Development of Combinatory method for the ordered arrangement of nanoparticles

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Introduction

Organizing nanoparticles on surfaces in an ordered manner is crucial for their use as active components in functional devices. However, patterning colloidal nanoparticles into a predefined structure with nanometre precision and scalability remains a significant challenge. Our work presents a combinatory approach that is fast, reliable, and scalable to solve this issue by forming ordered patterning of nanomaterials on the substrate. We form a metallic nanostructure using nanosphere lithography as the master substrate and trap the nanoparticles above it using Dielectrophoresis. Here, the formation of the master substrate and a simulation study to demonstrate the trapping ability of the aforementioned method is presented

Dielectrophoresis (DEP) trapping

- It is the motion of a particle caused by polarization effects in a non-uniform electric field

DEP Force, $\langle F_{DEP}\rangle = 2\pi r^3 \varepsilon_m \mathrm{Re}[f_{cm}]\nabla E^2$, $f_{cm}=\frac{\tilde{\varepsilon}_p-\tilde{\varepsilon}_m}{\tilde{\varepsilon}_p+2\tilde{\varepsilon}_m}$

Where, r is the radius of the particle, εm is the permittivity of the medium, and f_{cm} is the Clausius-Mossotti factor
$\tilde{\varepsilon}_p$ and $\tilde{\varepsilon}_m$ are the complex permittivity of the particle an the medium respectively

- Dielectrophoresis (DEP) can be used effectively for the formation of arrays of colloids or pattern formation due to its ability to manipulate particles with precision.
- Depending on the electrode geometry, different particle formations can be achieved (chains, bridges etc.) and particles can be placed on desired location based on positive dielectrophoresis (pDEP) or negative dielectrophoreis (nDEP).

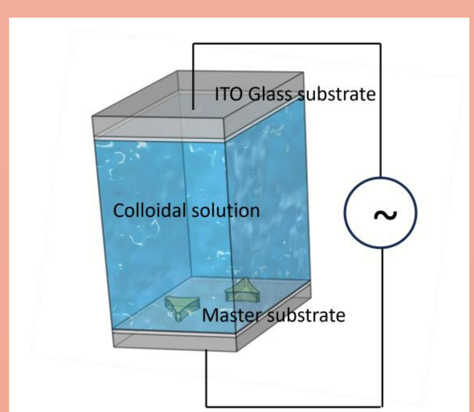

Figure 1

- The experimental setup for DEP trapping is a top-bottom electrode with 10 µm gap applied by an AC field. The master substrate, which is formed from NSL, serves as the bottom electrode while a plane ITO substrate is the top electrode. Figure 1 shows the unit cell used for the DEP trapping simulation study

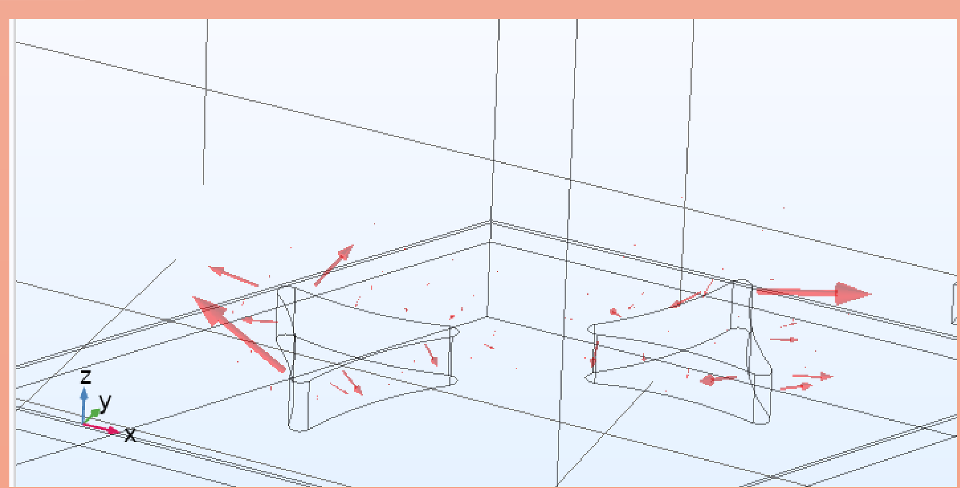

Figure 2 : Shows direction and magnitude of DEP force acting on 40 nm colloidal particle at z=75nm (close to the gold nanotriangles)

