

# Electric Field Process for the Fabrication of Higher Order Structures from Biomolecule Derivatized Nanoparticles (#1030)

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## ABSTRACT

An electronic microarray has been used to carry out directed self-assembly of higher order 3D structures from Biotin/Streptavidin and DNA derivatized nanoparticles. Structures with up to fifty layers of alternating biotin and streptavidin and DNA nanoparticles were fabricated using a 400 site CMOS microarray system. In this process, reconfigurable electric fields produced by the microarray device were used to rapidly transport, concentrate and accelerate the binding of 40 nanometer biotin, streptavidin and DNA derivatized nanoparticles to selected sites on the microarray. The nanoparticle layering process takes less than one minute per layer (10-20 seconds for addressing and binding nanoparticles, 40 seconds for washing). The nanoparticle addressing/binding process was monitored by changes in fluorescence intensity as each nanoparticle layer was deposited. The final multilayered 3-D structures are about two microns in thickness and 50 microns in diameter. Active structures with chemical to luminescent to fluorescent properties are now being fabricated. The use of a microelectronic array device for assisted self-assembly represents a unique example of combining “top-down” and “bottom-up” technologies into a unique nanofabrication process. Such a process will be useful for the hierarchical assembly of 3D nano, micro, and macrostructures for a variety of electronic/photonic, nanomaterials, energy and biosensor applications.

**Keywords:** electric field, self-assembly, nanofabrication, nanoparticles, higher order structures

## INTRODUCTION

One of the grand challenges in nanotechnology is the development of fabrication technologies that will lead to cost effective nanomanufacturing processes. In addition to the more classical top-down processes such as photolithography, so-called bottom-up processes are also being developed for carrying out self-assembly of nanostructures into higher order structures, materials and devices. To this end, considerable efforts have been carried out on both passive and active types of Layer-by-Layer (LBL) self-assembly processes as a way to make three dimensional layered structures which can have macroscopic x-y dimensions. Nevertheless, limitations of passive LBL and as well as active assembly processes provide considerable incentive to continue the development of better paradigms for nanofabrication and heterogeneous

integration. Electronic arrays have several important features that make them attractive for assisted self-assembly nanofabrication. First, a permeation layer or porous hydrogel is used to cover the microelectrode structures on the array. The permeation layer is usually impregnated with streptavidin which allows biotinylated DNA (antibodies, nanoparticles, etc.) to be bound at the selected site. This layer also allows relatively high DC electric field strengths to be used for rapid electrophoretic transport of molecules and nanostructures, while protecting the more sensitive DNA, proteins or nanostructures from the adverse effects of the electrolysis products generated at the electrodes. A second feature of electronic array devices is that they can be designed in a wide variety of shapes and sizes. To date, arrays have been fabricated in sizes from 2 mm x 2 mm to over 2.5 cm x 2.5 cm, with 25 to 10,000 electrodes and with electrode structures which range in size from 10 microns to several millimeters. A third feature is that sophisticated CMOS control elements can be integrated into the underlying silicon structure of electronic microarrays which allows precise control of currents and voltages to each of the individual microelectrodes on the array. Finally, significant size reduction in the electronic array controller system provides a relatively compact control unit that can be run with a laptop computer (Figure 1). Using a 400 site CMOS microarray device and controller system we have now demonstrated rapid and highly parallel assisted self-assembly of biotin and streptavidin derivatized nanoparticles into forty layer structures [ 1-5 ].

## RESULTS AND DISCUSSION

In order to determine optimal conditions for derivatized nanoparticle layering, experiments were carried out at addressing times of 5 seconds, 15 seconds and for 30 seconds. For each of the addressing time experiments, ten columns (16 sites) were activated with DC current levels that ranged from 0.025 uA to 0.4 uA, in increments of 0.025 uA. The activation of all 160 sites (at different current levels) was carried out in parallel. For each addressing time experiment (5 seconds, 15 seconds and 30 seconds) the addressing process was carried out forty times with alternating 40 nanometer red fluorescent streptavidin nanoparticles and green fluorescent biotin nanoparticles. In these experiments, the alternate columns were not activated. By the relative fluorescent intensity of the activated sites, the best conditions for nanoparticle layering appear to be at the 5 second and 15 second addressing times in the 0.30 to

