TuX2
13.45 - 14.00

Self-assembled liquid microlens arrays activated by pyroelectric effect

P. Ferraro *Senior, IEEE*, S. Grilli, L. Miccio, M. Paturzo, F. Merola, S. Coppola and V. Vespini

Istituto Nazionale di Ottica Applicata, Via Campi Flegrei 34, 80078 Pozzuoli (Na), Italy
pietro.ferraro@inoa.it

***Abstract* - We demonstrate that Tuneable Liquid Microlens Array are self-assembled and controlled by pyroelectric effect on functionalised $LiNbO_3$ substrates. Liquid microlens array having spherical, cylindrical and toroidal shape can be activated.**

I. Introduction

Microlenses have an important impact on micro-technologies in many field such as three dimensional imaging, microelectronics, optical communications, biotechnology. Different approaches have been investigated to fabricate either single and array of microlenses made with different materials. Among the different types of microlenses includes lenses made by liquids. One of the main advantage of liquid lenses is its tunability. For example by using liquid crystals, focal tunability is achieved by changing the index of refraction through application of electric voltage. Differently, in liquid microlenses based on hydrostatic pressure, a deformable membrane allows to change shape of the liquid meniscus to vary its focal power [1]. One valuable method to actuate liquid is based on electro-wetting (EW). By EW [2] various typology of lenses and other optofluidic components have been realized such as prisms, arrays elements for display, optical switches or axicon [3]. Recently a novel concept in EW has been demonstrated and named Pyro-Electro-Wetting (PEW) in which on a polar dielectric substrate the pyroelectric effect can be used to manipulate liquids. We demonstrate that liquid microlens array in an open microfluidic system with various geometric can be activated by a self-assembling process. Thousand of 100µm diameter spherical lenses can be obtained by the PEW approach. Moreover by an appropriate functionalization and preparation of the substrate it is possible to induce spontaneous formation of hemi-cylindrical or even hemi-toroidal liquid structures that could find application as resonant micro-cavities for whispering gallery modes. We have accurately characterized such lens by interferometric method based on Digital Holography. Such an array of liquid microlenses exhibits also a focal power tunability driven by temperature changes. Different types of liquids and also PDMS polymer was proofed to be self-assembled by the pyroelectric effect.

II. Self-assembling of liquid microlens array

We adopted a $LiNbO_3$ crystals as substrate to demonstrate the possibility to get microfluidic lens array. $LiNbO_3$ is a material very well known, in fact it is a key element in optical modulator for fibre optic telecommunication and non-linear optics. We discover that via the pyroelectric effect [4-5] in micro-engineered periodical poled structures in $LiNbO_3$ (PPLN) it is possible to change the topography of a thin layer of liquid quite easily. The topography change allows to build-up a liquid microlens-array activated by temperature gradients on the surface of the $LiNbO_3$ substrate. Our system can be defined as an open microfluidic system. In $LiNbO_3$ any change in temperature ΔT causes a change in the spontaneous polarization ΔP caused by such that $\Delta P = p\Delta T$ where p is the pyroelectric coefficient. As results of temperature change, an imbalance of surface charges between the Z faces is obtained and consequently an electric field is generated along the Z axis of the crystal [6]. $LiNbO_3$ crystals has been functionalized by micro-engineering its spontaneous polarization by means of electric field poling. Temperature changes ΔT create the electric charges patterning. Opposite charges appear at opposite surfaces depending from the orientation of the spontaneous polarization. When a thin layer of liquid is placed on the surface, the electric field generated by the pyroelectric effect induces a change of the topography of the interface liquid-air. In fact the presence of liquid induces, according to the electric double layer model [4-6], the build-up of charges in the liquid medium in very short proximity of the surface (few nm). It is possible to assume that the wettability is locally changed at solid-liquid interface due to the presence of electric forces. In correspondence of the reverse domains wall the charges at interface solid liquid are opposite, and a severe increasing of interface tension is expected. Young's equation is invoked to explain that contact angle θ changes depending from the surface tension at interface of solid-liquid

$$\gamma_{SL} + \gamma_{LG}\cos\vartheta = \gamma_{SG} \qquad (1)$$

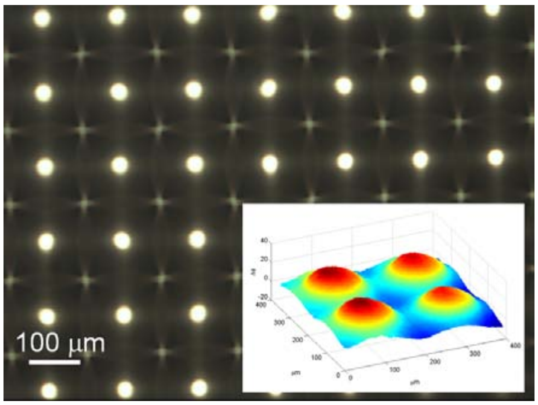
The charges at solid-liquid interface reduce the surface tension, according the Lippman's equation, that relates the applied electric potential V to the interfacial tension (γ)

978-1-4244-3681-1/09/$25.00 ©2009 IEEE

$$\gamma = \gamma_0 - \frac{1}{2} c V^2 \qquad (2)$$

where γ_0 is the surface tension of the solid-liquid interface at the potential of zero charge (i.e. no charges at the surface of the solid) and c is the capacitance per unit area assuming that the charge layer can be modelled as a symmetric Helmholtz capacitor.

