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Electrowetting optics on target for record optical performance

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Electro-optic technology can create switchable liquid prisms or change the visual area of colored liquids, allowing for significant improvements in wide-angle beam-steering and display applications.

The performance of classical or 'physical' optics remains, as yet, superior to that of electro-optic technology. For example, modern electro-optics cannot match the beam-steering response achieved by simply rotating or tilting a classical glass prism. Similarly, the color rendition of novel electronic-paper products is still far from reaching the visual brilliance of pigments printed onto bleached-wood fiber. For applications from laser radar to reflective displays, demand for improved optical technology is tremendous. This need could be met if one could simply electrically alter the geometry of a high-refractive-index material, or physically move the location of high-performance colorants. Electrowetting of optical fluids can do this, and it also provides a clear roadmap to unprecedented visual performance.

Largely driven by the potential improvement of optical applications, research in this area has seen some 70% annual growth in patents and publications since 2001.[1] The process involves the application of a voltage to a conductive liquid resting on a hydrophobic dielectric and a ground electrode (Figure 1).[2] At zero voltage, the hydrophobic surface results in a very large contact angle. With as little as a few volts, this angle can be reduced[3] by as much as 100°.

Electrowetting microprisms

Electrowetting microprisms rely on refraction of light at the meniscus between a high-refractive-index oil (n>1.5) and a low-refractive-index water solution (n<1.35). For a single prism, oil and water are enclosed in a square box with four individually-controlled electrowetting sidewalls. During prism operation, the oil-water interface is flat. It is tilted by using contact angles that are complimentary at opposite sidewalls (i.e., with a sum of 180°). The prism apex angle can therefore be adjusted[3] by ~30° with DC voltage, and by an even greater range with AC voltage (Figure 1).

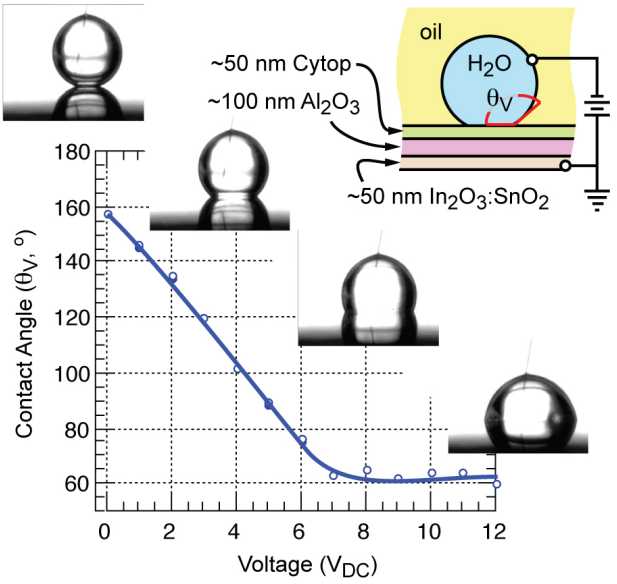


Figure 1. *Low-voltage electrowetting contact angle response.*

The microprism project currently under development will create arrays of millions of microprisms, sized ~50μm each, which are sealed between two glass plates. They can be used to create optical geometries equivalent to, e.g., windows, Fresnel lenses, or linear sawtooth phase profiles. Using high-refractive-index phenyl-based oils, any beam-steering angle within a ~40° cone can be selected. The small prism size allows angular adjustments at frequencies greater than 1kHz, whereas the expected fill factor approaches ≳85%. These attributes far exceed the beam-steering performance of conventional electro-optic technologies, which are typically characterized by only a few degrees of steering capability.

Pixels and chromatophores

Electrowetting pixels are an extension of the basic system of Figure 1. The water-contact angle can reach ~170° for a water/alkane/Cytop® system. Therefore, the alkane-oil contact

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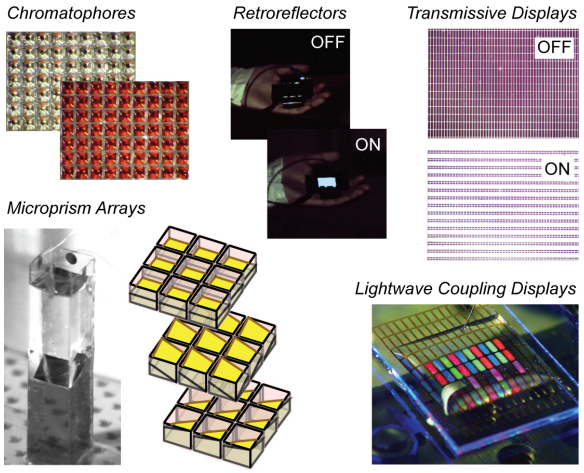


Figure 2. *Examples of recently developed electrowetting optical devices.*

angle is only ∼10° (and is complimentary to the water-contact angle). For displays, the system of Figure 1 is inverted (i.e., water is the ambient medium and oil the droplet). Given the very small contact angle of the oil, it nearly forms a film against the Cytop. (Adding non-polar dyes renders color to the surface covered.) When a voltage is then applied, the water-contact angle decreases, and the oil-contact angle must therefore increase. Thus, the oil transitions from a film (∼100% visual area) to a partial-bead geometry (∼20% area). This change in area can be used to alter surface reflection or light transmission: ∼80% transmission can be achieved, which is ∼10 times greater than that for commercial liquid-crystal display panels.

We have recently integrated ∼50μm-wide transmissive pixels onto display-standard thin-film transistors (Figure 2). We have also constructed flexible electrowetting displays, and a self-assembly process that allows precise and parallel dosing of liquids onto a substrate of any size.[3] In addition, we are developing a new chromatophore device for adaptive camouflage or electronic paper. We expect this new device to have up to ∼20% colorants in the liquid (by weight), <1.5% black-state and >80% white-state reflectivity, a contrast ratio of >10:1, and a closed-cell structure with total thickness <40μm. Such performance is highly favorable compared to existing electrophoretic technology in electronic paper that requires ∼100μm-thick liquid layers and lower white reflectivity of ∼30–40%.

Key challenges and outlook

Since electrowetting devices are already present in liquid-lens products from Varioptic S.A., there is a proven path for electrowetting commercialization. However, most of the new devices under development are arrayed devices (i.e., covering a large area, flat, and containing many individual optical elements). Therefore, the low-voltage push is critical since it allows each individual element, or small groups of elements, to be controlled by a thin-film transistor and active-matrix addressing. In production, this will allow calibration and software correction of contact-angle hysteresis and manufacturing non-uniformity. In terms of materials challenges, the dominant remaining challenge is the development of high-refractive-index oils for optics. High-index oils with low viscosity will allow strong refraction at the oil/water interface. With record-breaking laboratory performance already in hand, there is strong motivation to continue materials and arrayed-device development.

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