# "SP1 PROTEIN-NANOPARTICLE HYBRIDS AS BUILDING BLOCKS FOR NANOSTRUCTURES: MEMORY ARRAYS AND NANOWIRES"

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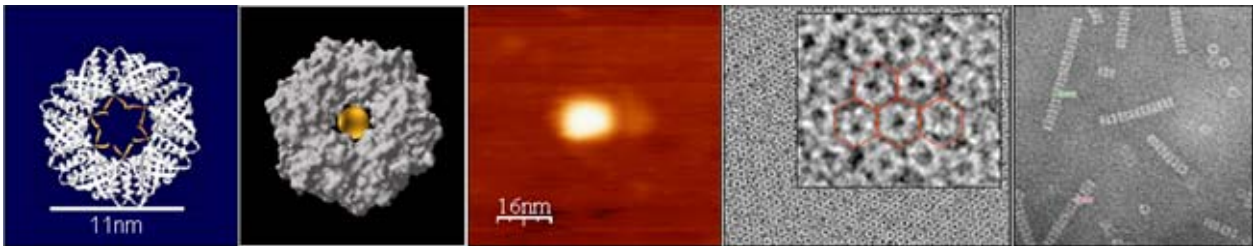
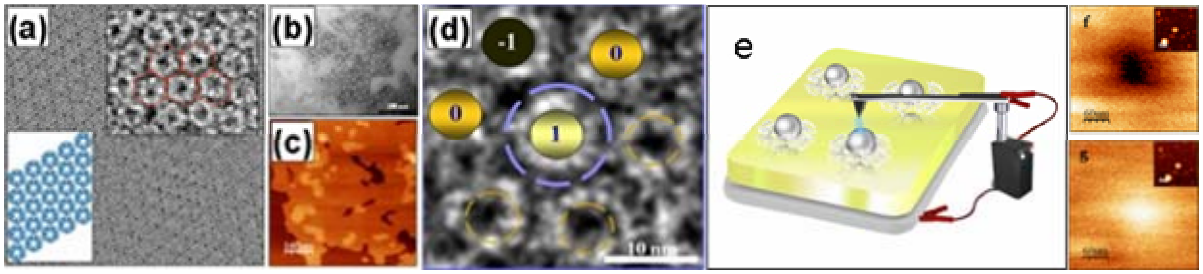


