High-speed Nanoscale Optical Trapping with plasmonic Double Nanohole Aperture

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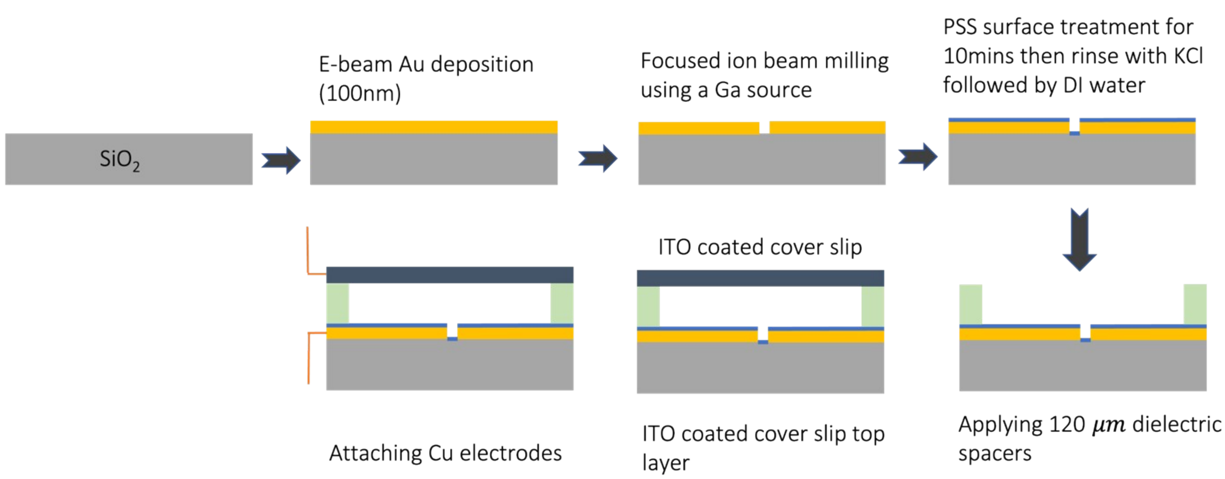
Materials and methods

Fabrication

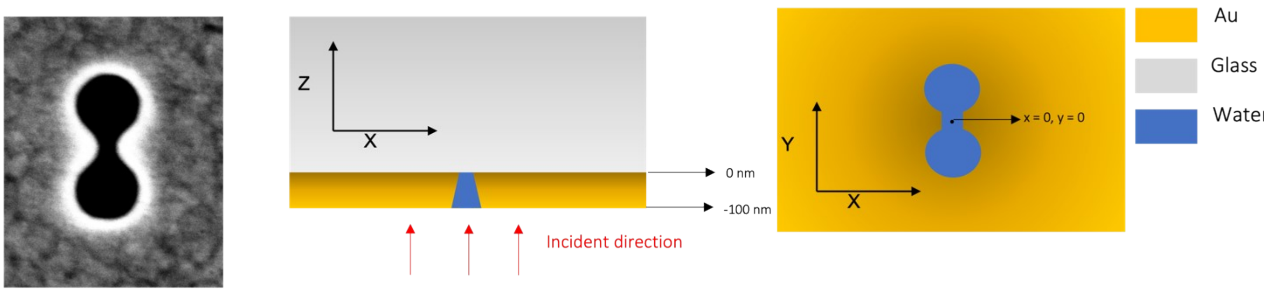
Firstly, a fused silica substrate is washed with acetone then rinsed with IPA. Next, a $10\,nm$ Cr adhesion layer is resistively deposited on the substrate in a multimode deposition chamber (Angstrom Amod – Combined e-beam, Resistive & Sputter Deposition chamber) followed by an electron-beam deposition of a $100\,nm$ Au film. Next, to define the double nanohole (DNH) in the Au film, we used a gallium source Dual Beam Focused Ion Beam – Scanning electron microscope (FEI Helios NanoLab G3CX) with an ion beam current of 1.1pA. This was done in series mode to minimize widening of the top gap of the DNH. To prevent adsorption of negatively charged polystyrene beads to the Au film, we treated the Au surface with negatively charged Poly (sodium 4-styrenesulfonate) (PSS) for 10 minutes and rinsed with potassium chloride (KCl) for 5 minutes followed by deionized water. Next, $120\,\mu m$ dielectric spacers were used to define the chamber and an ITO coated glass cover slip was used to cover the chamber. Lastly, electrical contacts were defined on the Au film and the ITO layer using copper tapes.