From Eq.(2) it is possible to infer that the interface tension solid-liquid γ_{SL} is modulated by the electric potential.



(c)

Fig. 1 Pictures by optical microscope of the focal spot of liquid microlens array. In the inset interferometric measurement of wavefront exit from 2x2 microlenses..

III. RESULTS

The LN samples was covered by a small drop of oil before to put it on a hotplate to increase its temperature up to about 100 °C for about a 60 s. The microfluidic system was observed during the cooling process by an interferometric apparatus based on Digital Holography [5]. Wavefront modifications when a collimated laser beam (plane wavefront) is transmitted through lens-array was analysed. Focal spot obtained by the liquid microlens array and curvature of the wavefront in correspondence of 2x2 micro-lenses of the array ae shown in the Fig. 1. The focal length *f* can be evaluated by the equation of phase of the wavefront by fitting by a polynomial at 2nd order. The curvature of the oil-air surface changes and it arrives down to less than a mm. A cylindrical lens is shown in Fig.2. The cylindrical shape is induced by a different geometry of the poled structure into the substrate. As final example of lenses is reported in Fig.3 where an array of toroidal-shaped liquid droplets is shown.

IV. CONCLUSION

We have demonstrated that liquid and tuneable liquid microlenses can be obtained by spontaneous self-assembling process driven by thermal stimuli. We outline important features of such configuration leading to a new concept in electrowetting. It is an electrodes-less configuration in the meaning that the electrodes are “intrinsically embedded” into the material. The self-patterned lens can found application in optofluidic as well as in bio-microfluidics field.

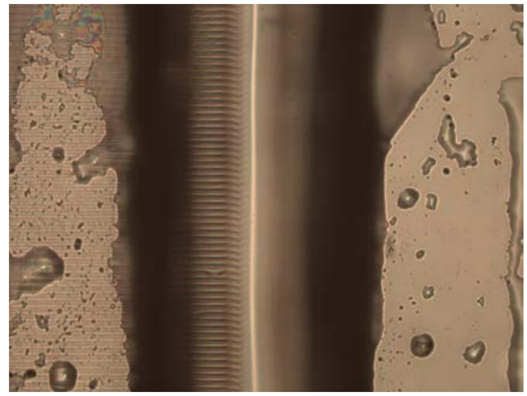


Fig. 2 (a) focal length vs. time during cooling step; (b) focusing of the microlens array.

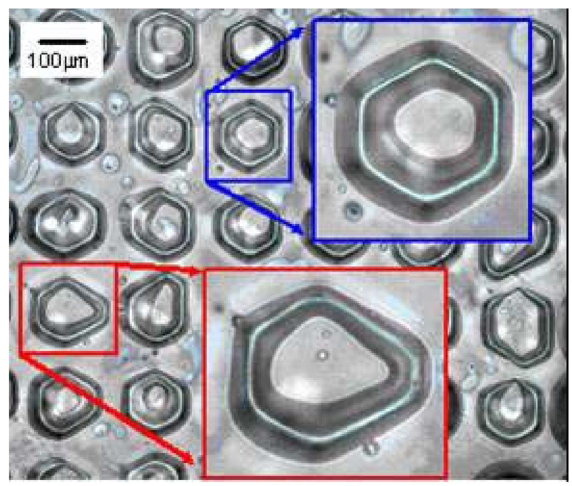


Fig. 3 (a) focal length vs. time during cooling step; (b) focusing of the microlens array.

REFERENCES

[1] P. M. Moran, S. Dharmatilleke, A. H. Khaw, K. W. Tan M. L. Chan and I. Rodriguez, App. Phys. Lett. **88** 0411201-0411203 (2006)

[2] H. Ren and Shin-Tson, Opt. Express **16** 2646-2652 (2008)

[3] H. Ren and Shin-Tson, Opt. Express **16** 2646-2652 (2008)

[4] P. Ferraro, L. Miccio, S. Grilli, A. Finizio, and V. Vespini, Optics & Photonics News 19 (12), 34 (2008).

[5] S. Grilli, L. Miccio, V. Vespini, A. Finizio, and P. Ferraro, Optics Express 16, 8084-8093 (2008)

[6], P. Ferraro, S. Grilli, L. Miccio, and V. Vespini Applied Physics Letters 92, 213107 (2008).

[7] S. Grilli, V. Vespini, P. Ferraro, Langmuir 24, 13262-13265 (2008).