Vivid pulsations of an oil droplet induced by laser

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In previous work [1] we reported that directed forward and backward motion of an oil droplet floating in an aqueous solution can be generated by using a laser beam. This motion is caused by local heating that induces a specific mode of steady convection inside the droplet, and this generated convective motion produces translational directed motion of the droplet.

In the present study, we performed experiments on a nitrobenzene oil droplet in a water solution under strong laser irradiation. Pulsating motion of an oil droplet, with aluminium powder inside, floating in an aqueous solution is generated by using a continuous laser beam. This oscillation is caused above a certain critical power of the laser, and above this value the frequency increases almost linearly with the power.

Figure 1 shows the floating geometry of a droplet in an narrow cylindrical glass vessel. The laser beam is aimed at the oil droplet from above. The oil droplet pulsates (or oscillates) depending on the laser power: the higher power of the laser is the faster droplet oscillates.

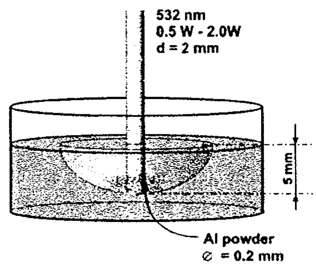

Figure 1: Schematic diagram of the experiment: a c.w. laser beam irradiates the droplet (approx. 5 mm in diameter) from above.

For greater detail, in Fig. 2 we show a spatio-temporal plot of the oil droplet movement throughout the whole experiment. The snapshots were prepared using a CCD camera attached to the front wall of the vessel.

The key point of these experiments on the forcing to pulsate of an oil droplet by a laser beam is that local heating of the oil leads the system far from equilibrium, and as a result to complex non-stationary convection inside the droplet. For a detailed analysis of convective flow in oil, we conducted some experiments and concentrate attention on movements of oil inside the droplet.

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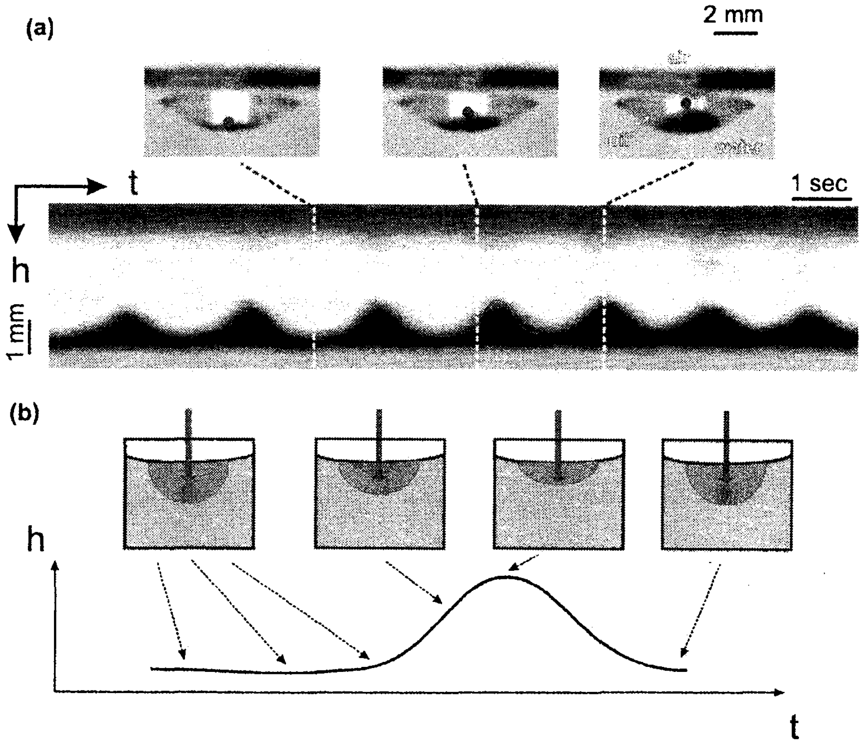

Figure 2: (a)Spatio-temporal images of droplet oscillations constructed from time-successive video frames. (b)Single time-period trace of the spot depicted in red in (a) and schematic representation of the droplet pulsation in the different phases of motion.

We consider a simple phenomenological two-species model to demonstrate the above descried oscillations. The model assumes that, in the present of aluminium particles (with the total amount N) at the bottom of oil droplet under laser irradiation, the temperature T of the bottom part grows exponentially until a specific critical value. The resulting mathematical model is a system of two ordinary differential equations,

$$\begin{aligned} \frac{dN}{dt} &= rN(N_0 - N) - \frac{aT}{b+T}N \\ \frac{dT}{dt} &= cNT^2 - \frac{dT}{N^{\varepsilon}} \end{aligned} \tag{1}$$

where N is the total amount of the aluminium particles, T is the temperature at the bottom of droplet, r, a, b, c, d and ε are the parameters. The amount N follows the logistic growth law (first term) and the rapid decrease (second term) when the temperature reaches the threshold. The temperature T grows exponentially due to the laser energy adsorption (heating term) and falls down (cooling term) because the convection removes the particles from the laser irradiating region.

References

[1] S. Rybalko, N. Magome, and K. Yoshikawa, Phys. Rev. E **70**, 046301 (2004).