Radiation Force Effect at the Dielectric Water-Air Interface

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Introduction: The effects of radiation pressure exerted on a dielectric surface exposed to electromagnetic radiation has been a long-standing debate for over a century. The effect can be interpreted as the transfer of momentum from photons at the surface in the direction of propagation of the incident electromagnetic radiation[1,2].

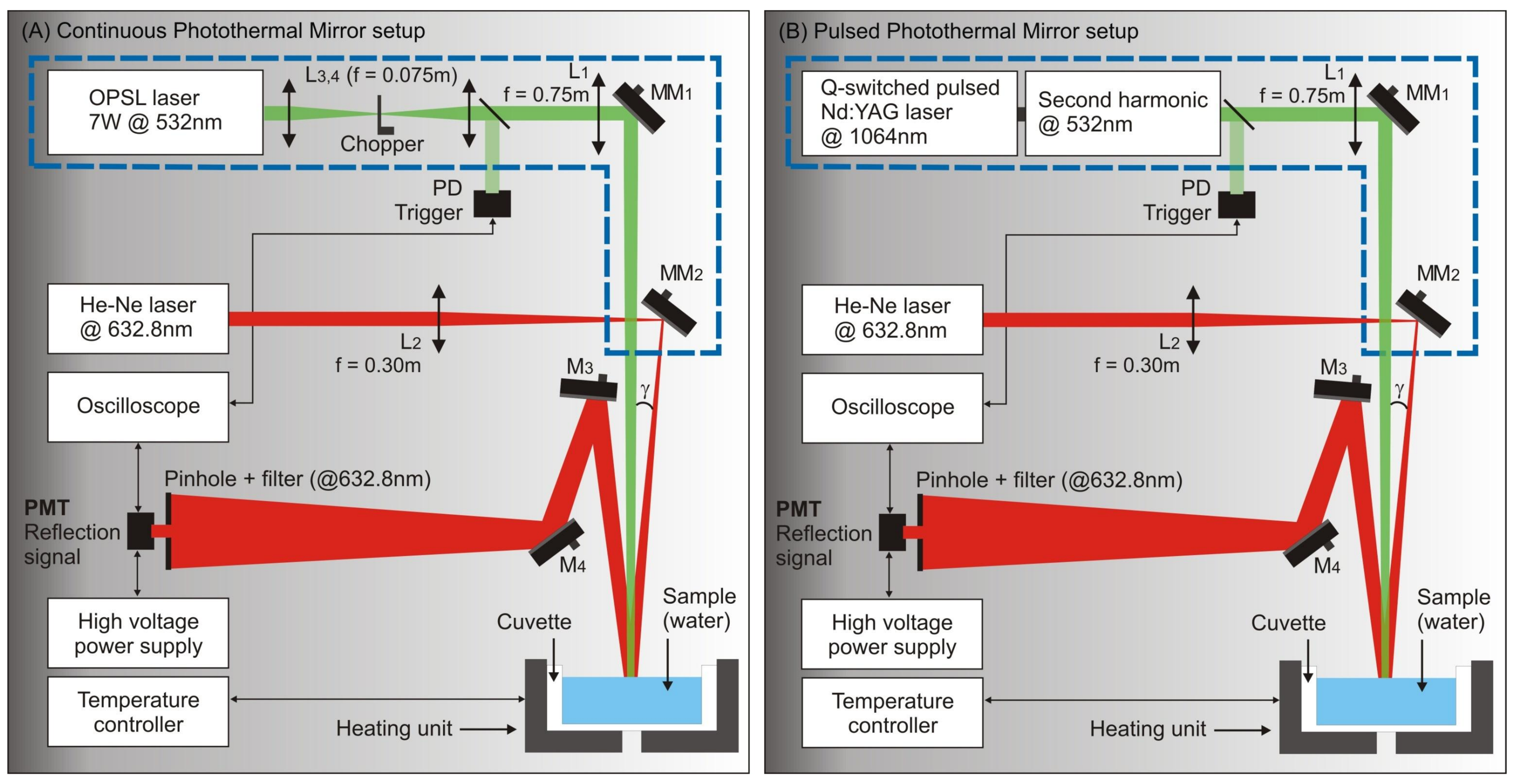

Figure 1. Schematic diagram of the time-resolved photomechanical mirror under continuous (a) and pulsed (b) experiments[1].

