# CHARACTERIZING SURFACE-SUPPORTED MICRODROPLETS FOR OPTOFLUIDICS APPLICATIONS: FINAL SUMMARY REPORT

*Alexandr Jonas, Alper Kiraz*
*Department of Physics, Koc University, Istanbul, Turkey*

Optofluidics is a fast-developing research field that exploits unique properties of fluids for creating flexible optical parts and systems which cannot be realized with traditional solid state materials. In this context, liquid microdroplets with spherical geometry, smooth surface, and readily adjustable size, shape, and refractive index are ideally suited for optofluidic applications. The main challenge in using microdroplets in such applications lies in the stabilization of their position and size. For microdroplets of water and other similar liquids, a natural solution lies in depositing the droplets on water-repellent supporting surfaces with superhydrophobic wetting properties. While such surfaces preserve sphericity of aqueous microdroplets (Fig. 1), they also provide a robust position stabilization mechanism and allow interfacing the droplets with other optical and electronic components of integrated lab-on-a-chip systems.

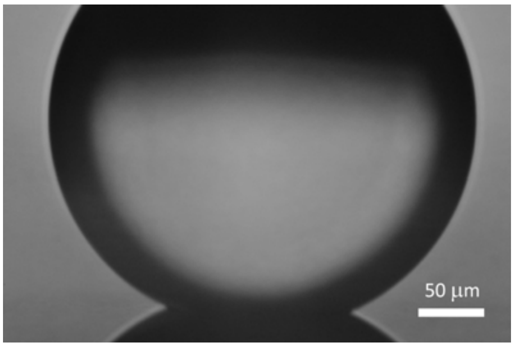

Figure 1: An aqueous microdroplet supported by a superhydrophobic surface (view along the plane of the surface).

In our project, we focused on exploration of intriguing optical properties of surface-supported liquid microdroplets that can act as micron-sized, ultrahigh-quality optical resonators. In general, performance of a resonator can be described by the width of its resonant modes which is characterized by the quality factor (Q-factor) of the resonances. Narrower resonances with higher Q-factors then correspond to better resonators that can confine energy – in the form of oscillations – for longer times. In the case of optical resonators, high Q-factors imply very high density of internal optical field that in turn mediates strong coupling between the light and matter. This strong light-matter coupling, along with the sensitivity of spectral positions of the droplet resonances to the droplet size, shape and refractive indices inside and outside the droplet, is a prerequisite for various applications of liquid microresonators including, for example, miniature sources of laser light or chemical and biological sensors.

We characterized the Q-factors of the optical modes of liquid resonators and studied how the values of Q-factors reflect changes in the droplet and its environment. To this end, we developed original experimental setups and methodology for high-resolution optical spectroscopy of microdroplets based on tapered optical fibers that enabled efficient coupling of tunable-wavelength laser light into the droplets. Newly developed instrumentation and methods then allowed us to carry out unique studies of Q-factors of individual liquid microdroplets standing on a superhydrophobic surface in air. Prolonged measurements in a controlled humidity environment revealed Q-factors of the droplet modes on the order of $10^6$ that were stable on the time scale of an hour (Fig. 2). These values of Q-factors are among the highest achieved with optical microresonators, thus underlining the potential of microdroplets for fundamental quantum-optical studies and practical applications. We carried out pilot experiments that employed controlled heating of the droplet liquid by infrared laser light coupled into the same

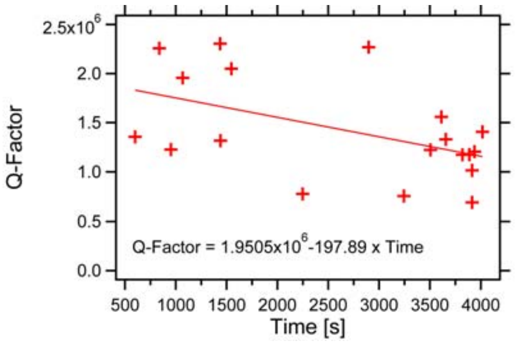

Figure 2: Temporal evolution of the Q-factor of microdroplet optical resonances. Time t = 0 s corresponds to droplet deposition on the surface.