- The edges and tips of the nanotriangles produce higher field gradients compared to flat surfaces, making them ideal for exerting DEP forces on nearby particles
- The patterned surface allows for multiple particles to be trapped simultaneously at different nanotriangle sites

Results

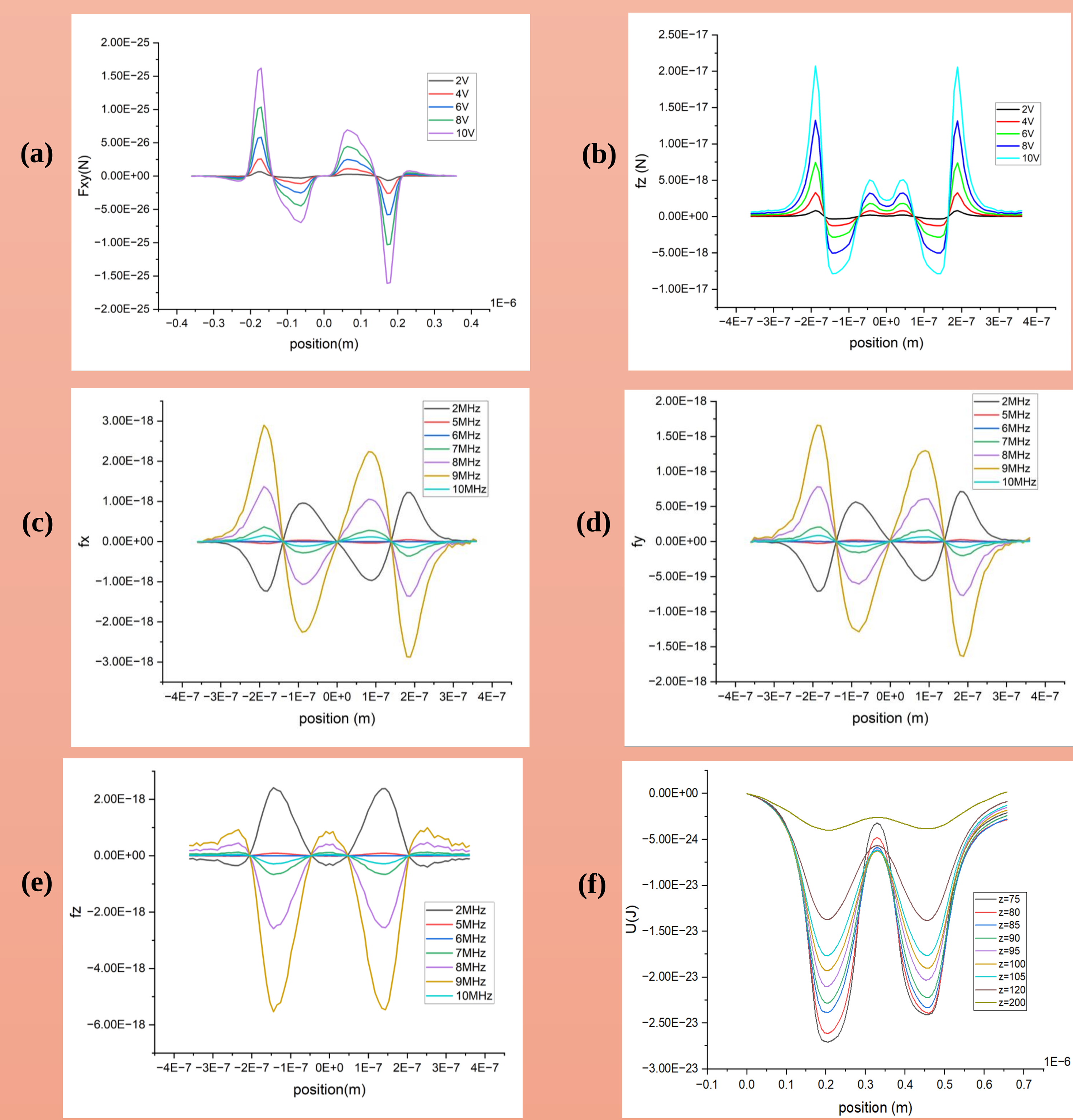

Figure 4: (a) and (b) shows variation of force with respect to voltage (c),(d) and (e) shows variation of force with respect to frequency and (f) variation of potential energy with height of the particle from the surface of the substrate

