Bioinspired Templates for the Growth of Semiconductor Nanowires

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Proposal Title: Bionanofabrication of Si Nanowire Array Using Bacterial Surface Layer Protein/Nanoparticle Templates

Research Achievement:

Biologically derived materials hold great promise as templates for a number of nanotechnological applications. They can self-assemble and have a long range order due to the complex inter and intramolecular interactions. In the case of proteins additional advantages lie in the ability to manipulate the amino acid sequence to introduce greater functionality. The use of biologically derived materials is becoming increasing in vogue as the search continues for novel material with enhanced functionality and the potential to make processes more environmentally friendly (*1*). Our group has been looking at different materials derived from biological sources (*2*).

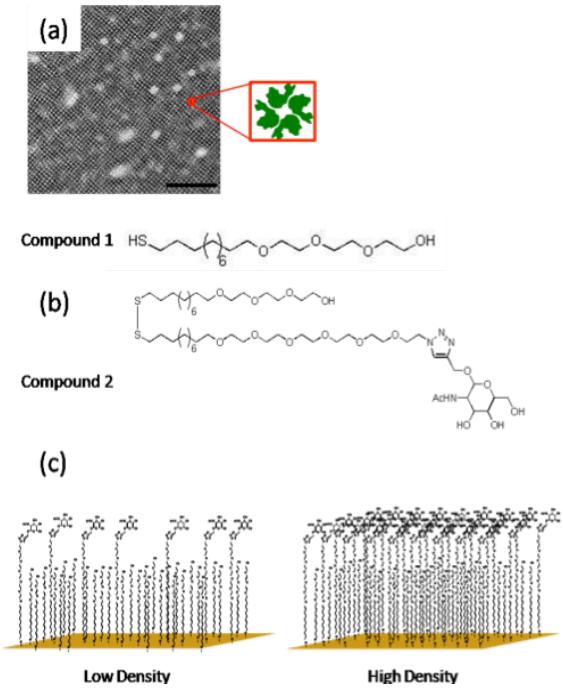

Figure 1. (a). Noise-filtered inverse FFT Brightfield TEM (negative-stain) images of native self-assembled SbpA, with a diagram illustrating the interaction of the protein monomers. (b). Compounds used for the formation of the mixed self-assembled monolayers (SAMs) (c). Diagrams illustrating SAMs with a low density, and a high density of compound 2.

The long range order that can be achieved with biologically derived materials is well known. As a result of this long range order, periodic arrays with nanometer precision over many microns can be achieved with biologically derived materials. One such material is S-layers, a two-dimensional protein crystal that is found as the 'surface layer' of many bacteria. It can be isolated and in many cases reassembled on planar surfaces. Our work on S-layers has focused on its application as a scaffold for the fabrication of nanometer-scale devices. Efforts have included the synthesis of a sugar-based foundation for crystallization of S-layer proteins and also the genetic engineering of mutations to these proteins to introduce site-specific functionality. S-layer from *Lysinibacillus sphaericus* (SbpA) forms an array with square symmetry (p4) (Fig. 1a), with a center-to-center spacing of the morphological units of 13.1 nm. It has been demonstrated that SbpA recognizes the Secondary Cell Wall Polymer (SCWP) of *L. sphaericus,* and can self-assembly *in vitro.*

We have synthesized mixed SAMs of carbohydrate-terminates disulfides (compound 2) and hydroxyl-terminated thiols (compound 1) (Figure 1b), and found that when lower densities of compound 2 are present in the Mixed SAMs (Figure 1c), SbpA had a stronger binding affinity to the SAM (Figure 2). By mimicking the SCWP on a gold surface with mixed SAMs, we anticipate the formation of larger monocrystal, which are essential for its use as scaffold for nanofabrication.

