Summary of thesis: Driving micro-scale object by a dc electric field

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In this thesis, we report on bifurcation analysis of a water droplet oscillating in an oil phase under a dc electric field. From this analysis, we expected that the addition of noise would induce the coherence oscillation of the oscillating water droplet. We also demonstrated that the addition of noise to a dc bias voltage induced this coherent motion of the droplet in our experiment. We also employed oil flow containing plastic beads instead of a water droplet in an oil phase under a dc voltage. We could observe rotation of the droplets and assumed it to be caused by the oil flow.

On the nano- and micro scales, the viscosity is much larger than inertia. Furthermore, we cannot ignore thermal fluctuations on such scales. Under these conditions, it is difficult to drive a micro- or nano-sized object made by a conventional method typically employed on macro scale. One solution is to apply the relevant phenomena on the microscale. In the present study, We attempted to use a water droplet oscillating in an oil phase under a dc electric field as a novel mechanism for driving a micro- or nano-sized object. To accomplish this, we investigated the oscillating mechanism in this thesis.

In Chapter 3, we report on the bifurcation analysis of a water droplet oscillating in an oil phase under a dc electric field. In our experiment, we changed both the distance and the voltage between the electrodes. This oscillation phenomenon of a water droplet in an oil phase under a dc electric field is well known since the 1990s. However, the threshold voltage has thus far not been determined, and its dependence on the scale of the system has not been evaluated. To our best of our knowledge, the present study is the first attempt to reveal the scale dependence of the oscillation phenomenon. We also made a numerical model of the droplet motion in the oscillation phenomena, on the basis of which we expected the droplet oscillation to be the limit cycle oscillation. We also expected that the addition of noise stabilize the oscillation near the threshold voltage. In Chapter 4, we evaluated this expectation. We added Gaussian white noise to a dc bias voltage. Although the voltage between the electrodes was slightly smaller

than the threshold voltage, the additional noise enhanced the oscillation of the water droplet in the oil phase. We examined the dependence of the droplet motion on the magnitude of noise and found a suitable magnitude of noise exists at which oscillation of the droplet occurs. We think that this droplet oscillation is a kind of coherence resonance.

The nature of the oscillation as the limit cycle is crucial for driving a micro- or nano-sized object, since the limit cycle is stable against disturbances. Droplet oscillation also generates coherence resonance, which is a desirable characteristic for the micromachines functioning in noisy environments to account for instabilities such as thermal fluctuation and so on.

In this study, we found that a water droplet oscillating in an oil phase under dc voltage has some beneficial characteristics. Nevertheless, the water droplet is unsuitable in some scenarios. Water droplets suffer from the disadvantage of easily breaking up and coalescing under an electric field.

To overcome these disadvantages, we used plastic beads instead of a water droplet in the present study, as described in Chapter 5. As a result, we observed that they rotated between the electrodes. Since plastic beads are not conductive, we did not consider them to be charged. We expected this rotation to be caused by electrohydrodynamic (EHD) flow. We calculated the EHD flow numerically and obtained a vortex similar to that of the rotating beads. As a result, we confirmed that EHD flow caused the rotation of the beads.

EHD flow is commonly used to drive a micro-pump. However, it has not been used as a power source for driving a microsized object. In the present study, we found that EHD flow could be used to drive a microsized object.

Although generation of rotational motion on the microscale is difficult because of large friction, we were able to generate a rotational motion under a dc electric field.

In summary, we examined the scale dependence of the oscillation of a water droplet in an oil phase and found the oscillation to be a limit cycle and to have a characteristic of coherence resonance. We also confirmed that EHD flow could rotate a microsized object under a dc electric field and established a novel mechanism for driving a microsized object. We anticipate this mechanism to be applicable to a micromachines in the future.