Micro-optical Foundry: "Freezing" Polymer Liquid Instabilities

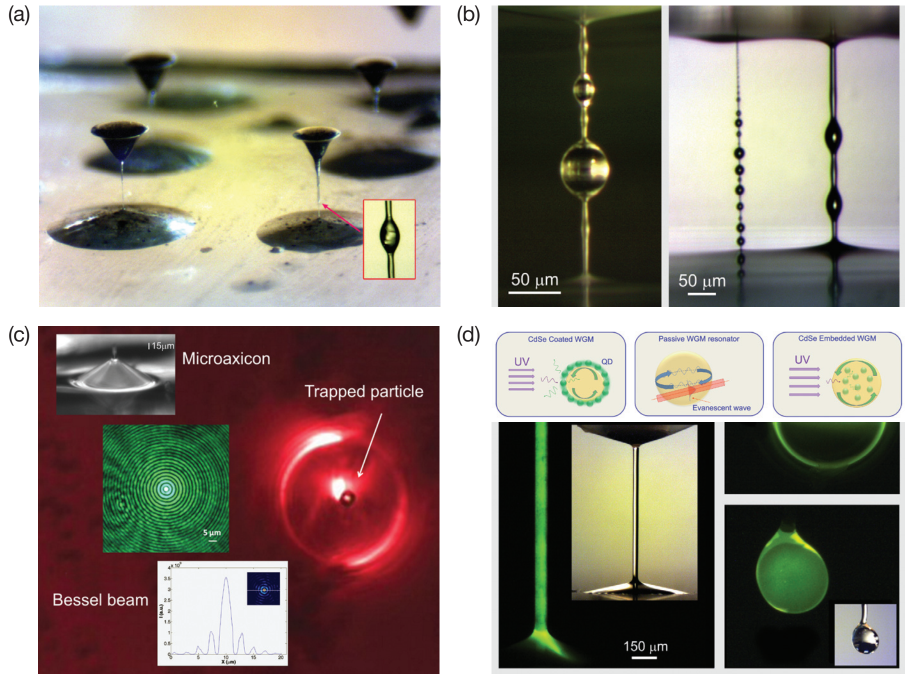
S. Grilli, S. Coppola, V. Vespini, A. Finizio, F. Merola and P. Ferraro

Water droplets exhibit optically smooth surfaces that are naturally stable due to their minimal surface-free energy and surface tension. The pearl-like structures have a liquid interface of nearly flawless optical quality. Mother Nature generates many of these fascinating liquid silhouettes with unsteady structures. Such structures, shaped in polymeric (e.g., polydimethylsiloxane) liquids under an electric field, can be "frozen" by thermal rapid crosslinking for solid figure fabrication. By using this method, it is possible to produce several types of hardened 3-D microstructures.[1]

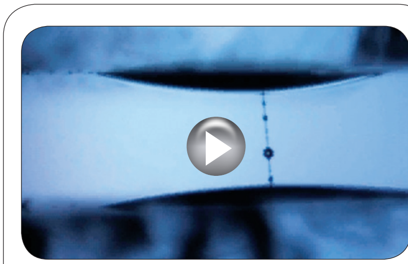
This new concept in lithography is driven by the electrohydrodynamic pressure exerted onto a polymer liquid film. The electric field, e.g., the pyroelectric effect in a lithium niobate crystal ($LiNbO_3$), generates fluidic instabilities at the nanoscale. Cones, beads-on-a-string, pillars, tiny wires and other curious structures with mushroom-like shapes form as a result of the evolutionary history of these fluidic instabilities. The fate of these delicate fluid structures is, of course, collapse. However, if rapid cross-linking is adopted, any of these structures can be "frozen."[1]

Optics and photonics can exploit many of these unstable shapes. Microaxicons have been realized and used for generating Bessel beams. Bessel beams can be used as optical tweezers in microfluidics (i.e., for trapping and sorting particles and biological cells by the light forces), which have clear advantages over Gaussian beams produced by microscope objectives. In fact, undiffracted beams produced by axicons have remarkably higher depth-of-focus and allow simultaneous multiple particle trapping in different planes along the optical axis.[1,2]

Spherical polymer beads are another class of micro-optical elements. Microspheres can be used as either passive or active Whispering Gallery Mode (WGM) resonators.[3,4] As passive WMG resonators, they provide label-free detection of biosamples by classical evanescent field coupling. They can also be used as remotely excitable, i.e., active, microstructures by embedding them with dye or quantum dots. These processes avoid intimate contact between the resonator and the evanescent wave source for coupling light.[5] Spherical polymer beads do not require a complex fabrication processes; and their smooth shells are naturally produced by surface tension. This approach will make possible the development of a novel 3-D lithography concept/platform in which nanoliquid instabilities could be "fluidynamically" designed and fabricated for application in many fields.



(a) Array of polymetric conical and wire structures with beads-on-a-string. (b) Typical spherical structures used as WGM optical resonators. Intensity ring image and Bessel beam intensity profile generated by the "frozen" micro-axicon. (c) On the right, a latex particle trapped by the Bessel beams. (d) Polymer beads applied as optical resonators and luminescent structures by embedding CdSe quantum dots in liquid polymer. Luminescence is excited by ultraviolet laser.



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