Supplementary Information

Laser-Assisted Photothermal Heating of a Plasmonic Nanoparticle-Suspended Droplet in a Microchannel

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1. Finite Element Analysis of Microdroplet Temperature in a Microchannel

Upon the calculation of the spectral absorptance distribution, the total volumetric photothermal absorption rate can be calculated by

\[ q^w(z) = \frac{d}{dz} \left[ \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \tau A_\lambda(z) P_\lambda \, d\lambda \right] \]

where \( \tau \) is the transmittance of the PDMS microchannel cover, and \( P_\lambda \) is the spectral laser power density. The laser power density was assumed to be wavelength-dependent with Gaussian distribution that has a full-width at half maximum of 3 nm. In order to calculate the temperature distribution of a microdroplet-in-microchannel system, the present study numerically solved the heat transfer equation using a commercial finite element analysis package (COMSOL Multiphysics). The FEA domain is illustrated in Figure S1a, where a nanoparticle-suspended droplet is placed in the center and mineral oil is filled in the remaining of the PDMS microchannel. The heat transfer equation can be written as

\[
\rho c \frac{\partial T(\mathbf{r}, t)}{\partial t} = \nabla \cdot (k \nabla T) + q^w(\mathbf{r}) \quad \text{\# MERGEFORMAT (2)}
\]
Where $\rho$ is the density, $c$ is the specific heat, and $k$ is the thermal conductivity. It should be noted that a microdroplet was assumed to be stationary and natural convection within the microdroplet was not considered, as the Rayleigh number was found to be $\ll 1$. Since the volume concentration of nanoparticles under consideration is very low (i.e., less than 1 %), thermophysical properties of the nanofluid droplet were assumed to be the same as those of pure water. Figure S2 shows the computation results for GNS and GNR suspension cases, demonstrating the capability of photothermal heating in a microchannel due to the enhanced light absorption upon the localized surface plasmon excitation.

2. Video Clip for Bubble Formation in a Microdroplet

The supplemental video 1 shows local bubble formation in a ~30 nL GNR PNF droplet of ~20.0 ppm GNR concentration as a result of laser heating at 10x magnification. The GNR/QD solution was not well dispersed, leading to coalescing of vapor and induced flow within the microchannel. The medium surrounding the droplet is mineral oil and the laser power density is ~200 W·cm$^{-2}$.

3. Video Clip for Convection in a Microdroplet

Supplemental video 2 shows local convection within a ~30 nL GNS PNF droplet of ~0.5 ppm GNS concentration as a result of laser heating at 20x magnification. The surrounding GNS particles, as well as the small agglomerations, can be seen being drawn into a circulating column of fluid centered about the laser spot of ~550 W·cm$^{-2}$ power density.
Figure S1. (a) Full FEA model in COMSOL with dimensions and subdomains: PDMS, water, and mineral oil USP labeled 1, 2, 3 respectively. (b) The discretization process of the volumetric heat generation in the microdroplet. (c) Fully meshed FEA model in COMSOL: 2807 tetrahedral elements and 106729 degrees of freedom.
Figure S2. Simulated temperature steady-state distribution under 500W·cm\(^{-2}\) and 450W·cm\(^{-2}\) respectively for (a) 0.5ppm GNS concentration (b) 20.0ppm GNR concentration. **Top-to-bottom:** 3D isothermal plot, x-axis temperature profile (a\(_1\),b\(_1\)), y-axis temperature profile (a\(_2\),b\(_2\)), and z-axis temperature along microchannel center (a\(_3\),b\(_3\)).