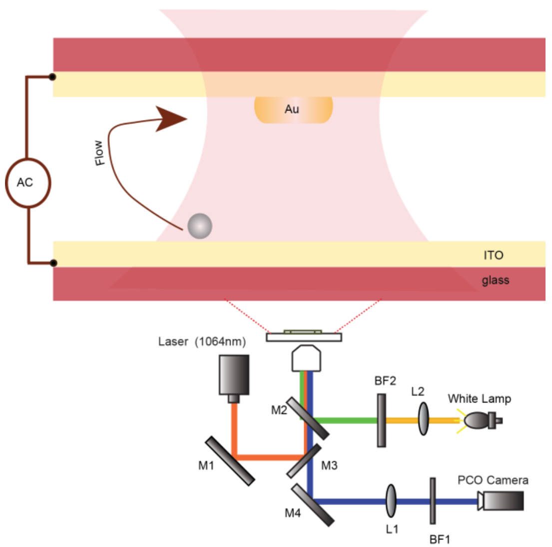
Plasmon-Assisted Optoelectrofluidics

PURDUE UNIVERSITY Discovery Park

Justus C. Ndukaife, Alexander V. Kildishev, Agbai G. A. Nnanna, Steven T. Wereley, Vladimir M. Shalaev, Alexandra Boltasseva

Motivation

- Overcoming diffusion-limited transport in plasmon-assisted optical trapping
- Addressing the issue of loss of control over particle dynamics
- Optofluidic control with a single plasmonic nanostructure has been reported to be impossible so far[1].



Schematic of plasmofluidic device for fast, on-demand fluidic control.

Mechanism

- Photo-induced heating creates local gradients in fluid's electrical properties.
- An applied AC field acts on these gradients to induce an electrothermal vortex.

Theory

$$\nabla \times \nabla \times \mathbf{E} - k_0^2 \epsilon(r)\mathbf{E} = 0 \qquad (1)$$

(EM Wave equation)

$$\nabla \cdot \left[\kappa \nabla T(\mathbf{r}) + \rho c_p T(\mathbf{r})\mathbf{u}(\mathbf{r})\right] = q(\mathbf{r}) \qquad (2)$$

(Heat equation)

$$\rho_0(\mathbf{u}(\mathbf{r}) \cdot \nabla)\mathbf{u}(\mathbf{r}) + \nabla p(\mathbf{r}) - \eta \nabla^2 \mathbf{u}(\mathbf{r}) = \mathbf{F}, \qquad (3)$$

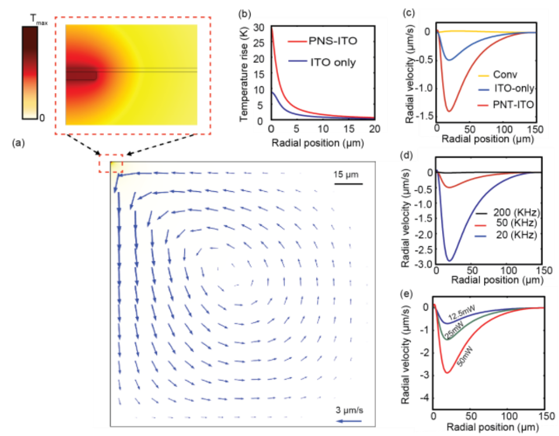
(Navier-Stokes equation)

with $\nabla \cdot u = 0$

$$\mathbf{F}_{\mathbf{CONV}} = g\rho_0 \beta(T)[T(r) - T_0] \qquad (4)$$

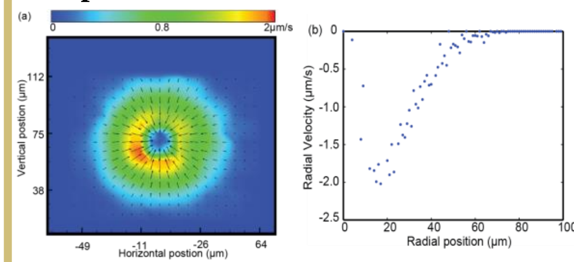
$$\langle \mathbf{F}_{\mathbf{ETH}} \rangle = \frac{1}{2}\epsilon \left[\frac{(\alpha - \gamma)}{1+(\omega\tau)^2}(\nabla T \cdot \boldsymbol{E}_{AC})\boldsymbol{E} - \frac{1}{2}\alpha |\boldsymbol{E}_{AC}|^2 \nabla T\right] \qquad (5)$$

Simulation Results



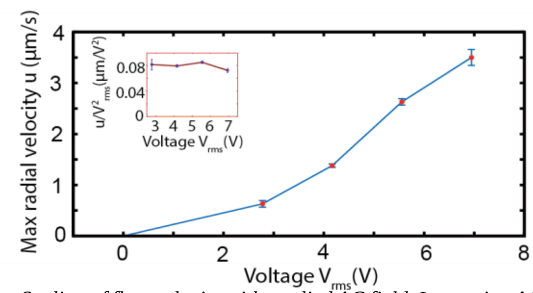
(a)Flow velocity field overlaid on the temperature distribution. The inset shows the temperature field near the plasmonic nanostructure. (b) Radial temperature profile in the fluid (c) Radial velocity component resulting from fast electrothermal flow (for PNS on ITO, and ITO-only system) and from slow thermoplasmonic convection. (d) Variation with AC frequency. (e) Variation with laser power. PNS is "plasmonic nanostructure".

Experimental Results



(a) *Vector plot shows that velocity vectors are directed radially inwards.*

(b) *Variation of radial velocity with position .*



Scaling of flow velocity with applied AC field. Increasing AC field increases the flow quadratically.

Conclusion

- Our system decouples fluidic motion from LSPR induced plasmonic heating
- Fluid motion is on-demand and occur only when Laser and AC field are ON
- We obtained over two orders of magnitude faster transport than previously predicted in ref 1
- Our result will enable rapid particle delivery, trapping in seconds and printing on plasmonic hotspots.

1.) Donner et. al. "Plasmon-assisted optofluidics" *Acs nano* 5.7 (2011): 5457-5462.
2.) Ndukaife, et. al. "Plasmon-Assisted Optoelectrofluidics", (accepted for CLEO 2015 Conference).
3.) Ndukaife et. al. "Hybrid Electroplasmonic NanoTweezers (HENT): Highly resolved long-range optofluidic control and delivery of single nano-elements on-demand" (to be submitted)