Optical manipulation with an optothermal surface bubble for ultrasensitive sensing

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Abstract: We report an optical manipulation method based on an optothermal surface bubble. Nanogap-rich structures that are fabricated with this method are used to detect chemical substance down to femtomolar concentrations.

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1. Introduction

An "optothermal surface bubble (OSB)" describes a micro/nano-sized bubble that is formed at a liquid–solid interface through a laser-induced thermal effect (i.e. an optothermal effect). In this process, a laser beam is focused on an absorbing surface or nanostructure to heat up that area selectively. Above a certain minimum power of the laser, a gas bubble can be generated on the surface where the laser is focused. The bubble stays in contact with the surface in a truncated spherical shape; therefore, we call it a "surface bubble" to distinguish it from a "floating bubble" that suspends in the liquid [1].

Once the OSB is formed on a surface, its position and size on the surface can be remotely controlled by changing the laser focal position and power. This non-invasive and maneuverable OSB also induces a temperature gradient and a long-range hydrodynamic force that can be used for a wide variety of applications [2–6]. We will demonstrate the rapid and cost-effective fabrication of nanogap-rich structures for the ultrasensitive bio and chemical sensing [7].

2. Results and Discussion

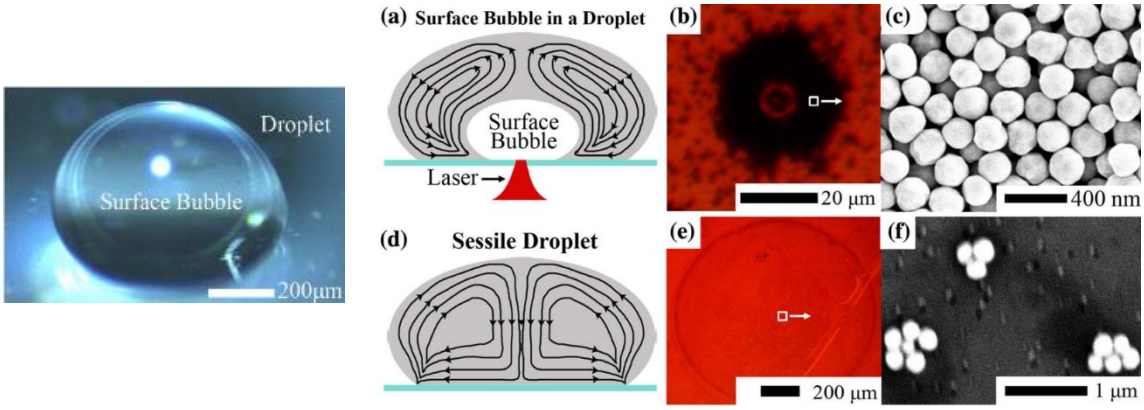

Fig. 1. The figure to the left shows an OSB inside a water droplet. (a) Schematic of the flow pattern around a surface bubble inside a droplet. (b) Optical image of nanogap-rich structures formed on a gold-coated cover glass. (c) The SEM image of the corresponding area marked in (b) with a white box. (d) Schematic of the flow pattern inside a sessile droplet. (e) Optical image of the final pattern formed on the same substrate due to the coffee-ring effect. (f) The SEM image of the corresponding area marked in (e) with a white box. Images are from Ref. [7].

An OSB that is generated inside a water droplet with a continuous-wave laser is shown in Fig. 1. Associated with the OSB is a Marangoni convection inside the droplet that can be used to deposit gold nanoparticles (GNPs) on the substrate as schematically shown in Fig. 1a. The laser power at the donor substrate can be carefully calibrated following the same procedure as discussed in Ref. [2]. Fig. 1b shows the optical image of the final structures that are deposited on the substrate. Fig. 1c shows the SEM image of the GNPs in the area marked by a white box in Fig. 1b. GNPs accumulate on the substrate and form nanogap-rich nanostructures. It should be noted that GNPs can also be deposited on a substrate by evaporating a sessile droplet of GNP solution; however, the GNPs will be deposited at the edge of the droplet but not in the center as shown in Fig. 1e and 1f. The natural evaporation induces a primary radial flow in a droplet as schematically shown in Fig. 1d. The radial flow typically carries the GNPs to the periphery of the droplet and forms a concentrated ring pattern, known as the "coffee-stain effect".

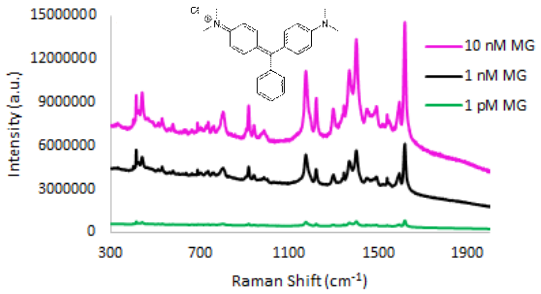

Fig. 2. Surface enhanced Raman spectroscopy of Malachite Green at different concentrations.

The GNPs forms nanogap-rich structures that can be used as an effective SERS (Surface Enhanced Raman Spectroscopy) substrate for bio and chemical sensing. Malachite green (MG), an organic compound that was used controversially as an antimicrobial in aquaculture, is detected with our method. The MG residual in fish may result in adverse health consequences for humans. Fig. 2 shows the Raman spectrum of MG at different concentrations. The detection of MG with concentration as low as femto molar is possible with our method.

3. Conclusion

An OSB can be used for the rapid and affordable fabrication of SERS substrate for the concentration and detection of bio and chemical substance.

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