Enhancing the Response Time of Electrowetting Lenses Using Voltage Shaping

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Abstract: We have demonstrated tunability of the response time of electrowetting lenses from underdamped to overdamped through input voltage shaping. This strategy shows great promise to further optimize the response time of electrowetting lenses.
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1. Introduction

The electrowetting on dielectric (EWOD) principle enables control of the shape of a liquid droplet or liquid-liquid interface with an actuating voltage. The result is an ultra-smooth, tunable liquid interface that is an ideal platform for tunable focus lenses and prisms [1], as well as high rejection ratio optical switches [2] without moving parts. Other applications include optical displays [3], lab-on-a-chip (LOC) systems and micro-total analysis systems (μTAS) [4,5].

Understanding the temporal dynamics of these devices, especially the response time, is important to move the technology forward. This has been studied for droplet spreading [6,7], capillary flow [8], and lenses [9], with particular emphasis on understanding the material properties and dimensional dependence of the actuation dynamics. In contrast, we focus on the effect of DC driving voltage functions on response time of EWOD lenses, as enhancing the dynamic response of these devices would enable many applications. We have also performed finite element simulations to compare with our experimental results.

2. Experimental Setup

Our devices are constructed in a 4-mm inner diameter glass tube with a height of 5-mm, that is coated with a transparent electrode, a dielectric, and a hydrophobic coating. The tube's interior wall is sputter-coated with a 300 nm thick layer of indium tin oxide (ITO), an optically transparent conductor, followed by vapor phase deposition of 1 μm thick layer of Parylene HT (Specialty Coating Systems) and a 1 wt% Teflon (DuPont) in FC-40 (Fluorinert) solution dip coat. The glass tube is epoxy bonded to an optical window with an annular patterned ground electrode. The lenses are filled with a polar liquid, 1% sodium dodecyl sulfate (SDS) aqueous solution, and a non-polar liquid, dodecane. This functionalized sidewall and bottom electrode sets the voltage between the sidewall and the liquid, allowing for tuning of the interface curvature between the two liquids.

We have simulated and experimentally characterized the dynamics of the liquid-liquid interface as the input driving voltage is changed. The dynamic lens response was simulated under varying input voltage functions, using the measured steady state contact angles. The simulations used the 2D axisymmetric two-phase Laminar flow with a moving mesh model in COMSOL.

For experimental characterization, a 780-nm cw laser is passed through the axis of the device, followed by a 400-μm aperture and a operated from positive curvature (0 V DC) to a flat liquid interface (28 V DC) as shown in Figure 1(a). The exponential driving voltage [Figure 1(b), inset] is generated using a function generator and an amplifier.

3. Results

Experimental results for the response time of the 4-mm lens are shown in Figure 1(b). The transmission of the laser through the aperture is plotted as a function of time. As predicted by simulations, the system response changes from underdamped to overdamped with increasing rise time of the input voltage. Figure 1(c) shows the simulated transient position of the meniscus at the liquid-liquid interface on the axis of the device. As expected, for fast rise times, the sudden motion of the meniscus creates capillary waves that cause the meniscus to oscillate until they decay, while for slow rise times the meniscus motion is gradual with minimal meniscus oscillations.

In our work, we define the response time as the time for the meniscus to settle to within 1% of its steady-state position. Figure 1(d) shows the simulated response time of a 4-mm lens. The response time vs. input rise time has a local minimum, suggesting an optimal rise time for lens operation. The fastest response for the 4-mm device was found to be 115 ms for the input rise time $\tau = 10$ ms. Increasing the input rise time further suppresses the meniscus oscillations, but increases the response time as the overdamped system follows the input voltage function. Pulse shaping to suppress the meniscus oscillations using posicast [10] can enhance the operating speed of the lens even further. Preliminary results show that suppressing oscillation, in the underdamped configuration, is plausible by using multiple exponential input rise time.

