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Dispensing nano-pico droplets and liquid patterning by pyroelectrodynamic shooting

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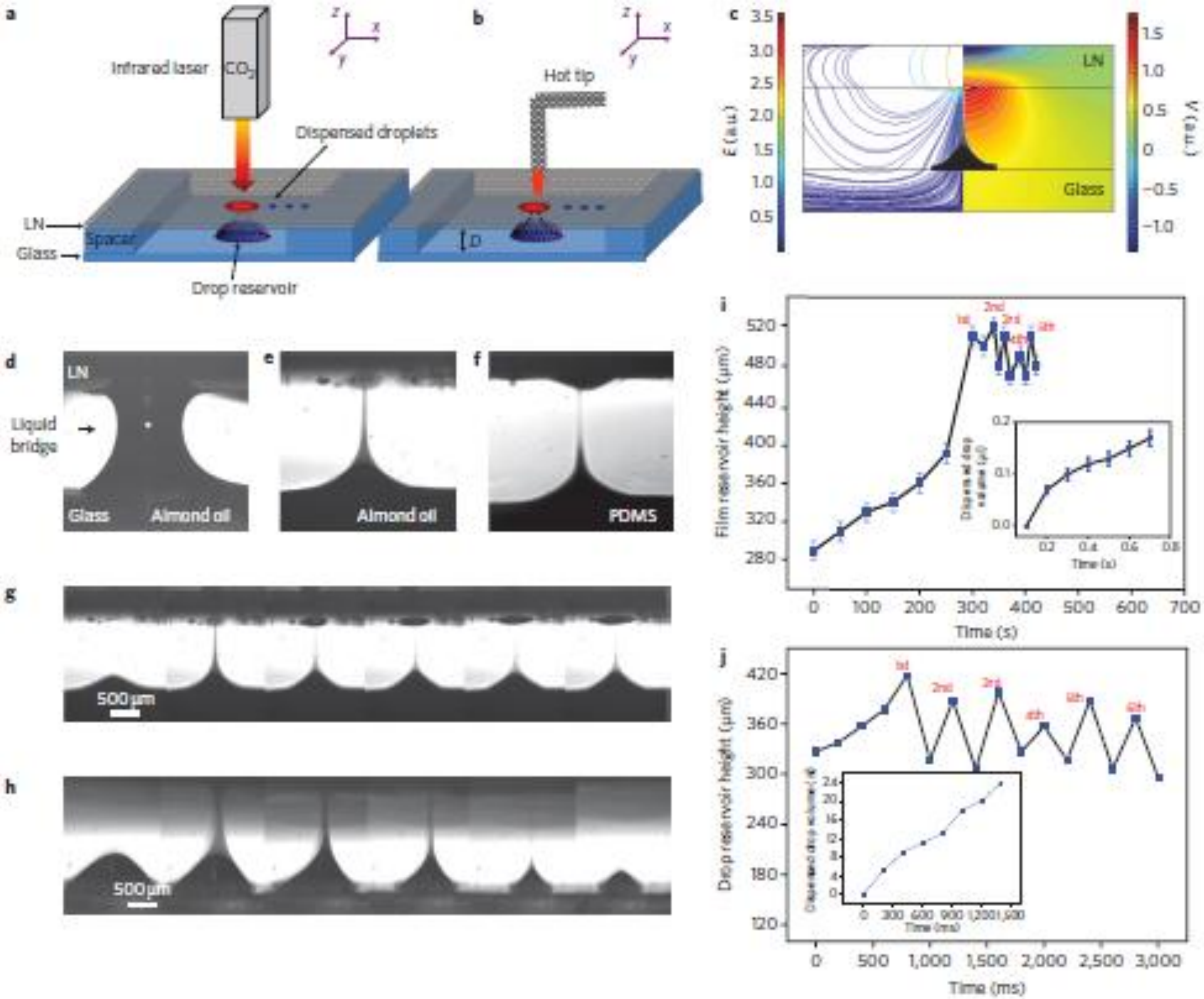
Manipulating and dispensing liquids on the micrometre- and nanoscale is important in biotechnology and combinatorial chemistry, and also for patterning inorganic, organic and biological inks. Several methods for dispensing liquids exist, but many require complicated electrodes and high-voltage circuits. Here, we show a simple way to draw attolitre liquid droplets from one or multiple sessile drops or liquid film reservoirs using a pyroelectrohydrodynamic dispenser. Local pyroelectric forces, which are activated by scanning a hot tip or an infrared laser beam over a lithium niobate substrate, draw liquid droplets from the reservoir below the substrate, and deposit them on the underside of the lithium niobate substrate. The shooting direction is altered by moving the hot tip or laser to form various patterns at different angles and locations. Our system does not require electrodes, nozzles or circuits, and is expected to have many applications in biochemical assays and various transport and mixing processes.

