zero. Finally, at the receding edge, the micropillar is pulled upward in normal direction and forward in shear direction. The result shows that the friction force of acting on the droplet mainly distributes at the receding edge of the droplet.

Moreover, a fluctuation can be seen in the normal force inside the contact area which indicates that the droplet was vibrating during the sliding on the micropillar array. The frequency of this sliding induced vibration was in the range of several kHz in case of water droplets. In fact, the spectrum of the vibration is not affected by the droplet volume nor the sliding velocity. However, as the pitch of the micropillar array increases, the spectrum shifts to the lower frequency region. These results suggest that the sliding induced vibration of the droplet is caused by the local detachment of the droplet from the substrate at its rear edge. From the power spectral density of the measured normal force, it is also possible to estimate the viscosity of the

droplets.

4. Experimental results on droplet vibration

First, normal force distribution along the contact area during the resonant vibration of droplet was investigated. The measurement result shows that the normal force change at the edge of the contact area was largest. In fact, the normal force change at the edge of the contact area was approximately 100 times larger than that at the center of the contact area.

Next, the effect of the liquid viscosity on the decay rate of the vibration was investigated. From the experiment results, it is shown that the higher the viscosity is, the faster the vibration decays due to the damping effect. Moreover, the attenuation rate is approximately proportional to the viscosity of the liquid. Therefore, it is possible to estimate the liquid viscosity by measuring the droplet vibration using the proposed sensor.

5. Conclusion

In this study, dynamical interactions between a droplet and a micropillar array was studied using MEMS based force sensors. Using the proposed sensors, the interaction force distribution on the contact area during the sliding and vibration of the droplet was directly measured. From the measurement results, it was shown that, during the sliding of a droplet on a micropillar array, vibration of the droplet at relatively high frequency (several kHz) was induced by the detachment of the droplet at the receding and the vibration amplitude was greatly affected by the liquid viscosity. For droplet resonant vibration, the normal force change was largest on the peripheral of the contact area, and the decay rate of the droplet vibration was shown to be proportional to the liquid viscosity. The experimental results show that it is possible to estimate the viscosity of small droplets by the proposed sensors.