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Observation of Ripplon Resonance on Micro Liquid Surface

微小液体表面のリプロン共鳴現象の観察

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1. Introduction

Ripplon is a thermaly excited capillary wave, whose propagation can be observed with a light scattering technique in a non-contact and non-destructive manner. Up to now, we have applied our ripplon spectroscopy technique for the measurement of dynamic molecular properties at free liquid surfaces or liquid-liquid interfaces. Recently, fabrication of micro liquid structures attracts a lot of interest and is actively studied. The typical spatial scale of these structures is $10^{-6}\,\mathrm{m}$, and the surface tension and the bulk viscosity play a dominant role in the fabrication process. Also, the motion of the micro liquids are influenced by the size of the liquid and the boundaries. It is difficult, however, to measure the properties of the micro liquid surface using the contact measurement technique, such as the Wilhelmy plate method, while it would be possible if we use the non-contact measurement method, such as our ripplon spectroscopy.

In this presentation, we report the observation of the ripplon propagation on a micro liquid surface. On the micro liquid surface, ripplon spectra are expected to split due to the resonance of the ripplon. We show experimentally the resonant spectra of ripplon on the surfaces of silicon oil with kinetic viscosity of 0.65 cSt confined in the thin belt-shaped and circular areas.

2. Ripplon Spectroscopy

The propagation and damping of ripplons are determined by the surface tension σ, the density of the liquid ρ, and the bulk viscosity of the liquid η. In our experiments, the angular frequency ω_0 and the temporal damping constant Γ of the ripplon can be approximated to:

$$\omega_0 = \sqrt{\frac{\sigma k^3}{\rho}},$$

$$\Gamma = \frac{2\eta k^2}{\rho}.$$

The detail of the ripplon spectroscopy technique was reported[1], and we will give a brief account of the principle. The laser light incident to the liquid surface is scattered by ripplons, acting as weak phase gratings to the light. The wavenumber of the observed ripplon is determined by the scattered angle θ, which follows the Bragg condition describing the momentum conservation:

$$k = K\sin\theta,$$

where k and K and are the wavenumbers of the observed ripplon and the incident light, respectively. Ripplon propagates with a constant phase velocity, and the frequency of the incident light is modulated through the scattering process by the Doppler effect describing the energy conservation:

$$\omega_\mathrm{s} = \omega_\mathrm{i} \pm \omega_0,$$

where ω_s, ω_i, and ω_0 are the frequencies of the scattered light, incident light and the observed ripplon, respectively. The frequency of the scattered light is shifted up by the ripplon propagating in one direction, and down in the opposite direction. Analyzing the powewr spectrum of the scattered light with the optical heterodyne technique, we can obtain that of the ripplon. This spectrum consists of two components, and each component is known to be approximated by the Lorentz curve, which has a sharp peak at $\omega = \pm\omega_0$ and a half width at the half maximum Γ. The above discussion holds for the ripplon propagating on a free liquid surface.

3. Observation of ripplon resonance

When ripplons are confined in a cavity much smaller than the spatial damping length of the ripplon, the ripplon would exhibit a resonant phenomenon as seen for the thermal phonon[2, 3]. In spite of the large angular ambiguity of the incident and reference laser beams, we can observe the ripplons whose wavenumbers are discretely selected by the resonance conditions. Therefore, we can measure the liquid surface properties on micro liquid surface with high accuracy by observing the ripplon resonance.

The resonance condition is determined by the geometric shape and the size of the sample cell.

When ripplons are confined in the two-dimensional parallel cavity or in the circular cavity, the resonance conditions are expressed as eqs. (1), and (2), respectively:

$$k_n L = n\pi, \quad (n = 1, 2, \cdots) \tag{1}$$

$$\frac{\partial J_m(k_n R)}{\partial r} = 0, \quad (m = 0, 1, 2, \cdots) \tag{2}$$

where k_n is the wavenumber of the resonant ripplon, L is a width of the resonance cavity, R is a radius of the cylindrical resonance cavity, and $J_m(r)$ is the m-th Bessel function.