Pyroelectricity

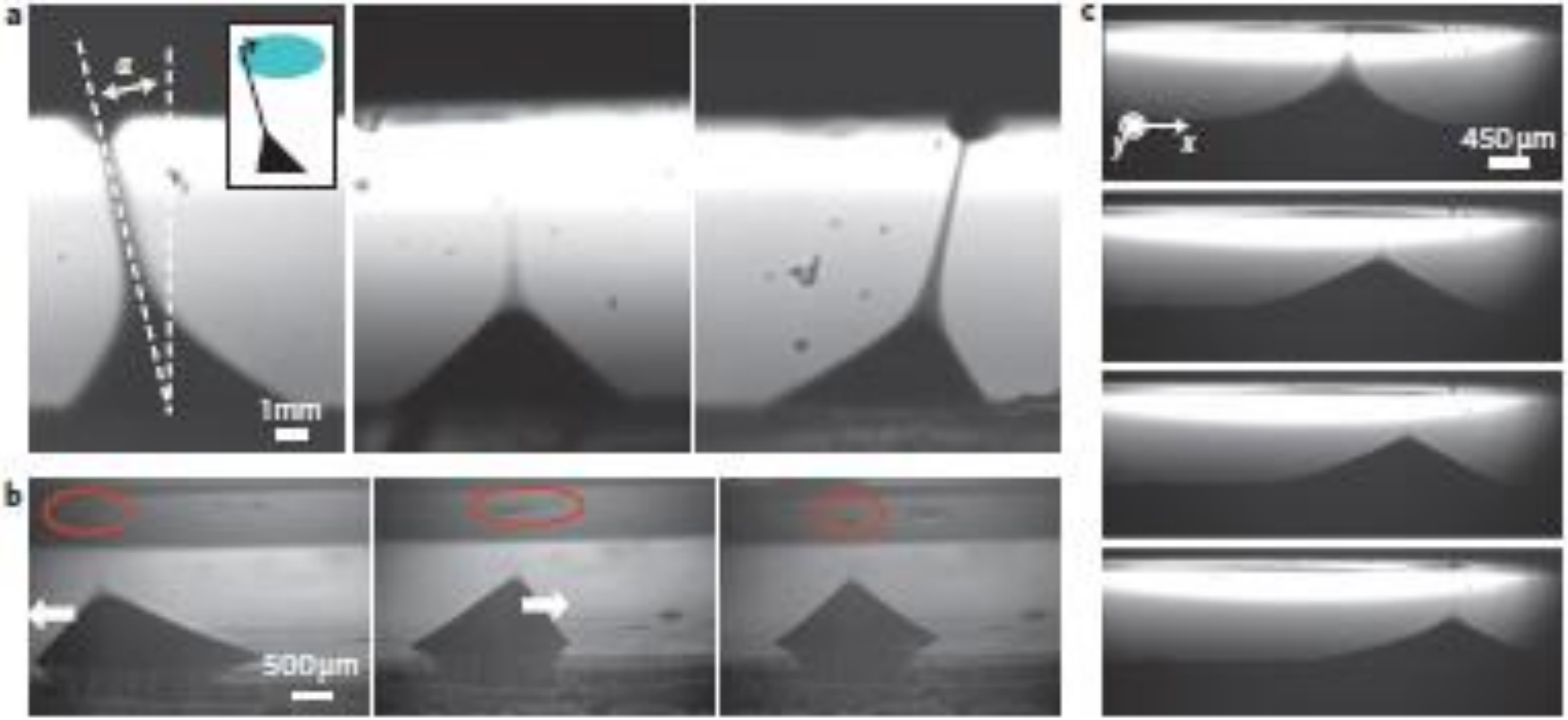
Pyroelectricity (from the Greek *pyr*, fire, and electricity) is a property of certain crystals which are naturally electrically polarized and as a result contain large electric fields. Pyroelectricity can be described as the ability of certain materials to generate a temporary voltage when they are heated or cooled. The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes. This polarization change gives rise to a voltage across the crystal. If the temperature stays constant at its new value, the pyroelectric voltage gradually disappears due to leakage current (the leakage can be due to electrons moving through the crystal, ions moving through the air, or current leaking through a voltmeter attached across the crystal).

