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Supporting Information

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Assembly of Topographical Micropatterns with Optoelectronic Tweezers

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Supplementary Information

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1. Supplementary Movie

Movie M1: Real-time movie depicting the assmebly of 10 μm polystryrene micro-beads in aqueous suspsensions into topographical micro-patterns (TMPs) depicting 'OET' (clip 1), 'Albert Einstein icon with mass energy equation' (clip 2), and 'U of T' (clip 3).

2. Simulations

3D simulations were generated in COMSOL Multiphysics using the AC/DC module (COMSOL Inc., Burlington, MA, accessed via license obtained through CMC Microsystems, Kingston, Canada). The model length (X-axis), width (Y-axis) and height (Z-axis) were set to 1000 μm, 500 μm, and 150 μm, respectively (Figure S1a). In this model, an a-Si:H surface was illuminated with a light pattern spelling 'OET'. Electric potential distribution and electric field distribution were simulated and are shown in Figure S1b,c, respectively (XY-slices at Z = 1.1 μm, i.e. for a micro-bead located 0.1 μm above the a-Si:H layer). As indicated in Figure S1b, there exists a large electrical potential difference between the illuminated and the dark regions, inducing a large lateral potential drop from the illuminated region to the dark region. Because of the potential difference between the illuminated and the dark regions, there exists stronger electric fields in the illuminated region and at the edge of the light pattern (Figure S1c), generating negative DEP force that pushes polystyrene micro-particles toward the dark region with weaker electric field.

In this model, the boundary conditions were set to perfect electrical insulation at the sides and continuity for all interior boundaries. Initial electric potential was set to 0 V for all domains. The top surface was set to 0 V and the bottom surface was set to 20 V to simulate the applied AC signal (frequency set to 20 kHz). The model included a 1-μm-thick a-Si:H layer at the bottom and a 150-μm-thick liquid chamber. The conductivities σ and permittivities ε were set to $\sigma_{silicon\text{-}light}$ = 1×10^{-4} S/m, $\sigma_{silicon\text{-}dark}$ =1×10^{-6} S/m, $\varepsilon_{silicon}$ = 11.7, σ_{medium} =5×10^{-3} S/m, and ε_{medium} =80. The model employed a free tetrahedral mesh with a maximum element size of 35 μm, a minimum element size of 1.5 μm, a maximum element growth rate of 1.35, a curvature factor of 0.3, and a resolution of narrow regions of 0.85.

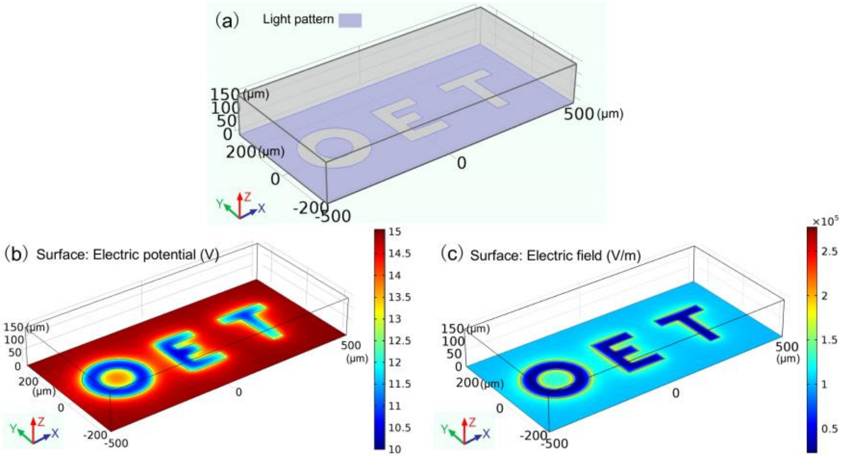

Figure S1. 3D simulation of the OET device used to form TMPs. a) Schematic of the simulation in which a light pattern (purple) is projected onto the a-Si:H surface of an OET device. XY-plots at Z = 1.1 μm of simulated b) electric potential distribution and c) electric field distribution, in which the electric potential and field are indicated in heat maps (blue = low, red = high). The device was driven with a simulated bias of 20 $V_{p\text{-}p}$ at 20 kHz.

