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Formation and alignment of silicon nanoparticles on DNA template

D P Singh, A K Singh and O N Srivastava*

Department of Physics, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India

E-mail : hepons@yahoo.com

Abstract : One and two-dimensional alignments of silicon nanoparticles have been achieved by the assembly on DNA template of kilo base pairs The silicon nanoparticles have a size of 15 nm and the alignment extends upto micrometer It has been suggested that interaction between the phosphate groups of the DNA template network and silicon nanoparticles leads to aligned arrangements of Si nanoparticles

Keywords : Alignment, nanoparticles, DNA template, phosphate group.

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1. Introduction

The ordered arrangement of nanoparticles in two and three dimensional structures is a matter of much interest in the present research scenario in applied condensed matter physics [1–5]. Different approaches have been developed for the arrangement of nanoparticles. The ability to assemble nanoparticles into arrays, networks, and circuits in a precise and controlled manner is key to fabrication of a variety of nanodevices. Networks of nanometer sized metal or semiconductor islands, or quantum dots, may exhibit a variety of quantum phenomena, with applications in optical devices, nanometer sized sensors, advanced computer architectures, ultradense memories and quantum information science. Interest in the concept of self-assembled nanostructures led to the idea of using DNA as a scaffold or template for the programmed assembly of nanoscale arrays [6–12]. Mirkin's *et al* and Alivisatoz *et al* have proposed "DNA-based methods" for constructing nanostructures [6–8]. They employed the electrostatic interaction between the DNA and nanoparticles for obtaining ordered arrangements of nanoparticles. The other attractive feature of using DNA as a particle interconnect is that, in principle one can synthetically program interparticle distances, particle periodicities, and particle compositions through choice of DNA sequence. Uncapped and capped gold nanoparticles [13,14] have been assembled into two and three dimensional complexes using DNA as a template. Optical as well as electrical properties of DNA linked gold nanoparticle assemblies have been intensively studied by the Mirkin's group [15,16].

In the present investigation, we have studied ordering of Si nanoparticles on DNA template. We choose the bacterial DNA of kilo base pairs to make the ordered arrangement of silicon nanoparticle to wider extents.

2. Experimental details

In our experiment we utilized double helical bacteria DNA of *Escherichia coli* of kilo base pairs. The double helical DNA was prepared in the deionized water in the Millipore filtration unit. The pH of the water was maintained at 7 to retain the double helicity of DNA. The droplets of the DNA solution were put on the formvar coated copper grids, two or three times to make the thick DNA template on the grid. The deposition experiment was performed in a high vacuum chamber. The silicon powder was evaporated on a substrate of formvar coated copper grid containing DNA template at a distance of 12 cm from the graphite boat. First the chamber was evacuated to 10^{-6} torr, and then a constant pressure of 200 torr of helium ambient was maintained at the time of deposition. The substrate was cooled by liquid nitrogen to prevent the denaturation of double helicity of DNA. Silicon nanoparticles formed at 200 torr helium ambience were deposited on the DNA template on the formvar coated copper grid. The abovesaid method of Si evaporation has been found in our earlier studies to lead to Si nanoparticles. The characterization of the sample was done by transmission electron microscopy.

*Corresponding Author

3. Results and discussion

In the following we proceed, to describe the transmission electron microscopic observations made on the deposited film of silicon nanoparticles on the DNA template.

Figure 1 illustrates the representative electron micrograph of the silicon nanoparticles deposited in 200 torr helium ambience on the bacterial DNA of kilo base pairs. The Si nanoparticles sitting on DNA were irradiated with focussed electron beam (Beam 100 kV, 50 μA and beam diam. ~0.2 μm). The intense electron beam irradiation through Si/DNA is the area surrounded by ABCDE. As is easily discernible, the microstructure in this region is different than the surrounding region. In fact within this region the arrangement of Si nanoparticles is clearly visible. Some such one dimensional aligned arrangements of Si nanoparticles are indicated by arrows. Several experiments on Si/DNA configurations were looked into TEM and the influence of the electron beam was analyzed. It was found that during evaporation of Si in He ambient on DNA template, many of the Si nanoparticle are already aligned on the DNA template. However, several clusters of Si particles, which are not aligned, are also present making the microstructure somewhat complex The major influence of the electron beam was to remove these unaligned clusters of Si nanoparticles. The removal seems to take place through localized melting and evaporation. Although the temperature rise could not be estimated, it may be noted that for nanoparticles the melting temperature is generally smaller than the bulk.

Figure 1(a). Transmission Electron Microscope of the silicon deposited at 200 torr helium pressure on DNA template. The region ABCDE is the region which is radiated by electron beam and which indicate the aligned silicon nanoparticles.

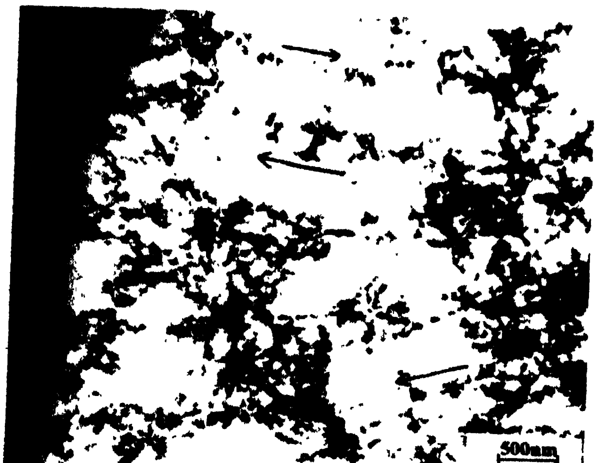

Figure 1(b). Aligned silicon nanoparticles after the electron beam radiation. Alignment is shown by arrows and alignment is upto micrometer.

