

Mode and sensing properties of the deformed micro-droplet

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Abstract: The resonant mode along meridian of a deformed droplet on a hydrophilic substrate with different contact angle CA is investigated. A relatively large $Q \sim 2000$ and a sensitivity $S \sim 550 \text{ nm/RIU}$ can still be achieved even with CA down to 150° .

OCIS codes: (140.3945) Microcavities; (280.4788) Optical sensing and sensors.

1. Introduction

Spherical optical microcavities, duo to their large Q value, have been studied for many applications ranging from optical filters, laser sources to high sensitivity sensors etc[1-8]. Among them are droplet microresonators. Compared with solid spherical counterpart, owing to their liquid nature, droplets possesses intrinsic spherical shape and nearly perfect smooth surface which would result in a potential high Q . Specially, when used for liquid analyte sensing, it has a maximum interaction between light wave and analyte. However, it is also due to its liquid nature that it suffers from easy deformation in meridian planes toward a truncated sphere when sitting on a substrate. All the reported droplet resonator were stimulated along equatorial round no matter in a tapered fiber or free space way. In order to maintain the spherical shape and afford an almost perfect equatorial round for whispering gallery mode generation, various methods for fixing a droplet such as suspending the droplet in air (which requires complex position stabilization techniques such as optical tweezing), oil, or on a wire [1,3,4], have been proposed, which are intrinsically unstable and hardly feasible for practical use. The recent year's advances in the superhydrophobic surface technique bring hopes for stable and easy utilization of droplet resonators. A superhydrophobic surface of 180° CA corresponding to no deformation of droplet on it has been reported and a superhydrophobic surface of 155° CA can be routinely obtained very easily. A large CA means a less deformation along meridian of droplet. Therefore, it is prospective to stimulate resonate mode along meridian plane by a planar waveguide embedded in the substrate with superhydrophobic surface where droplet sitting on.

In this presentation, the impact of CA on resonate mode along deformed meridian plane is investigated and its potential application to sensing is also analyzed.

2. Analysis of the deformed microdroplet with different contact angle

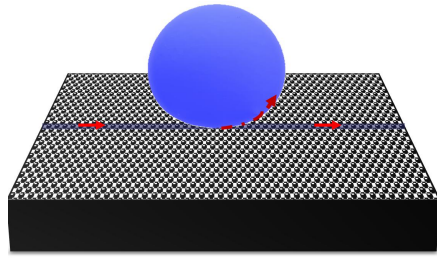


Fig. 1. Geometry of the droplet on superhydrophobic surface

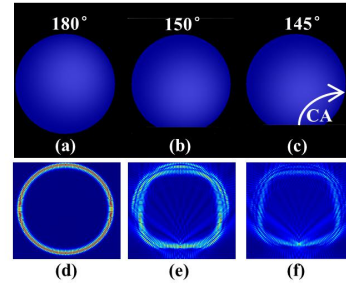


Fig. 2. Cross section (a)-(c) and electric field distributions (d)-(f) of the droplet with CA 180° , 150° and 145° respectively

To simulate the deformation of a droplet toward a truncated sphere on superhydrophobic surface as shown in figure 1, the top section of an ideal sphere are cut with CA of 180° , 150° , and 145° respectively as graphed in figure 2 (a)-(c). The radius r of the ideal sphere is $10 \mu\text{m}$. Considering the absorption loss of water increasing in the near-infrared range, stimulating wavelength around 750 nm is chosen. The electric field distributions of water microdroplet with above three CAs at the resonance wavelength as shown in figure 2 (d)-(f) are obtained by a finite difference time domain (FDTD) method.

To better comprehend the properties of the deformed droplet, the spectrum is measured (figure 3). The quality factor Q , a key parameter, can be evaluated by $Q = \lambda/FWHM$. Here, λ and $FWHM$ which can be achieved from the spectrum are the resonance wavelength and the full width at half-maximum of the resonant wavelength band,

respectively. As shown in figure 3, the *FWHM* increases with contact angle *CA* and thus a smaller *Q*. This is because the loss introduced by the deformation increases at smaller contact angle *CA*. Generally, multiple loss channels including water absorption-related loss, Q_{wat} , radiation-related loss, Q_{rad} , surface scattering-related loss, Q_{ss} , deformation-related loss, Q_{def} , are contributing to the quality factor Q ($Q = 1/Q_{\text{wat}} + 1/Q_{\text{rad}} + 1/Q_{\text{ss}} + Q_{\text{def}}$). Among them, the deformation-related loss dominate the quality factor of our droplet resonator. Moreover, it can be seen that even though the droplet contact angle *CA* is down to 150° , the Q is still relatively large ~ 2000 . The Q , however, will decrease dramatically to 300 as the contact angle *CA* is less than 150° . Those results are in agreement with the mode distributions in figure 2. On the other hand, given that there is a tradeoff between the easy manufacture of superhydrophobic surface and the large contact angle, the droplet with contact angle *CA* between 160° and 150° may bring hopes, which is because that, to data, liquid microdroplets on substrate with high contact angle larger than 150° can be easily achieved by exploiting the superhydrophobic surface.

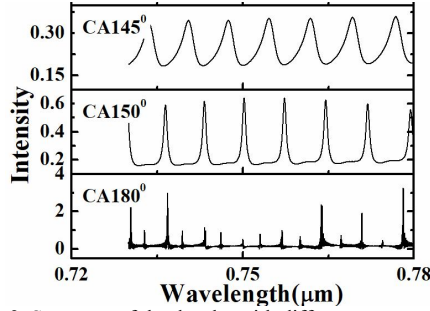


Fig. 3. Spectrum of the droplet with different contact angle

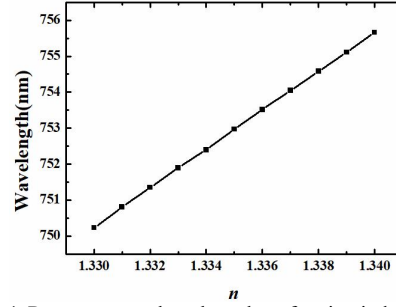


Fig. 4. Resonant wavelength vs the refractive index n of the droplet

As an application of the deformed water microdroplet with contact angle 150° , we demonstrate an optic refractive index sensor with a high sensitivity. This microdroplet resonator serves simultaneously as the sample and optical cavity. For refractive index sensing, shifts in resonant frequency occur when the effective refractive index of the droplet changes. Sensitivity, a key parameter in characterizing such a refractive index optical sensor, is defined as the shift rate of the resonances: $S = d\lambda / dn$. Where n denotes the refractive index of droplet to be detected. We can derive S by changing n and calculating the resonant wavelength. To demonstrate this potential, figure 4 plots a very good linear dependence of the resonance wavelength on n . For the typical evanescent wave interaction with the fluid, the sensitivity is below 100nm/RIU [5]. While for this non-evanescent wave with high optical field in the water droplet region, a high sensitivity of ~ 542 nm/RIU can be achieved. Furthermore, this system can easily cooperate with electrowetting. Using this technique, the droplet can be driven to move to contain the target analytes (biological species or chemical reagents) and thus a digital sensor in real-time can be obtained.

3. Conclusion

In conclusion, we have studied a deformed microdroplet with different contact angle *CA*. Results show that although the droplet contact angle is small to 150° , a relatively high $Q \sim 2000$ and a high sensitivity $S \sim 542$ nm/RIU can be still achieved. This work was supported by National Natural Science Foundation of China (61775008).

4. References

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