Computational Methods: The radiation force effects on the surface displacement can be calculated by solving the Navier-Stokes equation with appropriate boundary conditions. The surface deformation can be described by the radiation pressure as well as those forces due to gravity and surface tension.

Navier-Stokes equation:

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p + \mu\nabla^2\mathbf{u} + \mathbf{F}$$

$$\nabla\cdot\mathbf{u} = 0$$

Volume force:

$$\mathbf{F} = -\rho g\,\hat{z}$$

Pressure radiation:

$$P_{cw}(r,t) = -\frac{2}{c}\left(\frac{n-1}{n+1}\right)\frac{2P_e}{\pi w_e^2}\exp\left(-\frac{2r^2}{w_e^2}\right)$$

$$P_{Pulsed}(r,t) = -\frac{2}{c}\left(\frac{n-1}{n+1}\right)\frac{2Q}{\pi w_e^2}\exp\left(-\frac{2r^2}{w_e^2}\right)\frac{1}{t_0}\exp\left[-\frac{(t-\xi)^2}{\tau^2}\right]$$

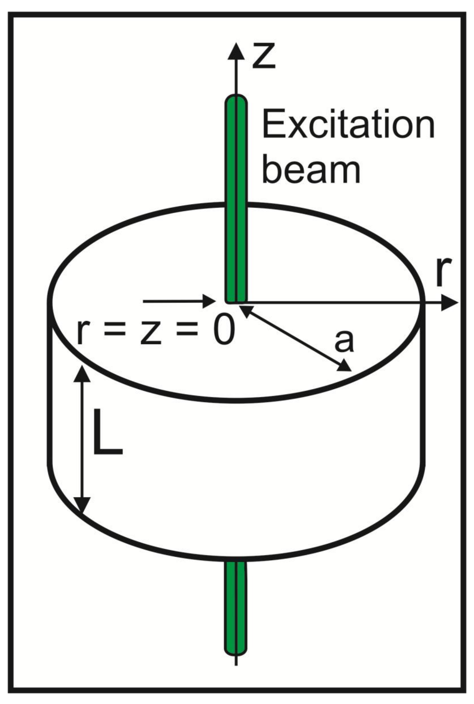

Figure 2. The model was built in the 2D axisymmetric geometry.

Table 1. Parameters used for the simulations.

	Variable	Value	Units
ρ	Density	998.2	Kg/m^3
μ	Dynamic Viscosity	0.893	10^{-3} Pa.s
σ	Surface Tension	72	N/m
n	Refractive Index	1.33	
a	Radius	30	mm
L	Thickness	8	mm

Results: Figures 3 and 4 display the actual deformation of water at different exposure times[1]. Under continuous (cw) excitation, the liquid surface rises with time reaching a maximum deformation of around 30nm at the center of the excitation beam, Figure 3. As for the pulsed excitation, a sharp peak appears at short time, which is dispersed rapidly on the surface, Figure 4.

