Assembling and manipulating metallic beads using optoelectronic tweezer

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Introduction: The aim of this work is to develop a new method with the potential to revolutionise the process of assembling micron/nanoscale electronic components into circuits. This will be accomplished by developing a radically new assembly strategy based on a touch-less opto-electro-fluidic manipulation technique known as optoelectronic tweezers (OET). In this work, we demonstrated the use of OET to manipulate conductive silver-coated Poly(methyl methacrylate) (PMMA) microspheres (50 micron diameter) into different patterns. It is found that the microspheres can be moved at a max velocity of 3200 µm/s, corresponding to 4.18 nano-newton (10^{-9} N) DEP force, and also be positioned with high accuracy due to this high DEP force.

Background

What are optoelectronic tweezers?

Optoelectronic tweezers (OET) is a technology using a light-patterned photoconductive electrode to provide real time control over the positioning of electric fields, thus achieving particle trapping and manipulation [1].

The structure of an OET device

An OET device, shown in Fig.1 (a), typically consists of an upper and a lower glass slide coated with a transparent conductor (typically indium tin oxide, ITO) with the lower slide coated with an additional photoconductive layer (typically amorphous silicon (a-Si:H)).

How does an OET device work?

A light pattern is projected onto the device which creates non-uniform distribution of electric field around the area which has been illuminated. In this case, 'virtual electrodes' are generated, which can be used to corral polystyrene microbeads via dielectrophoresis (DEP), as shown in Fig.1 (b).

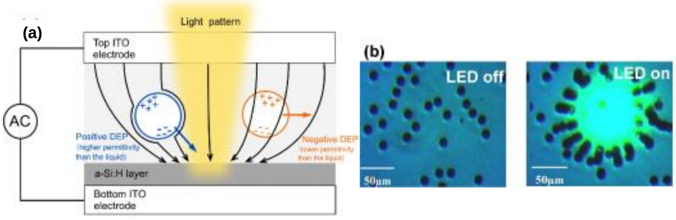

Fig.1 (a): Schematic of a typical OET device; (b) polystyrene microbeads manipulation and trapping using OET [2].

Aims

Moving Electronic Components

The main aim of this work is to assemble electronic components into circuits using OET, producing a step change in the size of the smallest components that can be assembled using the current surface mount technology. We expect to fabricate high-performance micron-sized (or even nano-sized) circuits using OET. A schematic and an microscope image of using OET to move a resistor are shown in Fig.2 (a) and (b).

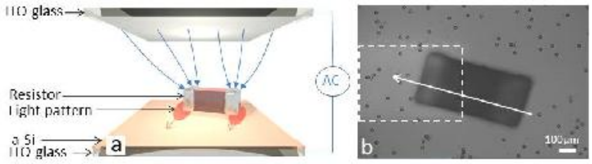

Fig.2 (a): Schematic of using OET device to move a resistor ; (b) a microscope image of using OET device to move a resistor (400×200 µm).

Moving Metallic beads to Create Conductive Path

Another aim is to use OET device to manipulate and pattern lines of conductive microbeads to form metal conductive paths acting as electrical contacts for the circuit, essentially as a form of mask-less lithography. Experimental results will be shown in the following part.

Experimental results

- Scanning electron microscope (SEM) image of silver-coated PMMA microspheres is shown in Fig.3
- Schematic experimental setup is shown in Fig.4 (a). The metallic microspheres were attracted to the illumination region due to positive DEP force, as shown in Fig.4 (b) and (c).

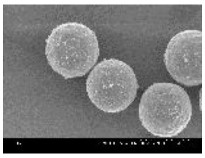

Fig.3: SEM image of silver-coated PMMA microspheres with 700 magnification times.

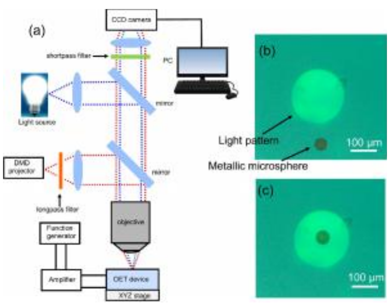

Fig.4 (a):Schematic experimental setup; microscope images of a metallic microsphere (b) before and (c) after being trapped by a 200 µm circular light pattern.