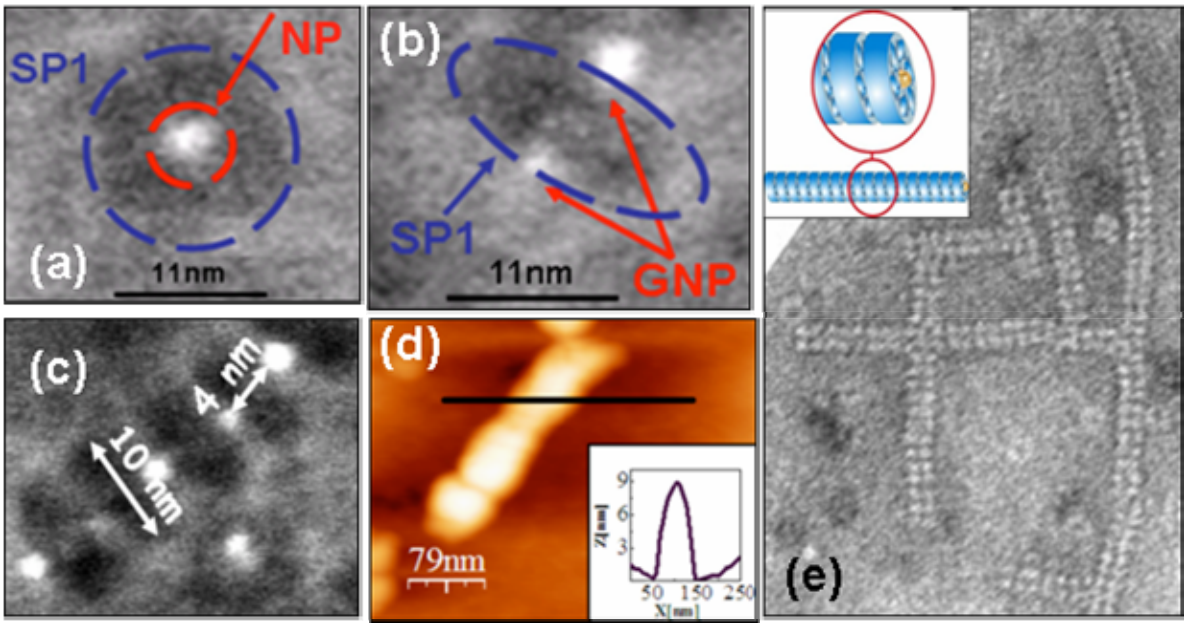

***SP1 nanostructures: (a) The X-ray structure of the SP1. (b) A computer image of the SP1-nanpoparticle hybrid. (c) An AFM image of an SP1 molecule. (d) A close packed hexagonal SP1 array and enlargement. (e) TEM image of SP1 nanotubes (width 10 nm).***

Controlled formation of complex nanostructures is one of the main goals of nanoscience and nanotechnology. SP1 (Stable Protein 1) is a boiling-stable ring protein complex, 11 nm in diameter, which self-assembles from 12 identical monomers. SP1 can be utilized to form large ordered arrays; it can be easily modified by genetic engineering to produce various mutants; it is also capable of binding gold nanoparticles (GNPs) and thus forming protein-GNP chains made of alternating SP1s and GNPs. We form those nanostructures and characterize them by transmission electron microscopy (TEM), atomic force microscopy (AFM) and electrostatic force microscopy (EFM). Further control over the GNP inter-distances within the protein-GNP chains may lead to the formation of nanowires and structures that may be useful for nanoelectronics.




***SP1 array as a basis for a memory array: (a) a large packed ordered array of SP1 molecules. Lower inset: a scheme of the array, upper inset: enlargement of part of the array, where the hexagonal packing is marked. (b) An array of NP-binding SP1 mutants. (c) An AFM image of an array as in (b). (d) Overlaid scheme of the suggested memory, where the writing is by charging individual particles with AFM and reading by EFM. (e) The charging scheme. (f-g) Two charged states of the hybrid and topography (inset)***

Proteins as a mean of a versatile isolating template on one hand and a nanoparticle (NP) as an electric storage device on the other hand have long been investigated as independent entities. The ability to combine the two species to form an addressable single nanoparticle isolated from a conductive surface and adjacent NPs gives rise to a wide range of nanoelectronic devices. For this purpose we have connected a 5 nm $SiO_2$ NP to the SP1, and investigated the electric storage capabilities of the hybrid using Conductive AFM (cAFM). Such memory unit is capable of storing at least 3 states (0, 1, -1). With storage time of over 10 min at room temperature this hybrid can be considered as a nanometric memory unit.




***6His-SP1-GNP rings and tubes imaged with different microscopes. (a,b) HAADF-STEM images of an SP1-GNP hybrid (1.8 nm GNP), top view (a) and side view (b. (c) HAADF-STEM image of an SP1-GNP tube with 4 nm gap between consecutive GNPs. (d) AFM image SP1-GNP tube on mica: the inset shows the height measured on the black segment. (e) TEM image of more complex SP1-nanoparticles structures. The inset shows a scheme of the nanotubes.***

The SP1-nanopartcle hybrids can form long nanotubes in which the SP1 protein serves as a template for a ordered chain of nanoparticles. This chain, when optimized, can serve as a conductive wire and potentially, by using a different nanoparticle in specific positions, as a chain of embedded devices. More complex architectures based on such wires may be very attractive for nanoelectronic applications.

Reference:

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