3. Scanning electron microscopy

SEM images were collected using an enviromental SEM (QUANTA FEG 250 ESEM) at the Centre for Nanostructure Imaging at the Department of Chemistry, University of Toronto. Under low pressure mode, the enviromental SEM allows direct imaging of non-conductive samples without requiring that their surface be coated with a conductive layer. The SEM images shown in the main text and in Figure S2 were collected under a pressure of 130 Pa using an electron beam with 10 keV enegy and 3 nm spot size.

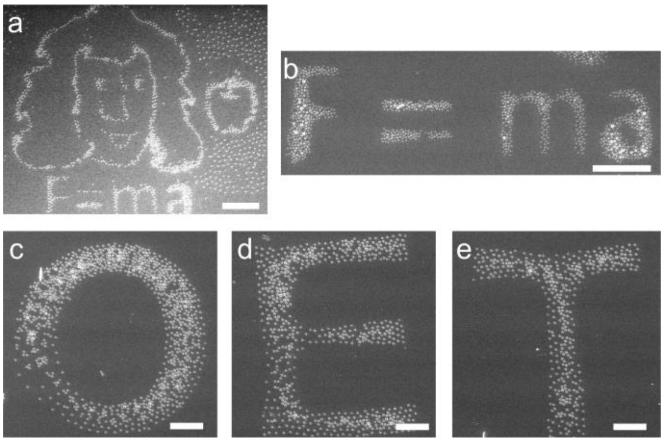

Figure S2. Scanning electron microscope images of topographical micro-patterns transferred to alternative substrates, depicting a) 'Isaac Newton caricature with apple and Newton's second law of motion' (formed from 6 μm dia. polystryrene micro-beads) on double-sided tape (scale bar: 200 μm), b) 'Newton's second law of motion' (formed from 6 μm dia. polystryrene micro-beads) on double-sided tape (scale bar: 200 μm), and c-e) 'O', 'E' and 'T' (formed from 10 μm dia. polystryrene micro-beads) on a PDMS substrate (scale bar: 100 μm).

4. Evaluation of TMP transfer fidelity

An image comparsion algorithm was developed in Matlab R2014a to evaluate the fidelity of TMPs upon transfer to a destination substrate. In the algorithm, an average perceptual hashing is applied to extract image "fingerprints" to enable quantative comparison of similarities. The procedure includes 4 steps, outlined below, followed by the matlab code for the process.

In **step 1**, a pair of images of a given TMP –"pre-transfer" (collected after freeze-drying) and "post-transfer" (collected after transferring to a destination substrate) is cropped and normalized to the same size.

In **step 2**, the images are converted from colour to greyscale using the MatLab "rgb2gray" function.

In **step 3**, the pre-transfer images are then flipped horizontally, and the background brightness of each image is equalized to the same level using "imadjust" fuction.

In **step 4**, each processed image is divided into 16 x 16 un-overlapped blocks, and an average grey-value of the whole image is calcuated. Then, the grey-value of each block in each image is compared with the global grey-value; if the grey value of the block is equal to or higher than the global grey value, the hash-value of the block is set to 1, otherwise, the hash value is set to 0. This results in a string of 256 binary hash-values for each image, known as the "fingerprint." The fingerprints of the processed pre- and post-transfer images are compared and the number of mismatched binary values are counted. The number of mismatches is called the 'Hamming distance' h, which is used to calulate the similarity index η according to the following equation.

$$\eta = \frac{256\text{-}h}{256} \times 100\%$$

Figure S3 shows the similariy indexes for images of several different pre- and post-transfer TMPs. As shown, all similartiy indixes are above 90%, indicating good fidelity/similairty of the transferred TMPs to the original patterns. The MatLab code for the four-step procedure is listed below (following figure S3).

