Light propagation in electrically driven liquid-core/liquid-cladding optical waveguides with electromicrofluidics

Liquid-core/liquid-cladding optical waveguides offer optically smooth liquid/liquid interfaces to guide light along microfluidic liquid streams with adjustable optical properties. We investigated dielectrophoresis (DEP) on an electromicrofluidic platform to construct reconfigurable liquid-core/liquid-cladding optical waveguides by applying adequate electric fields between parallel plates without the constant liquid supply usually needed for laminar flow in physical microchannels. L-shaped, spiral, and straight stationary waveguides were prepared to investigate light guiding and propagation, whereas moving waveguides were established to perform light switching.

As shown in Figure 1, liquid optical waveguide cores were driven on an electromicrofluidic platform between two parallel plates without physical channel walls. With a sufficient nonuniform electric field, DEP generated surface forces to continuously deform and pump the higher-permittivity liquid (core liquid) along the strong electric field into the region containing the lower-permittivity medium (cladding liquid). Because the core liquid was defined by the electric field instead of by laminar flow along physical microchannels, waveguides with arbitrary two-dimensional shapes were obtained by applying a voltage to appropriately designed electrode patterns on the plates. After forming the waveguide, light was coupled to it.

The core liquid, γ-butyrolactone (GBL, $C_4H_6O_2$, n_{core} = 1.4341, ε_{core} = 39), was tested and manipulated with DEP in silicone oil ($n_{cladding}$ = 1.401, $\varepsilon_{cladding}$ = 2.5) as the cladding liquid by applying a voltage to Teflon-coated ITO (indium tin oxide) electrodes on the inner surfaces of two parallel glass plates. In the stationary L-shaped waveguide, light was guided into the GBL virtual microchannel core for a total of 27.85 mm via a 90° bend (radius 5 mm) before exiting the light outlet with a cross-sectional area of 100 μm × 100 μm. For the stationary spiral waveguide (cross-sectional area of 100 μm × 100 μm), light was guided into the GBL core

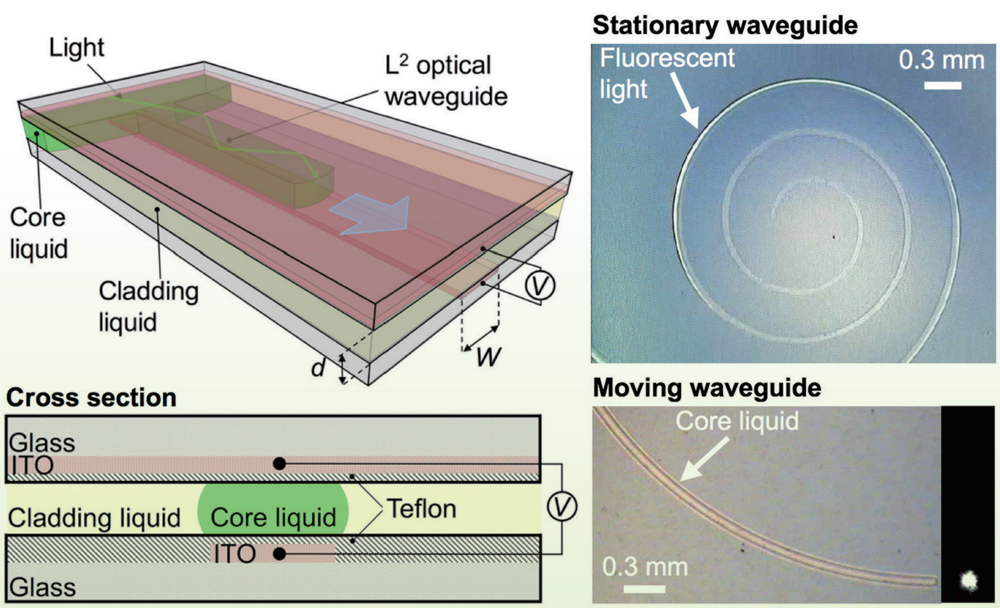

Figure 1. Liquid-core/liquid-cladding optical waveguides driven by dielectrophoresis on an electromicrofluidic platform. Various stationary and moving waveguides were demonstrated.

