# **Supplementary Information**

# **Dielectrophoretically Controlled Fresnel Zone Plate**

Adam F. Chrimes<sup>1,\*</sup>, Iryna Khodasevych<sup>1</sup>, Arnan Mitchell<sup>1</sup>, Gary Rosengarten<sup>2</sup>, Kourosh Kalantarzadeh<sup>1</sup>

1. School of electrical and computer engineering, RMIT University, Melbourne, Australia.

2. School of aerospace, mechanical and manufacturing engineering, RMIT University, Melbourne,

Australia.

### **DEVICE FABRICATION PROCESS**

The process for fabricating the ITO microelectrode pattern is depicted in Figure S1. The ITO-coated glass substrate was e-beam coated in 50nm of chrome. The substrate was cleaned with Acetone, Isopropanol, deionised water, dried with nitrogen gas and dehydrated at 150 degrees Celsius for 5 minutes. It was then coated with AZ1512 photoresist at 3000 rpm for 30 second and placed in a 90 degree oven for 20 minutes. Following that, the substrate was exposed to the centre stop mask for the required 102 mJ.cm<sup>-2</sup> and developed in AZ400K developer diluted in water at a ratio of 1:4. The chrome layer was then etched using a Cr etchant made up from perchloric acid (HClO<sub>4</sub>) and ceric ammonium nitrate (NH<sub>4</sub>)<sub>2</sub>[Ce(NO<sub>3</sub>)<sub>6</sub>]. The substrate was then washed clean with Acetone, Isopropanol, deionised water, dried with nitrogen gas and dehydrated at 150 degrees Celsius for 5 minutes. It was then re-coated with AZ1512 photoresist at 3000 rpm for 30 seconds and placed in a 90 degree oven for 20 minutes. Following that, the substrate was exposed to the centre stop mask for the required 153 mJ.cm<sup>-2</sup> and developed in AZ400K developer diluted in water at a ratio of 1:4. The ITO was then etched using a solution of 9M HCl, which took 40 minutes.

To create a chamber to hold the liquid, SU8-3050 (Microchem, USA) was used. It was spin coated onto the cleaned substrate at 1700 rpm for 30 seconds, with edge bead removal. The substrate was exposed to a suitable mask to create the reservoir shape around the lens. The SU8-3050 was baked, developed and hard baked according to the manufacturer's instructions.

A polydimethylsiloxane (PDMS) blocked was placed over the reservoir to contain the liquid, and to prevent evaporation of the water/particle solution. The PDMS was made by mixing 1:10 ratio of silane with the curing agent. Baking of the PDMS was done at 70 degrees for 25 minutes, followed by pealing it off the Si wafer and cutting it into manageable sizes with a sharp blade. The PDMS was placed over the chamber once the liquid was in place. No special method was used to hold the PDMS in place, as the natural sticky quality of the PDMS provided enough sealing strength for this

application. The nanofluid mixture was placed into position manually using a 10  $\mu$ L pipette, after which the PDMS block was placed over the top.



Figure S1 - Graphical illustration showing the fabrication process for the ITO electrodes on a glass substrate. The process uses both AZ1512 and SU-8 3050 photoresists to create the final pattern. Consult the datasheet for the photoresists to determine optimum bake temperature, spin speeds, exposure doses and developing times.

### NANOPARTICLE SUSPENSION ABSORBANCE

The absorption of these particles for the target wavelength (532 nm) is quite good, with silicon proving to be slight more improved than tungsten trioxide (Figure S2).



Figure S2 - Transmission spectra of stock solutions of Si (4.3% w/w) and WO<sub>3</sub> (0.56% w/w) nanoparticles in water.

# DIELECTROPHORESIS SIMULATION PARAMETERS

Table S1 lists the parameters required for the simulation of the Clausius-Mossotti (CM) factor, which indicates the electric field frequencies that cause positive and negative forces. The parameters are obtained from either direct measurements, or from previously published data.

 Table S1 - Particle and medium parameters for the calculation of the CM factor, and trapping force
 polarity at various applied electric field frequencies.

Parameter	Value	Source
Medium (water) conductivity (S/m)	0.0001	Measured
Medium (water) permittivity	78	1
Si bulk conductivity (S/m)	0.012	2
Si surface conductivity (S/m)	4×10 <sup>-13</sup>	3
Si permittivity	11.5	4
Si particle radius (nm)	60	Measured
WO <sub>3</sub> bulk conductivity (S/m)	0.1	5,6
WO <sub>3</sub> surface conductivity (S/m)	1×10 <sup>-13</sup>	7
WO <sub>3</sub> permittivity	39	8
WO <sub>3</sub> particle radius (nm)	80	Measured

#### LENS OFF-STATE CHARACTERISATIONS

Due to the structure of the electrode pattern, and the refractive index of the ITO (n=-1.9), glass (n=-1.5) and water (n=-1.3), there is some residual focussing of light. This is more noticeable when there is no liquid placed on the electrode structure. However, once a solution of nanoparticles is placed on the lens-forming electrodes, the scattering from the homogeneously suspended particles dramatically reduces this effect. Figure S3 shows CCD images of the light at the focal spot for a naked lens, and a lens with homogeneous WO<sub>3</sub> and Si nanoparticle suspensions (in the un-actuated state). Numerically, the WO<sub>3</sub> and Si systems have x5 less focussing power in the non-actuated state when compared to the lens with no liquid. Further, when the WO<sub>3</sub> and Si systems are actuated, their focussing power is x11 times compared to their off-state levels.



Figure S3 - CCD images at the first order focal plane of the lens with (a) no liquid on the lens (b) a suspension of Si nanoparticles and (c) a suspension of WO<sub>3</sub> nanoparticles.

## LENS STABILITY CHARACTERISATIONS

In order to assess the switchability of the lens over the long term, an experiment was designed such that the lens was actuated (turned on) for one minute, then off for the next minute. This was repeated for a 12 hour period, which provided 360 actuations, and 360 deactivations of the lens. The CCD camera was positioned at the first order focal plane and was set to record the peak intensity value at 5 second intervals. The intensity value is scaled to the CCD's internal ADC chip, where 100% is a saturated reading from CCD. The background level of the CCD with a beam block was found to be  $\sim$ 3%.

Figure S4 shows the results of the experiment using the WO<sub>3</sub> suspension system. The lens was relatively stable for the first 7 hours of the experiment, averaging about 75% intensity. The observed fluctuations during the first 7 hours are due to instabilities in the light source power and artefacts from the room lighting. However, at the 7 hour mark the water in the suspension began to evaporate, but the lens was still able to actuate with some noticeable effect (~50% average peak intensity). The system based on Si suspension demonstrates similar results, and also contains evaporation effects at the 8 hour mark (not shown for brevity).



**Figure S4 -** CCD peak intensity for the WO<sub>3</sub> lens, actuated for 1 minute on and 1 minute off repeatedly for 12 hours.

## REFERENCES

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