Pyroelectrohydrodynamic dispenser



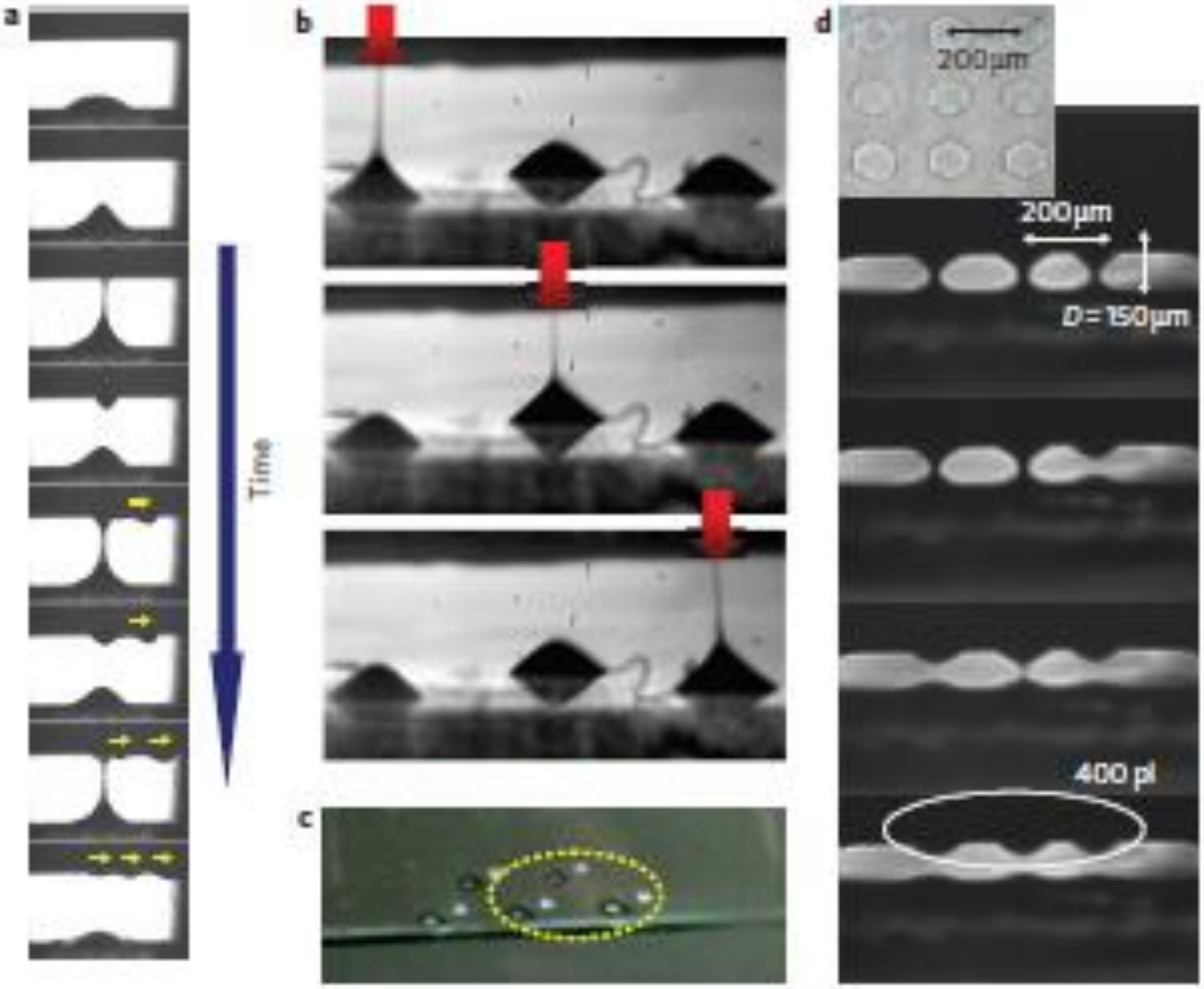
a,b, Schematic of the microfluidic system consisting of two plates and a heat source (an IR laser or hot tip of a conventional soldering iron). c, Three-dimensional axially symmetric plot of the electric field lines (left) and electric potential (right) obtained using the finite-element method. d, Liquid bridge obtained when D is shorter than the critical distance; equation (1). e,f, Shooting of almond oil and PDMS (PDMS has a continuous blasting cone due to its higher viscosity). g,h, Sequence of almond oil shots taken from a film stimulated by hot tip (g) and from a sessile drop stimulated by IR laser (h). i,j, Plot of temporal height variation of the film (i) and drop (j). Single shots are detectable. Insets: plots of the corresponding volume transfer rate.