containing rhodamine 6G (R6G, 1 mM) dye through a series of 90° bends with radii decreasing from 5 mm to 2.5 mm. In the stationary straight waveguide (height 100 µm, width 150 µm), the propagation loss was measured to be 2.09 dB/cm in the GBL with R6G (0.01 mM). To implement the moving L-shaped waveguide, electrowetting and DEP generated a precise GBL droplet and then formed a waveguide core on the electromicrofluidic platform. Upon sequentially applying the appropriate voltage to each of three parallel L-shaped driving electrodes, the GBL waveguide core shifted; the guided light was switched to a speed of up to 0.929 mm/s (switching period 70 ms, switching rate 14.3 Hz) when an adequate electric signal (173.1 V_{RMS}, 100 kHz) was applied.

The DEP-defined waveguide demonstrated simple fabrication, flexible optical and fluidic pathways, and static core/cladding liquids without flow disturbances. The demonstrated liquid-core/liquid-cladding optical waveguides are ready to be integrated with other microfluidic functionalities and optofluidic components on a single electromicrofluidic platform.

Reference

Shih-Kang Fan, Hsuan-Ping Lee, Chia-Chi Chien, Yi-Wen Lu, Yi Chiu, and Fan-Yi Lin (2016). Reconfigurable liquid-core/liquid-cladding optical waveguides with dielectrophoresis-driven virtual microchannels on an electromicrofluidic platform. *Lab on a Chip, 16*(5), 847-854. DOI:10.1039/c5lc01233c.

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A fast-track characterization protocol of spin-orbit torque efficiencies

Spin-orbit coupling is a source of many exotic physical phenomena found in various condensed matter systems; these phenomena, such as the current-induced spin Hall effect (SHE) and the spin-orbit torque (SOT), originate from transition metal-based and emergent material-based magnetic heterostructures. The SHE-induced SOT and its related effects have been widely studied both theoretically and experimentally and demonstrated by harnessing the magnetization dynamics in certain material systems (e.g., Pt-, Ta-, and W-based heterostructures). Therefore, the SOT effect might become a major mechanism for controlling next-generation spintronic devices, such as magnetic random access memory (MRAM)/SOT-

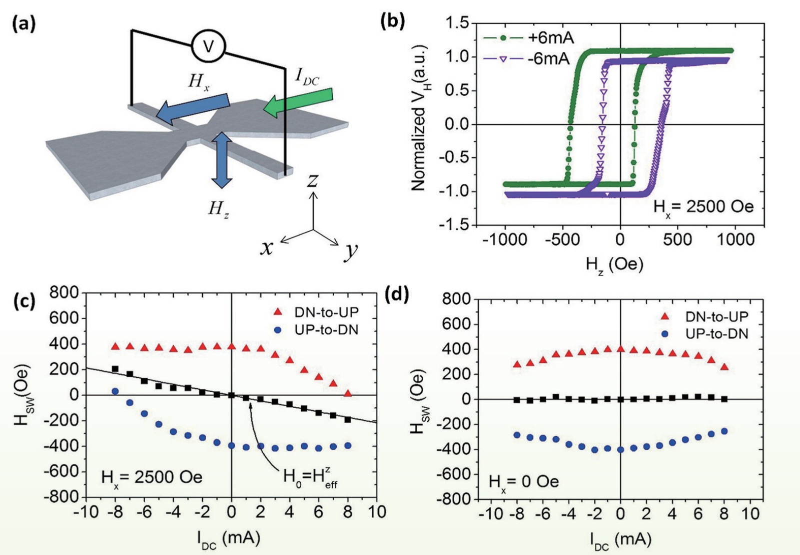

Figure 1. (a) Schematics of the current-induced hysteresis loop shift measurement setup. (b) Representative hysteresis loops under different currents obtained by anomalous Hall voltages. (c) The switching phase diagram of the measured device under an in-plane bias field of 2500 Oe. (d) Without any biasing field, the SHE-induced SOT efficiency is virtually zero. (Reproduced from Ref. 1)