S1. Process flow for sample fabrication

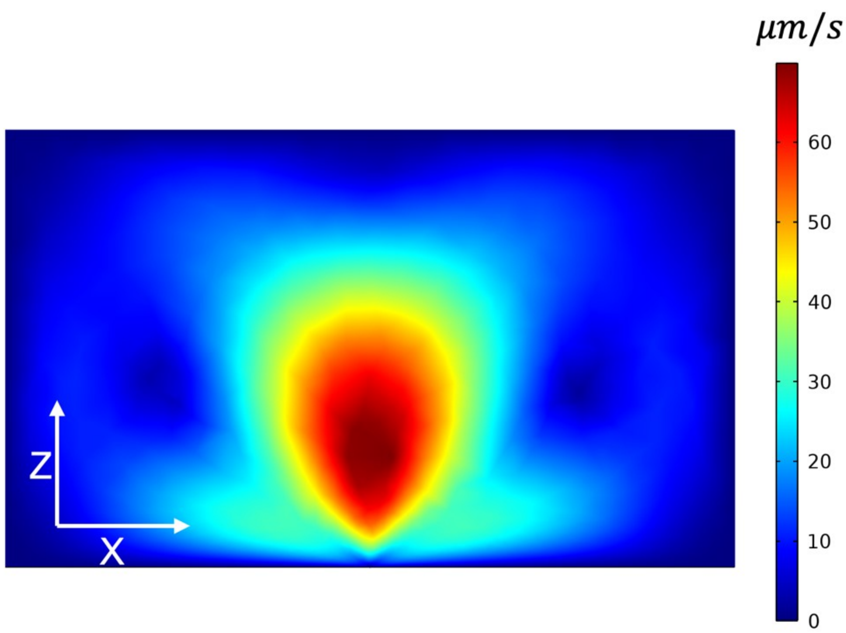
Experimental details

Trapping experiments are carried out on an inverted optical microscope (Nikon eclipse Ti2) using a $40\times$ objective lens with a 0.75 numerical aperture. For fluorescence tracking of polystyrene beads, we employ a white light source (Nikon INTENSILIGHT C-HGFI) coupled with a $532\ nm$ filter for excitation, while the emission wavelength is collected through dichroic mirrors D1 and D2 as shown in Fig (1b). To image the fluorescent particles, we use a CMOS camera (Photometrics PRIM 95B). The AC electric field was applied using a dual-channel function generator (BK Precision 4047B).

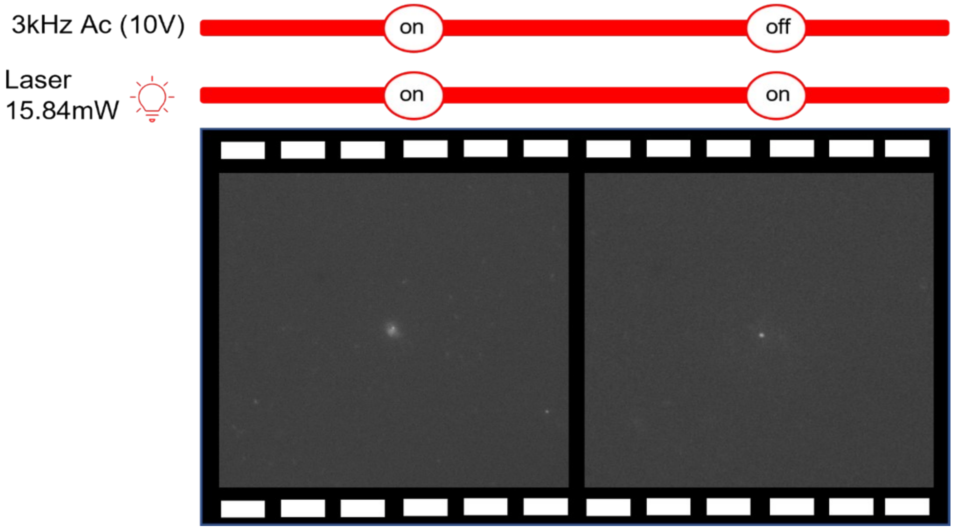


(a) (b)

S2. (a) SEM micrograph of the DNH in the XY plane. (b) Schematic of the DNH in the ZX plane showing the widening of the top gap due to the focused ion beam fabrication procedure in the left panel. The right panel shows the schematic in the XY plane.



S4. FEM simulation showing the velocity magnitudes in the ZX plane for the parameters: $I = 11.4\ mW/\mu m^2$, AC voltage $V = 10\ V$ and frequency $f = 20\ kHz$.



S3. Low frequency particle aggregation and trapping of $25\,nm$ polystyrene beds. Frame 1 shows initial aggregation of particles towards the hotspot while frame 2 shows a single particle trapped at the hotspot after the AC field is turned off.

Movie 1. ETP flow of $300\,nm$ tracer polystyrene particles under an illumination intensity *I = 11.4* $mW/\mu m^2$, AC voltage $V = 10\,V$ and frequency $f = 20\,kHz$**.**

Movie 2. ETP flow of $300\,nm$ tracer polystyrene particles under an illumination intensity *I = 11.4* $mW/\mu m^2$, AC voltage $V = 10\,V$ and frequency $f = 3\,kHz$, showing aggregation of particles at low frequencies.

Movie 3. Trapping of a $25\,nm$ polystyrene bead with a laser intensity of *11.4* $mW/\mu m^2$.

Movie 4. Trapping of a $25\,nm$ polystyrene bead with a laser intensity of *4.68* $mW/\mu m^2$.

Movie 5. ETP transport of a $25\,nm$ polystyrene bead under an illumination intensity *I = 11.4* $mW/\mu m^2$, AC voltage $V = 10\,V$ and frequency $f = 3\,kHz$, showing efficient transport and trapping.

Movie 6 Release of a trapped $25\,nm$ polystyrene beads