The schematic view of the sample cell and the ripplon light scattering technique are shown in **Fig. 1**. The laser beam with an initial diameter of 2.34 mm is focused by a lens with a focal length of 35 mm. The angular divergence of the beams induced by the lens gives a wider detection band of ripplons, which corresponds to the instrumental band. In our experiments, the optical slit is used as a parallel cavity with $L = 25\,\mu\text{m}$, and the pinholes are used as a circular cavity with $R = 10\,\mu\text{m}$, and $15\,\mu\text{m}$. The cavity is fixed on the sample liquid surface, and the local light and the incident light intersect in the center of the cavity.

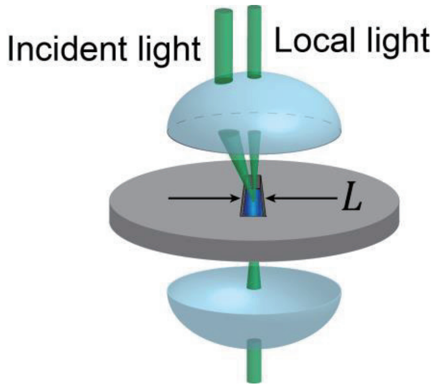

Fig. 1 Schematic view of the parallel cavity sample cell and the ripplon light scattering system.

Figure 2 shows the ripplon power spectrum obtained for 0.65 cSt silicone oil surface in the parallel cavity with the width of 25 μm at the scattered angle of 0.922°. The spatial decay length of ripplon due to the viscosity is 450 μm. We can clearly see two resonant peaks. The surface tension calculated with the frequency of the resonant peak and eq. (1) is 15.6 mN/m, which agrees well with the literature value (15.9 mN/m).

Figure 3 shows the ripplon power spectrum obtained for 0.65 cSt silicone oil surface in the circular cavity of 10 μm in radius at the scattered angle of 0.861°. The spatial damping length of ripplon due to viscosity is 532 μm.

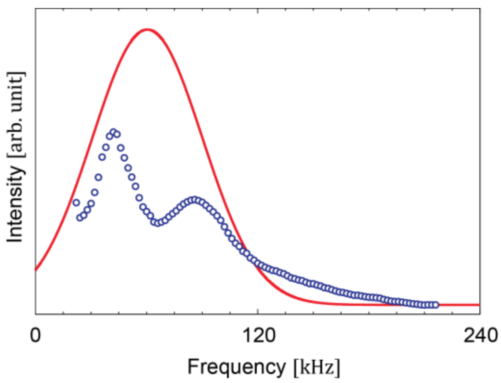

Fig. 2 Ripplon power spectrum obtained for 0.65 cSt silicone oil surface in the parallel cavity at the scattered angle of 0.922°. The solid curve, observed on the free surface of same liquid at the same scattered angle, gives the envelope of the resonant peaks.

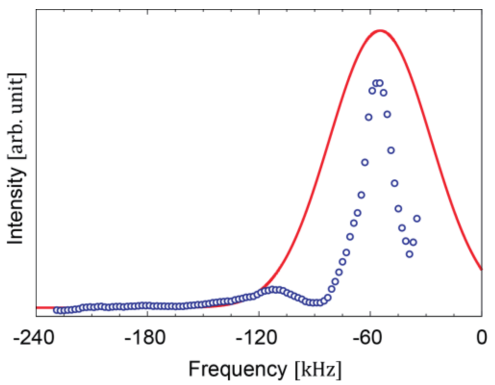

Fig. 3 Ripplon power spectrum obtained for 0.65 cSt silicone oil surface in the cylindrical cavity at the scattered angle of 0.861°.The solid curve, observed on the free surface of same liquid at the same scattered angle, gives the envelope of the resonant peaks.

The solid curves in **Figs. 2** and **3** show the spectrum observed on the free surface of the same liquid at the same scattered angle without any boundaries. These spectra approximately give the envelope of the resonant peaks. In the presentation, we would discuss the width of the resonant peaks.

References

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