Droplet microfluidics: fundamentals and applications

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LECTURE SYLLABUS

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I. Fluid mechanics at the microscale.
   1. Navier-Stokes equation, incompressible flows, laminar flows, Stokes equation, lubrication theory.
   2. Confined single-phase flows: Darcy's law, hydraulic resistance in channel networks - electric circuit analogy.
   3. Liquid-liquid interfaces: basics of capillarity and wetting phenomena.
   4. Emulsions: stability, role of surfactants; single-, double- and higher-order emulsions.

II. Microfabrication of microfluidic devices.
   1. Materials: glass, polycarbonate, PMMA, PDMS, resins, etc.; their advantages and disadvantages (resistance to solvents, swelling).
   2. Microfabrication methods: soft lithography, micromilling, etching, capillary pulling, 3D printing, other microfabrication methods.
   3. Surface properties and functionalization of channel walls: hydrophobic, hydrophilic, fluorophilic, solvent-resistant coatings.

III. Multi-phase flows in microfluidics.
   1. Confined two-phase flows: generation of droplets, bubbles and jets, dynamics of a single bubble in a channel (Bretherton problem), dynamics of multiple bubbles – from microfluidic networks (branched '1D' systems) to microfluidic crystals ('1.5D' systems).
   2. Confined three-phase flows: generation of double emulsions, compound jets, soft-granular dripping and jetting, capillary-arrested states.

IV. Applications.
   1. Miniaturization + automation: lab-on-a-chip devices, active vs. passive control: valves, switches, rails, traps, etc..
   2. Material science: from fabrication of porous materials to granular materials and fibers.
   3. Physics and chemistry in droplets: droplets as microreactors (mixing problem), from protein crystallization to colloidal self-assembly, phase separation, self-assembly of lipid bilayers, liposomes (artificial cells), multisomes, droplet networks (artificial tissues).
   4. Single-cell encapsulation: encapsulation statistics, cell barcoding, single-cell sequencing.
   5. Microbiology: encapsulation of bacteria, PCR in droplets, antibiotic susceptibility testing.
   6. Tissue engineering: microfluidic fabrication of hydrogel scaffolds, 3D cell culture in hydrogel droplets and fibers.