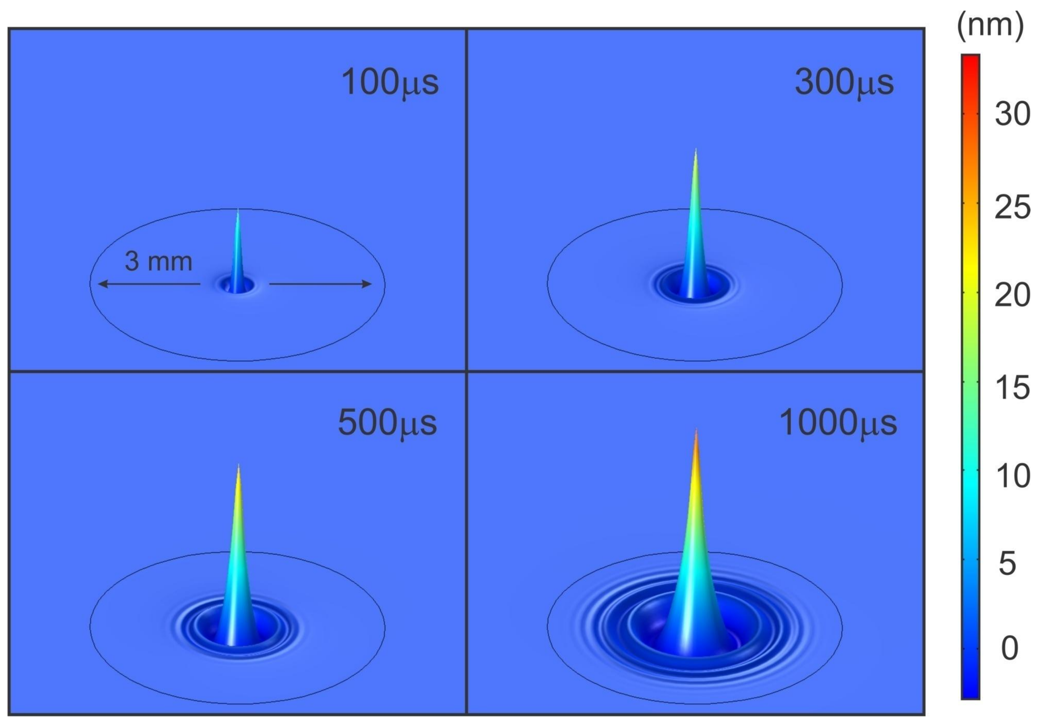

Figure 3. Water surface deformation under cw excitation.