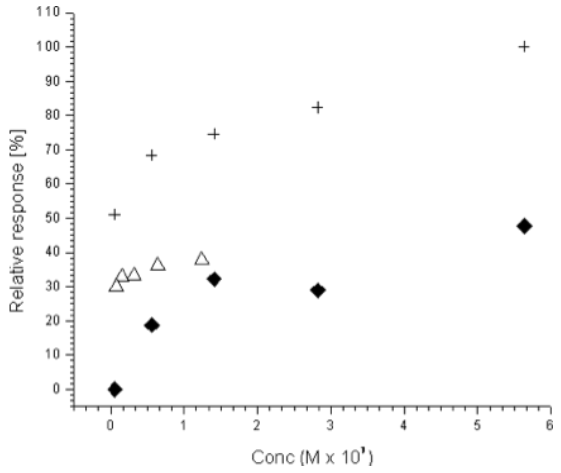

Figure.2. Dependence of the density of GlcNAc on the binding of SbpA to the SAMs formed on the sensor surface. Response levels reached after 240 s of protein injection. (+) 1% of GlcNAc, (Δ) 2.5% GlcNAc, (♦) 10% of GlcNAc.

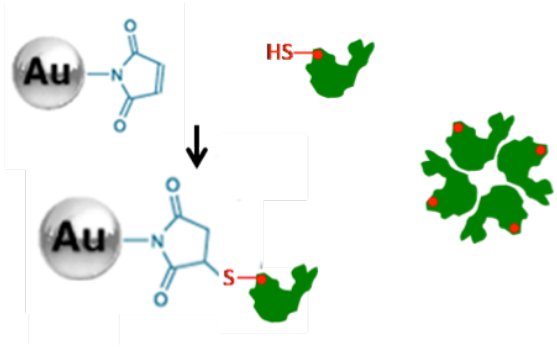

Figure.3. Diagram illustrating how a gold nanoparticle functionalized with maleimide can be covalently linked to the rSbpA-A1065C, and an illustration of how the single cysteine groups would be present in each monomer of the array.

In addition, we have engineered a recombinant SbpA, rSbpA-A1065C, in which 200 amino acids were truncated from the C-terminus of the protein to improve its surface accessibility, and a single cysteine residue incorporated. This recombinant SbpA allows for the potential covalent binding of inorganic materials to the protein array in a 1:1 ratio, as no other cysteine is found in each protein monomer (Figure 3).

Of note is the use of S-layers as scaffolds for patterning catalyst particles to grow semiconductor nanowires and other nanometer structures (*3, 4*). Specifically very uniform vertical germanium nanowires have been grown from gold nanoparticle catalysts patterned using the S-layer proteins isolated from *Deinococcus radiodurans* (Figure 4a). Using this system Ge nanowires which are highly dense and nontapered with a strong preference for vertical growth were obtained on <111> germanium (Figure 4b-c). Recent work suggests that the substrate crystal along with the biotemplated catalyst can influence the orientation of the Ge nanowires. This observation can lead to a new processing scheme where not only the size and length but also the orientation of the nanowire relative to the substrate can be controlled. What functional properties these nanowires have yet to be fully explored.

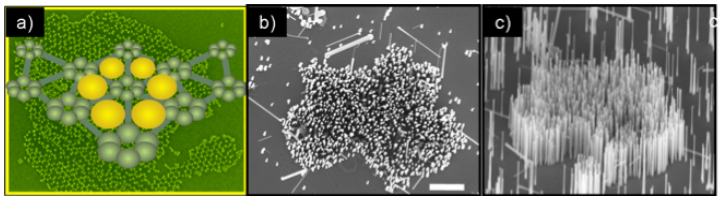

Figure 4. a) SEM image (background) of a honeycomb-like pattern of Au nanoparticles adsorbed on the hexagonal-closed packed intermediate (HPI) S-layer upon addition of 25 mM NaCl. The cartoon representation shows the hexagonal symmetry of HPI. b) top-view and c) 30º tilt view SEM images of vertical oriented Ge nanowires grown from

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References:

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