Functionalities of the dispensing gun



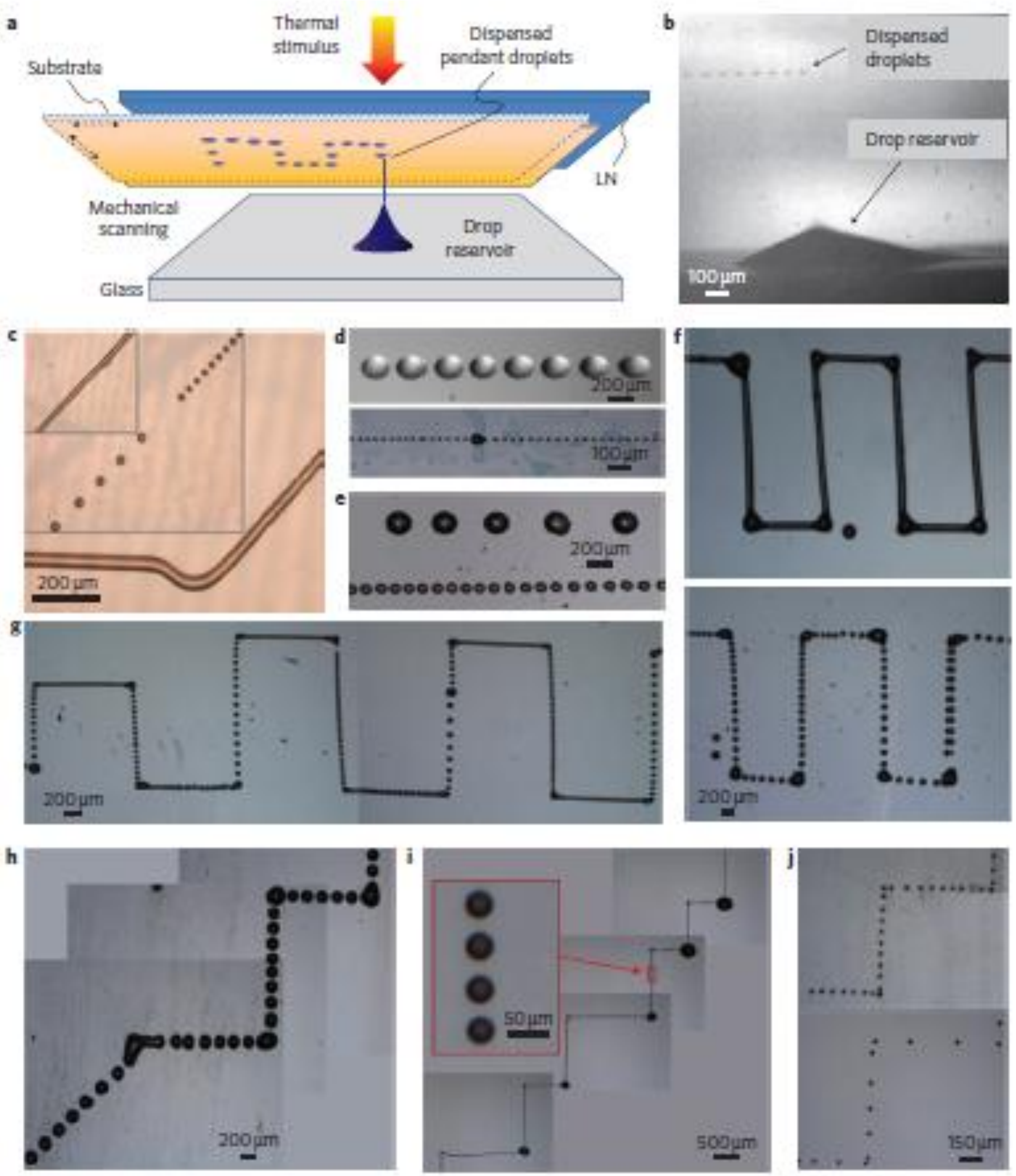
a, Shooting of nanolitre almond oil droplets within a solid angle (off-axis directions up to 208) from a standing sessile drop by moving the hot tip. The liquid was deposited over an area of 23 mm2. b,c, Shooting of almond oil droplets to different locations from a sessile drop (b), which is induced to translate onto the PDMS-coated glass by moving the hot tip beyond the threshold angle, and from a film (c), where the dispensing gun moves more easily and in two dimensions. A lateral displacement of 1.6 mm along the x-axis is visible between the first (top) and last frames (bottom), and the translation of 1 mm along the y-axis is noticeable through the variation in image focus (c).