- Time-averaged DEP force acting on a spherical particle was calculated using Maxwell Stress Tensor method (MST)
- According to the simulation results, 40 nm sized colloidal particle that are closer to the surface of the electrode can be trapped at the surface when supplied with an AC current of voltage 10V and 9MHz frequency using the top-bottom electrode

Preparation of master substrate- Nanosphere Lithography (NSL)

- NSL is an inexpensive, simple, high thorough put technique to form nanoparticle structure and well-ordered 2D arrays of nanoparticles. This involves the following steps:
- Formation of polymer mask using monodispersed colloidal polystyrene beads of size 600 nm (Figure (a) and (b)).
- Hexagonal nanotriangles formed by thermal evaporation of 40 nm gold over the polymer mask followed by ultrasonication to remove the mask

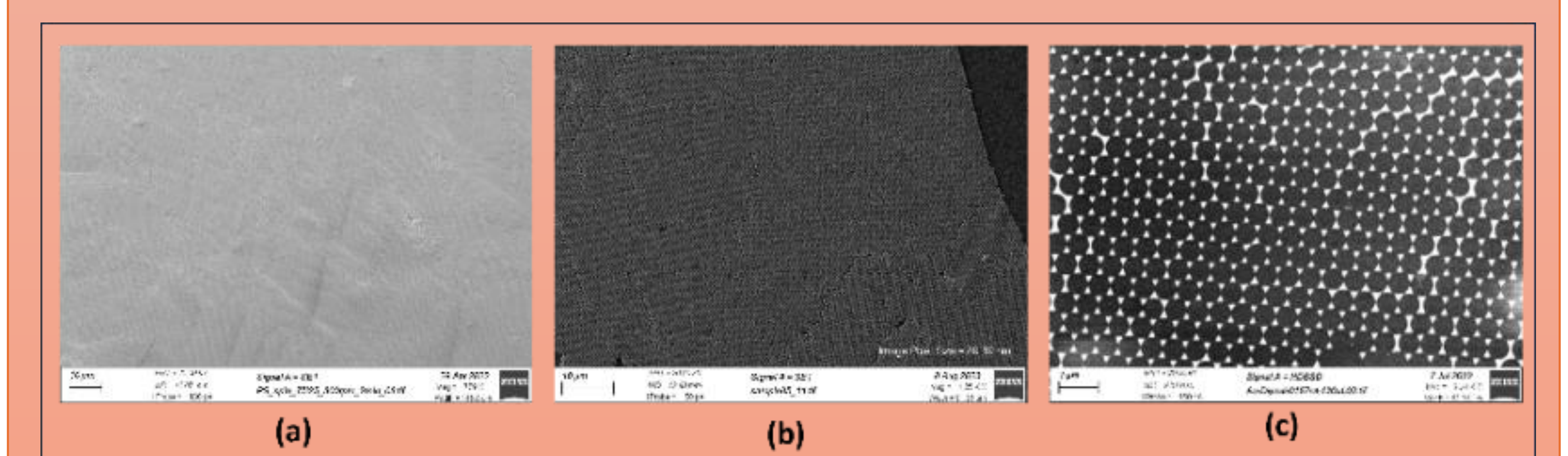

Figure 3: Polymer mask formed by **(a)** drop casting **(b)** convective assembly **(c)** Gold nanotriangles

Conclusion

A combinatory approach that is fast, reliable, and scalable by combining NSL and Dielectrophoresis to form ordered arrangement of nanoparticles is presented here.

Future works

Experimentally prove the trapping of colloidal particles using top and bottom electrodes by capturing a video of the trapped particle and conducting a statistical analysis.

Reference

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