Electrowetting driven flows

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Electrowetting allows for continuous tuning of the wettability of conductive liquids on hydrophobic surfaces over several tens of degrees with a switching speed that is limited by the characteristic hydrodynamic response time of the fluid. On substrates with specifically patterned electrodes, the contact angle can be controlled independently for every electrode at any time. These properties have made electrowetting an increasingly popular tool for manipulating fluids on small scales. The fields of applications include tunable lenses, displays, lab-on-a-chip, as well as electrowetting-assisted coating.

From the perspective of fundamental wetting science, electrowetting is attractive for the very same reasons: experiments that conventionally require tedious manufacturing of surfaces with variable chemical composition, can be performed with electrowetting on the very same surface with identical surface properties by changing the wettability externally.

In this lecture, I will present a series of experiments, in which we exploited electrowetting to control (i) the motion of contact lines, (ii) the generation of microdrops, and the (iii) generation of internal flows within drops to promote mixing.

(i) Ideally, the contact angle of a drop on a surface is determined exclusively by the surface energies. In practice, however, contact lines are usually pinned at heterogeneities. As a consequence, the equilibrium contact angle is not directly accessible experimentally, and the measured contact angle varies between an advancing and a receding value. Whenever contact lines are forced to move, the contact angle hysteresis has to be overcome. We found that contact angle *hysteresis* vanishes in AC electrowetting. This spectacular effect is explained by analyzing the force balance at the contact line in the presence of a time-dependent electrostatic force.

(ii) Microdrop generation for biotechnological and biophysical purposes is largely performed in continuous flow systems with two immiscible liquids, such as flow focusing and cross flow devices. In these systems, the drop generation is exclusively controlled by hydrodynamic forces. Wetting, in particular preferential wetting of the channel walls by one of the two phases is usually perceived as a problem that limits the device versatility. Using electrowetting, we made the wall wettability an additional control parameter to manipulate the fluid flow. I will show experiments in which we control the generation of microdrops in a flow focusing device by switching the wall wettability electrically. The device allows for on-demand generation of drops and for enhanced control over drop sizes. The experimental results are explained quantitatively in terms of a rather simple model that only takes into account the electrically controlled contact angle.

(iii) Mixing is a fundamental problem in microfluidics because of the characteristic low Reynolds numbers. We showed previously, the electrowetting-driven drop oscillations promote mixing in millimeter-sized drops making use of the chaotic advection principle that is frequently used in microfluidics. As the drops oscillate periodically between states of high and low contact angle, internal flow fields are generated that are almost reversible – but not entirely. Tracer particles injected into the microdrops display a net displacement from cycle to cycle that is comparable to the dye distribution patterns of our earlier experiments (F. Mugele et al. Appl. Phys. Lett. 2006). Here, I demonstrate that this net internal flow, which is responsible for the mixing process, originates from capillary waves that travel from the contact line to the top of the drop during the oscillations. These capillary waves produce a Stokes drift inside the drop.