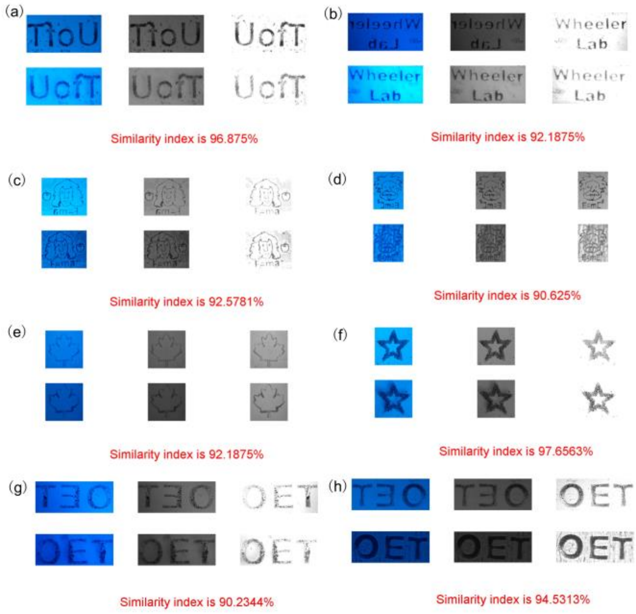

Figure S3. Evaluation of TMP transfer fidelity. Images were processed in four steps, as described in the supplementary text. Each panel (a-h) includes two rows (pre-transfer above, post-transfer below), and three columns. The left column images were collected after step 1, the middle column images were collected after step 2, and the right-column images were collected after step 3. The similarity index for each pair was generated in step 4 and is listed in red font. The TMPs shown include (subject/particle-type/transfer-substrate): a) OET/polystyrene beads/PDMS, b) Wheeler Lab/polystyrene beads/PDMS, c) Newton/polystyrene beads/double-sided tape, d) Einstein/polystyrene beads/double-sided tape, e) maple leaf/graphene nanoplatelets/double-sided tape, f) star/metallic beads/double-sided tape, g) OET/polystyrene beads/PDMS, h) OET/polystyrene beads/double-sided tape.

Matlab Code:

```
clear all;
close all;
clc;
img=imread('C:\Users\XX.png');
img2=imread('C:\Users\XX\.png');
tmp=rgb2gray(img);
tmp2=rgb2gray(img2);
tmp5=flip(tmp,2);
tmp3=imadjust(tmp5,[0 0.4],[0 1]);
tmp4=imadjust(tmp2,[0 0.4],[0 1]);
avg3=mean(tmp3(:));
avg4=mean(tmp4(:));
subplot(3,3,1);imshow(img);
subplot(3,3,4);imshow(img2);
subplot(3,3,2);imshow(tmp);
subplot(3,3,5);imshow(tmp2);
subplot(3,3,3);imshow(tmp3);
subplot(3,3,6);imshow(tmp4);
img_re=imresize(tmp3,[16 16]);
img_re2=imresize(tmp4,[16 16]);
img_re=uint8(double(img_re)/4);
img_re2=uint8(double(img_re2)/4);
me=mean(mean(img_re));
me2=mean(mean(img_re2));

for i=1:16
    for j=1:16
        if img_re(i,j)>=me
            img_re(i,j)=1;
        else
            img_re(i,j)=0;
        end

        if img_re2(i,j)>=me2
            img_re2(i,j)=1;
        else
            img_re2(i,j)=0;
        end
    end
end

re=uint8(double(img_re)-double(img_re2));

num=0;
for i=1:16
    for j=1:16
        if re(i,j)~=0
            num=num+1;
        end
    end
end
num;
similarity=((256-num)/256)*100;
txt = ['Similarity index is ' num2str(similarity) '%'];
subplot(3,3,[7 8 9]);
text(0.3,0.5,txt,'Color','red','FontSize',32);axis off
```