Light-shaped virtual electrodes on Fe:LiNbO$_3$ to control confined droplets

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Introduction

Reliable manipulation of microfluidic droplets is needed for efficient miniaturization of chemical and biological assays [1], as well as for the synthesis of new materials [2] using droplets as units in complex protocols within portable devices. Light-based techniques offer the utmost flexibility due to the advanced technologies for sculpting and shaping light [3]. A wide range of optical methods were investigated to control droplets, such as by mechanical actuation [4], optical trapping [5], photophoresis [6], photopyrophoresis [7], and light-induced dielectrophoresis [8]. Among these techniques, light-shaped virtual electrodes are the most promising for the unlimited control of the electric field configurations. Such a feature is, indeed, highly demanded in the new generation of lab-on-a-chip[10], which aims to integrate multiple operations on different droplets into the same platform.

The photo-induction of virtual electrodes requires a layer within the device capable to convert the light stimuli into charge distribution (e.g. photoconductive, or photopyroelectric). The most exploited material for the generation of electric fields for droplet manipulation (i.e. several kV mm^{-1}) is iron-doped lithium niobate (Fe:LiNbO$_3$). This ferroelectric crystal enabled the light-induced manipulation of microfluidic droplets using virtual electrodes, either generated by its bulk photovoltaic effect [9] or by the optothermally actuated pyroelectric effect [7].

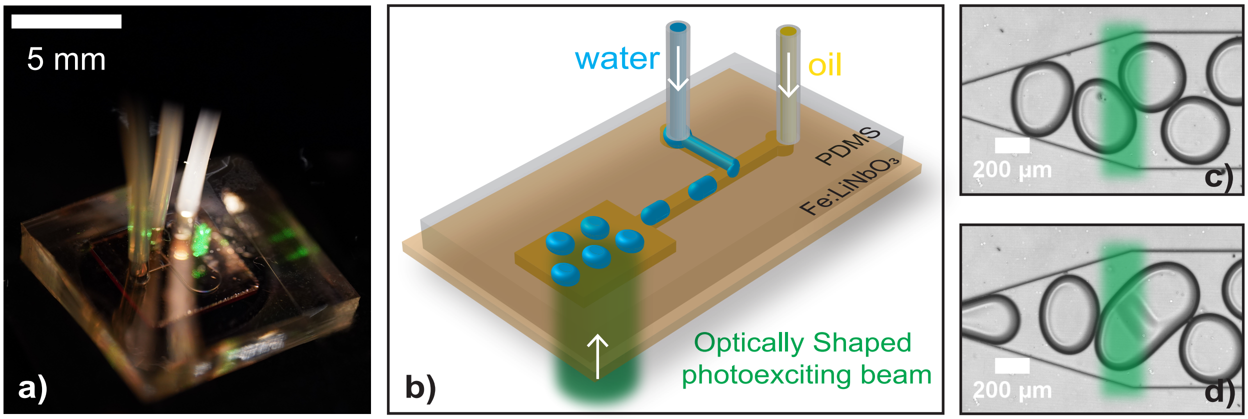

Figure 1: The image in a) shows the device during the exposure of the virtual electrodes with green light from a cw laser. PDMS and Fe:LiNbO$_3$ are the two layers of the devices, shown in the sketch in b). The green light is optically shaped by an amplitude spatial light modulator (Holoeye) in a 4f lens configuration. A 240 µm wide stripe enabled the droplets merging, as shown by two images captured before c) and after d) the exposure of the pattern, respectively.

In this contribution, we present virtual electrodes on Fe:LiNbO$_3$ for the manipulation of confined aqueous droplets (See the device in Fig. 1a)). As in a typical lab-on-a-chip, the droplets flow in a channel with a cross-section smaller than the radius of unconfined ones. As shown in the sketch in Fig. 1b), a layer of Polydimethylsiloxane (PDMS) contains the microfluidic channels, consisting of a T-junction to produce water droplets immersed in an insulating oil medium. The droplets interact with the electric field photoinduced on a 0.5 mm thick Fe:LiNbO$_3$ (Altechna) with an iron concentration of 0.1% mol. Either droplet merging or trajectories are achieved using stripe-shaped light-induced virtual electrodes on the ferroelectric layer. Fig. 1c) and 1d) show an example of two droplets merging right after the exposure of the crystal with a stripe pattern. The number of droplets merged and the speed of the phenomena are proportional to the strip width and light intensity. Similarly, the trajectories of a single droplet can be designed by the shape of the virtual electrodes and the light intensity of the pattern used during the exposure time. Notably, droplet merging presented two different behaviors at two timescales. For exposures in the range of milliseconds, two droplets merge as shown in Fig. 1c), while in the range of seconds the whole emulsions broke into a single larger droplet.

Conclusions

This contribution aims to demonstrate the introduction of light-induced virtual electrodes for the manipulation of aqueous droplets confined in microfluidic channels using a Fe:LiNbO$_3$ crystal. Optical shaping techniques were used to define stripe-shaped virtual electrodes within this platform for droplet manipulation, either for on-demand droplet merging, or controlling droplet trajectories.

The integration of this material in lab-on-a-chip devices may satisfy the demand for the introduction of a reconfigurable droplet manipulation tool. In addition, lab-on-a-chips can benefit from the exploitation of other recent development of this material for this type of application such as an optically integrated system [11] or its biocompatibility [12].

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