Figures 2(a) and 2(b) are the high-resolution transmission electron micrograph of aligned nanoparticles on DNA. In both figures alignment pattern is outlined by arrows. These are the one dimensional aligned nanoparticles on DNA. In Figure 2(a) whereas the particle size is approximately 15 nm, the extent of alignment extends upto ~700 to 800 nm. In Figure 2(b) alignment is somewhat a clonger extent *i.e.* of micrometer range.

Figure 2(a). Transmission electron micrograph of one dimensional aligned Si nanoparticles of average size as ~50 nm The one dimensional alignment is outlined by arrows Alignment is upto 800 nm.

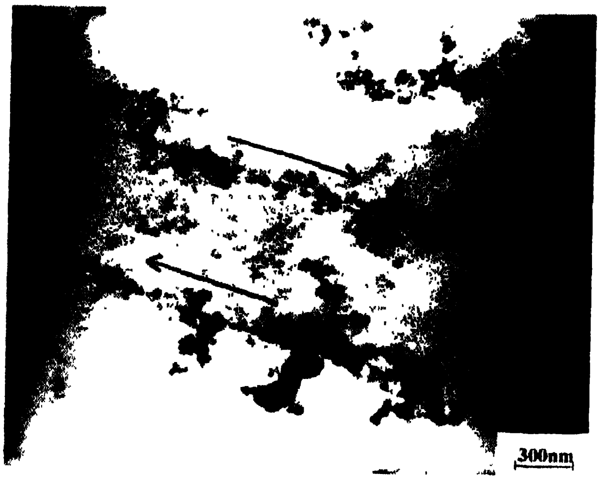

Figure 2(b). A more clear and longer arrangement (micrometer) of silicon nanoparticle on DNA template. The alignment pattern is outlined by arrows.

Figure 3 is a high resolution electron micrograph of two dimensional network of aligned silicon nanoparticles on bacterial DNA template. The nanoparticles are arranged in a hexagonal grid, the side of hexagon is ~200 nm. The Si nanoparticle size is ~15 nm.

A tentative scheme showing the effect of DNA on the creation of aligned arrangements of Si nanoparticles is shown in Figure 4. This figure shows the double helical structure of DNA It is known that the phosphate sites in this structure is a potential site for electrostatic interaction of any foreign entity e.g nanoparticles which is made to lie on the DNA template. Keeping this in view the most likely mechanism of alignment is the electrostatic attraction of the phosphate sites which is the negative radical and the deposited Si nanoparticles which act as positive radical.

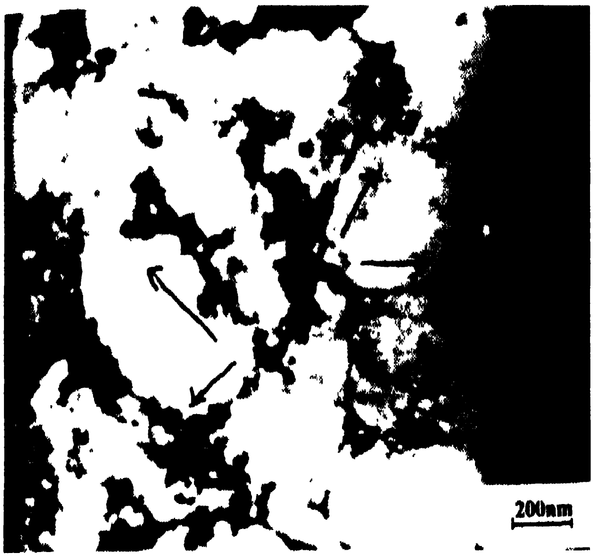

Figure 3. Alignment of Si nanoparticles in a two dimensional alignment on DNA template

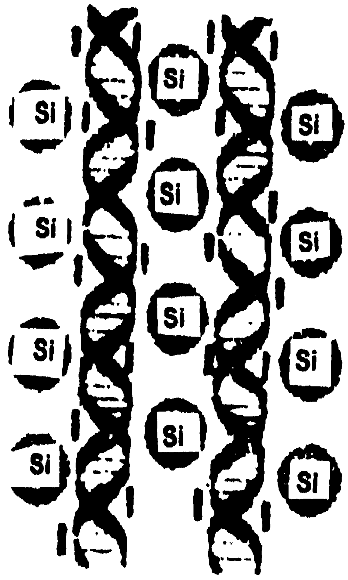

Figure 4. Schematic diagram showing the expected templating action of the DNA double helical molecules leading to the aligned arrangements of silicon nanoparticles-DNA (phosphate group).

4. Conclusion

It is possible to obtain aligned arrangements of Si nanoparticles (~15 nm) by depositing Si nanoparticles on DNA template. Alignments were upto micrometer.

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