- Fig.5 (a)-(f) shows the microscope images of metallic microspheres trapped by 200 µm diameter and 60 µm diameter circular light patterns at different velocities. As shown, the centre-to-centre distance between the microsphere and the light pattern increases as the velocity increases.
- By measuring the centre-to-centre distance between the trapped microsphere and circular light pattern at varying velocities, a trap profile can be plotted, which shows the DEP force experienced by a microsphere at different locations within the trap, as shown in Fig.6.`
- The metallic microspheres can be moved at a max velocity of 3200 µm/s by traps created by light patterns with 200 µm and 150 µm diameters, corresponding to a DEP force of 4.18 nN, and a max velocity of 3000 µm/s by traps created by light patterns with 100 µm and 50 µm diameters, corresponding to a DEP force of 3.9 nN.

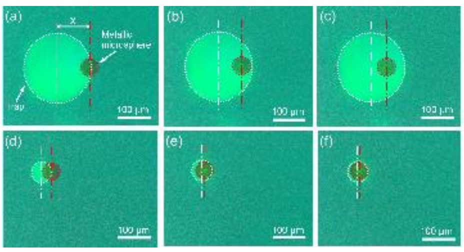

Fig.5 Microscope images of metallic microspheres trapped by 200 µm diameter circular light pattern at (a) 600 µm/s, (b) 1600 µm/s and (c) 3200 µm/s; microscope images of metallic microspheres trapped by 60 µm diameter circular light pattern at (d) 600 µm/s, (e) 1400 µm/s and (f) 3000 µm/s.

- Due to the strong DEP force, the metallic microspheres can be positioned with high accuracy, as shown in Fig.7 (a)-(j). The targeted separations between the bubble and bead are 1 µm, followed by 2 µm, 3 µm, 5 µm, 8 µm, 10 µm and 20 µm.

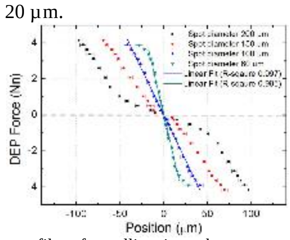

Fig.6: Trap profiles of metallic microspheres created by 200 µm, 150 µm, 100 µm and 60 µm diameter light pattern.

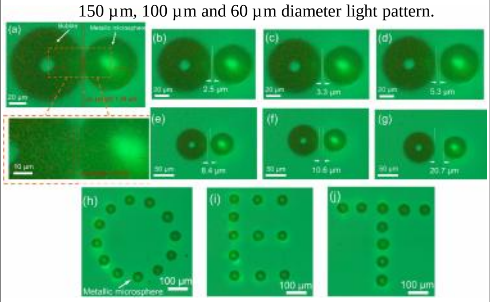

Fig.7:Microscope images of metallic microsphere and reference bubble with varied spacing: (a) 1.39 µm, (b) 2.5 µm, (c) 3.3 µm, (d) 5.3 µm, (e) 8.4 µm, (f) 10.6 µm and (g) 20.7 µm. An example of the measurement lines (red coloured) fitted to the microsphere and bubble boundaries to estimate the spacing, is shown in (a). Microscope images of (h) 'O', (i) 'E', (j) 'T' formed by assembling the metallic microspheres in parallel via the OET device.

Conclusion: We have demonstrated the use of OET to manipulate conductive silver microspheres into different patterns. It is found that the microspheres can be exerted with strong DEP force (10^{-9} N) and also be positioned with high accuracy. The aim of this work is to develop a new method to assemble micron/nanoscale electronic components into circuits.

References

[1] A. Zarowna-Dabrowska, et al., "Miniaturized optoelectronic tweezers controlled by GaN micro-pixel light emitting diode arrays," Opt. Express, vol 19, no. 3, pp. 2720-2728, 2012.
[2] A. H. Jeorrett, et al., "Optoelectronic tweezers system for single cell manipulation and fluorescence imaging of live immune cells," Opt. Express, vol 22, no. 2, pp. 1372-1380, 2014.

Acknowledgement

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