Additional functionalities



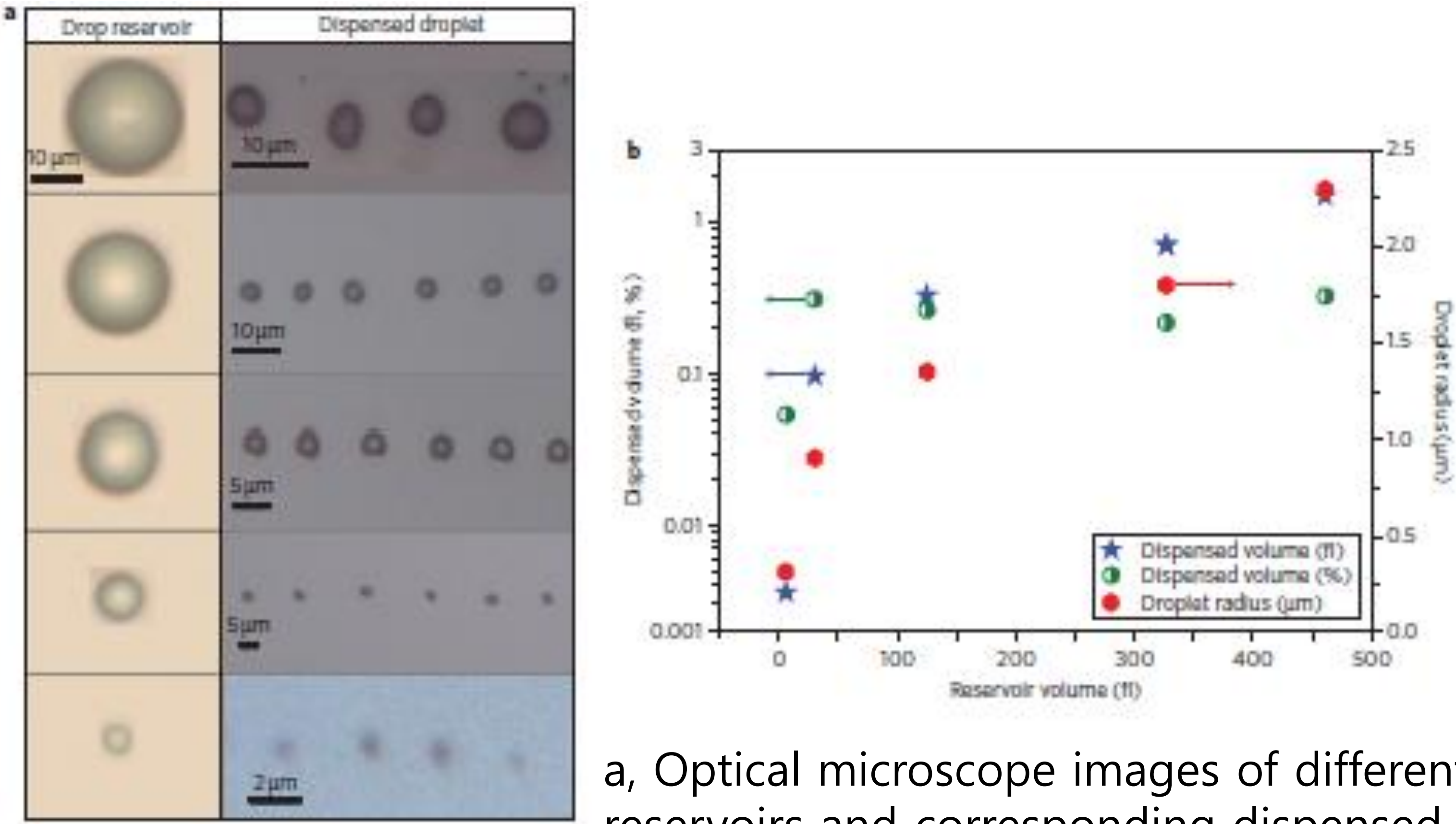
a, Sequential images of the dispensing and successive lateral sliding of nanolitre droplets. The hot tip was positioned closer to the edge of the LN plate, where the glass spacer favoured thermal dissipation and generated colder regions (right side in the picture) where the dispensed droplets slid by thermocapillarity. b, Sequential activation of three different drop reservoirs by the precise spatial scanning of the infrared laser beam.c, Perspective image of five almond oil sessile drops on PDMS-coated glass, where the circle indicates the drops activated in b. d, Simultaneous dispensing of 400-pl droplets of PDMS in correspondence with the ordered reversed domains of a 200-mm periodically poled LN wafer.