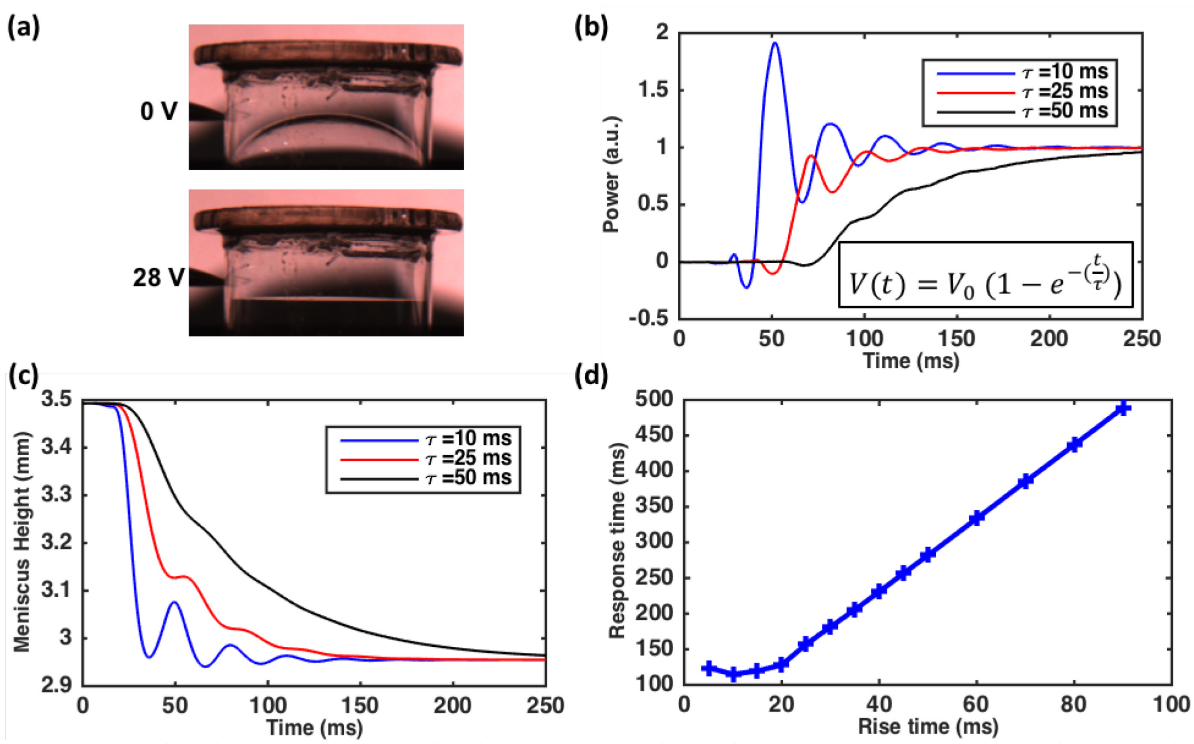

Figure 1: (a) Images of the electrowetting lens tuning from initial curvature to a flat interface at 28 V. (b) Experimental results for the 4-mm lens response time with varying input rise times. The lens response changes from underdamped to overdamped with increasing input rise time. (c) Simulated meniscus position on the axis of the lens at the liquid-liquid interface, the simulations are benchmarked to the experimental results using ray tracing in COMSOL. (d) Calculated response time of the 4-mm lens as a function of input rise time; the plot shows a local minimum suggesting an optimal rise time of 10 ms for the fastest response of 115 ms to drive the lens.

4. Conclusions

We have demonstrated tuning of the dynamic response of an electrowetting lens vs. input voltage function both numerically and experimentally. The response time of a 4 mm lens can be tuned from 115 ms for a 10 ms input rise time to more than 500 ms for a 100 ms input rise time. This strategy can be used to further optimize the response time of the lenses using more complex drive voltages such as multiple exponential rise times.

5. References

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