tapered fiber as the probe beam for improved stabilization of the droplet size. We applied time-resolved spectroscopy of the droplet optical modes to characterize droplet mechanical response to periodic external forcing of variable frequency. Thus found mechanical resonant frequencies of the droplets and their dependence on the droplet size served for determination of local contact angles of the droplet liquid on various superhydrophobic surfaces (Fig. 3). This novel experimental method for probing micron-scale wetting properties of solids can be used for characterization of structured surfaces with complex surface chemistry patterning under a wide range of ambient atmospheric conditions. We realized a portable, all-liquid microlaser based on optically pumped dye-doped emulsion microdroplets confined and manipulated in an immiscible host liquid with an optical trap (Fig. 4). We showed high stability of such a laser during prolonged optical manipulation of the droplets and tunability of the laser emission wavelength by changing droplet size and dye concentration inside the droplets. We studied spontaneous formation of filaments of polar liquids on superhydrophobic surfaces with patterned wetting properties and tested potential of such self-assembled filaments as optofluidic light waveguides.

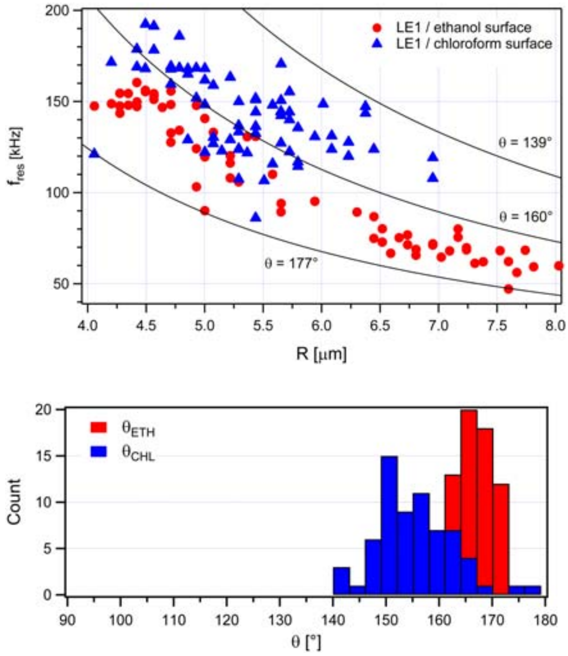

Figure 3: (top) Mechanical resonant frequency of surface-supported microdroplets as a function of the droplet size for two different supporting superhydrophobic surfaces. (bottom) Distribution of microdroplet contact angles θ for the two surfaces.

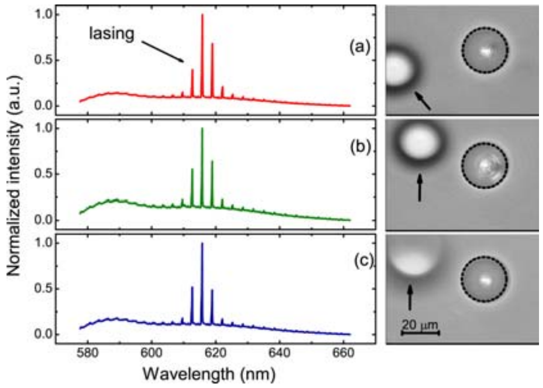

Figure 4: Laser emission spectra from an optically manipulated emulsion droplet (denoted by a dashed circle). Arrows indicate a stationary reference droplet resting on the surface of the sample chamber that is translated past the trapped droplet.

In summary, our work has brought important new knowledge concerning fundamental properties of liquid-based optical resonators formed on solid supporting surfaces and shown how such resonators can be used for monitoring changes in their environment. We expect that the results obtained within the project will contribute significantly to further practical utilization of microdroplets as highly-flexible, disposable micro-optical components of integrated lab-on-a-chip systems in a variety of research fields, e.g. quantum and nonlinear optics, aerosol physics and chemistry, and chemical and biological sensing.

Contact information

Prof. Alper Kiraz[1], Dr. Alexandr Jonas[2]
Nano-Optics Research Laboratory, Department of Physics, Koc University
Rumeli Feneri Yolu, Sariyer, Istanbul 34450, Turkey
http://nano-optics.ku.edu.tr/
[1]e-mail: akiraz@ku.edu.tr
[2]e-mail: ajonas@ku.edu.tr