Dispensing nanolitre droplets



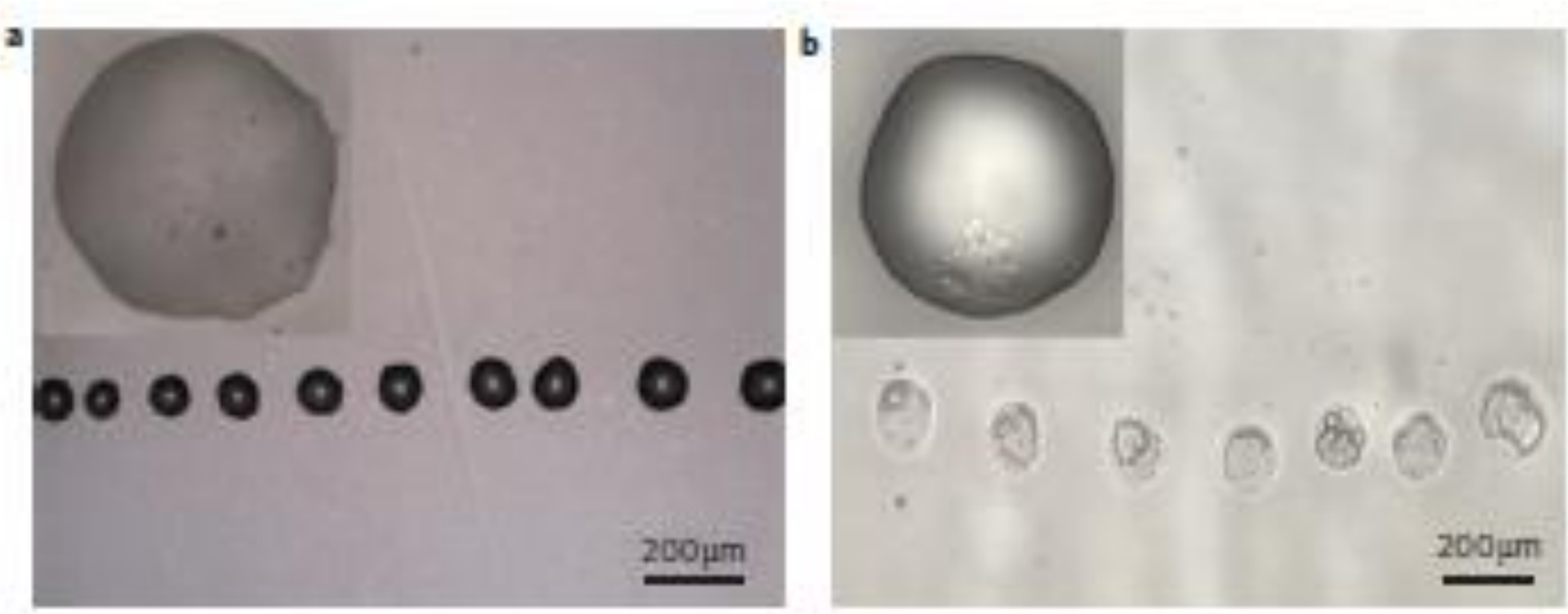
Dispensing nanolitre droplets for liquid patterning. a, Liquid is dispensed onto a translating substrate inserted between the LN and the glass plate. b, Side view of the typical printing functionality. c, Simple patterns printed by oleic acid: separate droplets (diameters, 40 and 25 mm), straight and curved lines (width, 40 mm). d, Linear array of periodic separate droplets printed by almond oil (top) and mineral oil (bottom) (diameter, 15 mm). e, Two parallel printed lines obtained using two different adjacent drop reservoirs. f, Continuous (top) and dotted (bottom) Greek fret printed by mineral oil. g, Continuous and dotted patterned Greek fret. h, Dotted staircase including a non-orthogonal angle. i, Staircase with smaller droplets (25 mm) printed with large vertices. j, Dotted staircase with small vertices (droplet diameter, 30 mm).

Nanoscale droplets



a, Optical microscope images of different drop reservoirs and corresponding dispensed tiny droplets of oleic acid. b, Corresponding volume and radius values of the dispensed droplets versus those of the reservoir (the left y-scale is logarithmic).

Daughter droplets of specific suspensions



a,b, Optical microscope images of dispensed droplets containing carbon nanotubes dispersed in mineral oil (a) and cell cultivation medium mixed with oleic acid, where typical salt crystallization is visible (b).

Conclusion

- Pyroelectrohydrodynamic droplet dispenser based on pyroelectric forces : Attolitre droplet

- After this paper, I could not found a big impact paper. ➔ Why?

- Pyroelectricity materials : Lithium Niobate, Zinc Oxide etc.

- **Check points?**