Voltage-Controllable Directed Assembly of Single Nanoparticles

Benjamin F Porter[1] & Harish Bhaskaran[1,*]

[1] Department of Materials, University of Oxford, 16 Parks Road, Oxford, OX1 3PH, United Kingdom
[*]e-mail: hansh.bhaskaran@materials.ox.ac.uk

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An elusive goal in nanomanufacturing has been the pick-and-place assembly of individual nanoparticles (NPs). We have previously examined the ideal electrical and structural parameters for driving the assembly of single nanoparticles with a controlled voltage into the centres of target sites. We can now report that with modifications to this design we have successfully demonstrated that this method of voltage-driven assembly is successful. Evaluating the optimum parameters for this design will allow the fabrication of devices that can consistently perform successful single NP placements at ambient temperatures, an important requirement for nanomanufacturing processes.

Much recent progress in NP assembly has been made, including recent results in geometry induced particle printing[1] as well as in dielectrophoretic[2] and optical[3] non-contact trapping. However, the goal of reliably picking up single NPs in colloidal solutions controllably and with high precision has proven difficult. Our design to accomplish this goal was inspired by the work of Huang et al. [4], which utilised self-limited gating mechanisms to self-assemble single NPs in solution with excellent precision. Whilst that strategy relied on surface functionalisation, our present report is on the use of an applied voltage to cause the directed assembly of NPs; the voltage attracts a NP from the colloidal solution to a specific location where the captured particle will repel any additional NPs. This would allow the pick-and-place of individual NPs, with high consistency, accuracy and speed, thus enabling a route to large-scale nanomanufacturing.

Our goal is to optimise conditions to capture a single NP within a target area (referred to as a gate). The funneling of negative charged, 20 nm diameter gold particles is achieved by electron-beam patterning of a silicon dioxide surface with a monolayer of trimethoxy(octadecyl)silane (TMODS) – patterning the target areas with this monolayer nullifies the surface charge that is intrinsic to silicon dioxide surfaces in water. The negative charge of this surrounding area funnels the negatives charged NPs away from the silica surface. These particles are attracted to the target sites by an applied electrical bias, with the positive terminal applied to the underlying highly doped silicon substrate, which is seperated from the solution by the 25 nm thick, thermally grown silicon dioxide surface. The target areas were patterned into 10 x 10 arrays of circles on the surface for the NPs to adhere to. In Figure 2a, the diameter of these target areas is given in the columns. The voltage to drive deposition successfully was a 1.25 V peak-to-peak square sine wave with a DC offset of 1 V and a frequency of 10 kHz. The result after 5 minutes of deposition saw NPs form even distributions across areas that had been coated with the TMODS monolayer (Figure 2b), spaced by their mutual electrical repulsion. In cases of areas coated with 125 nm diameter circles of TMODS, many NPs were captured individually by single gates (Figure 2c,d). Kelvin Probe Microscopy measurements will reveal the location of the monolayers relative to the NPs and thus how successful the funneling has been to the centre of the target sites.

In summary, we have demonstrated a method of voltage-driven nanoparticle assembly that can isolate individual nanoparticles from a bulk colloidal dispersion.

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Figure 1. Electrical pulses are applied to a highly doped Si layer (light grey), insulated from the solution by a 25 nm thick SiO_2 layer (dark grey) and patterned with a monolayer of trimethoxy(octadecyl)silane (TMODS). (a) The resulting electric field *E* attracts the 20 nm Au particles in the colloid towards the TMODS coated areas (or "gates") on the SiO_2, whilst the negative surface charge of the SiO_2 funnels the particles towards the centre of these regions. (b) Once occupied, the "plugging" particle provides a negative screening potential against the deposition of further nanoparticles.

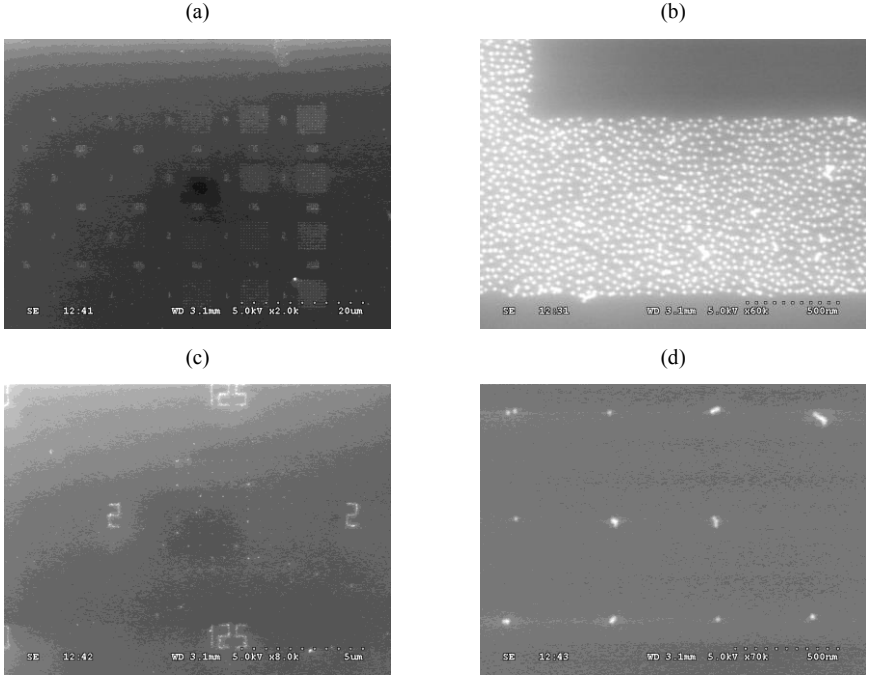

Figure 2. Scanning electron microscope images of 20 nm gold nanoparticles assembled onto patterned substrate after voltage-driven placement.