0.40 uA current level range. At the lower current levels ( $<0.30$  uA) the overall fluorescent intensity for the layers begins to decrease. At the longer 30 second addressing time, the nanoparticle layers become visibly damaged. Under real time epifluorescent microscope observation some of these fractured layers could actually be observed to flap when the sites were activated. Scanning electronic microscopy was used to examine the forty layer nanoparticle structures in more detail. Figure 2 shows an SEM image of the microarray surface where the alternating rows of the addressed or activated sites appear as the lighter areas, and un-addressed or un-activated sites (negative control sites) appear as somewhat darker areas. The un-addressed site (negative control site) shows little or no nanoparticle accumulation on the permeation gel layer surface, even though it was exposed forty times to the solutions containing nanoparticles. The SEM image of the addressed site shows a very well defined top layer of nanoparticles that appear to about 40 nanometers in diameter. Figure 3 shows a cross section of an activated site on which forty addressings of nanoparticles was carried out. A number of nanoparticle layers can be seen from the top nanoparticle layer down to what appears to be the lower surface of the permeation layers.

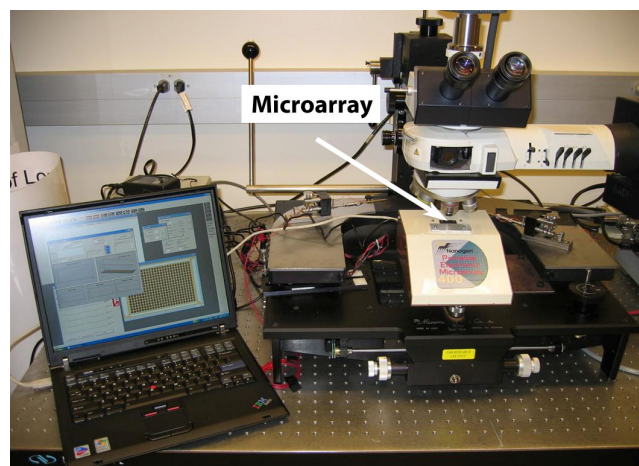


Figure 1 - Shows the complete electric field nanofabrication system for carrying out heterogeneous integration, nanoparticle layering and assisted self-assembly on the 400 site CMOS microarray device. The miniaturized CMOS array controller system (with a 400 site CMOS microarray) is mounted on a standard micro-manipulator probe station with an epifluorescent microscope and imaging system.

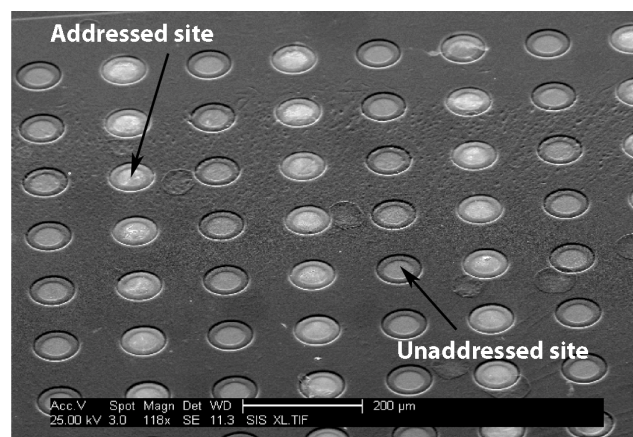


Figure 2 - shows an SEM image of the microarray surface with the alternating rows of the un-activated or un-addressed sites (darker areas), and the activated or addressed sites (lighter areas). The activated (light areas) were addressed 40 times with nanoparticles at the various current levels. The non-activated sites (darker areas) serve as controls for non-specific nanoparticle binding or accumulation.

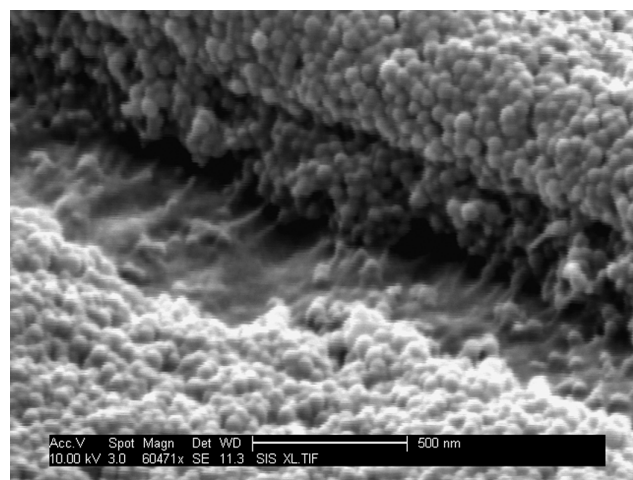


Figure 3 - shows a cross section from one of addressed sites on the microarray. A number of nanoparticle layers can be seen between the top nanoparticle layer all the way down to the surface of the permeation layer.

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