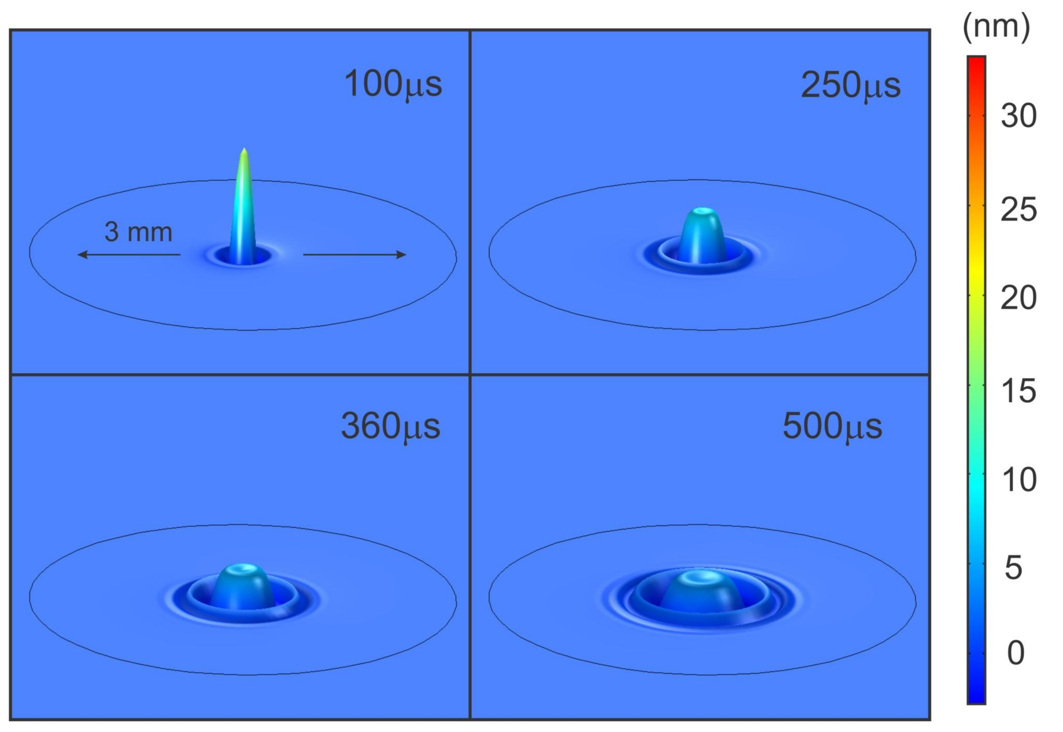

Figure 4. Water surface deformation under pulsed excitation.

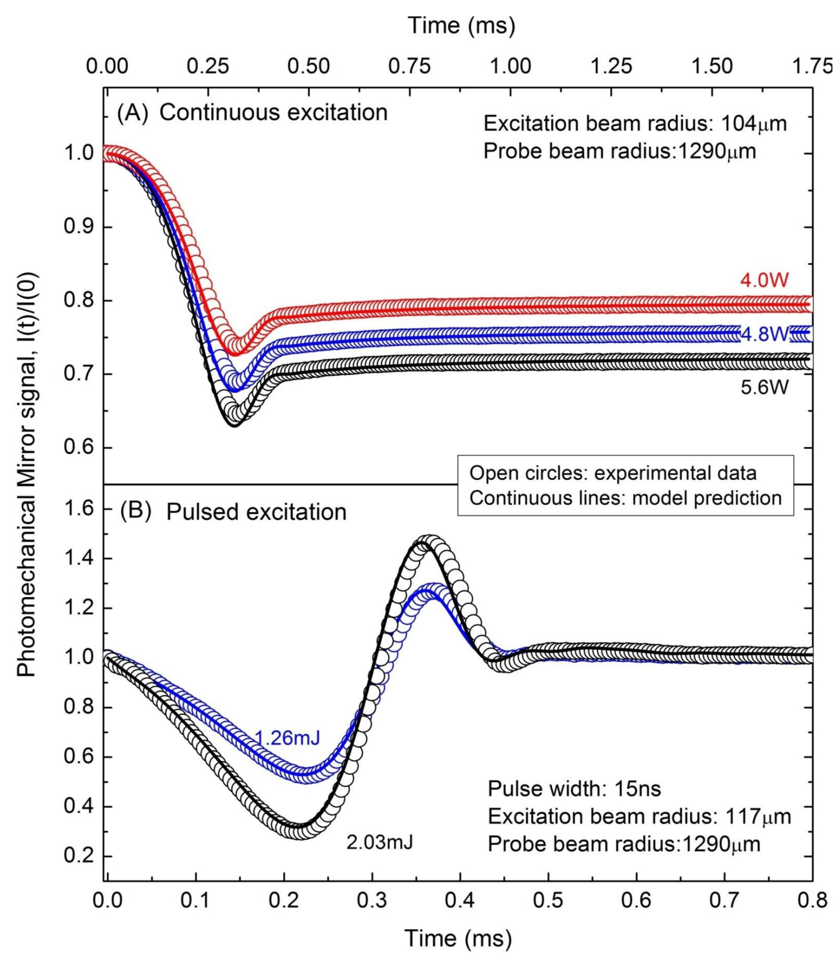

Figure 5. Time-resolved PM transients[1].

Conclusions: The numerical predictions are in excellent agreement for both the continuous and pulsed excitation transients. In fact, it shows quantitatively that the effects of radiation forces in water can be fully described.

References:

1. N. Astrath et al., Unraveling the effects of radiation forces in water, Nature Communications, 5, 5363 (2014).
2. R. Pfeifer et al., Colloquium: Momentum of an electromagnetic wave in dielectric media. Rev. Mod. Phys., 79, 1197-1216 (2007).

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