



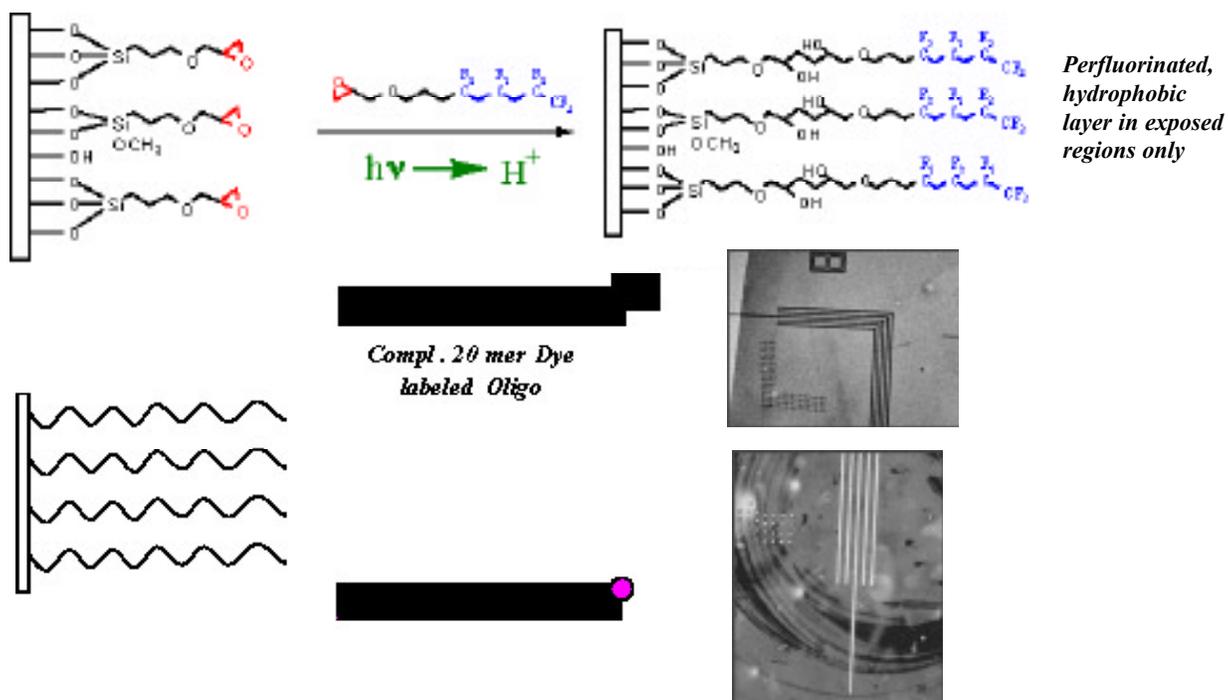
## DNA-Directed Assembly of Material

Serendipity—unsought good fortune—is not uncommon when seeking suitable materials for specific applications, and such may be the case when it comes to applying naturally occurring DNA as a potential engineering "scaffold" for assembling nanostructures.

DNA may contain your genetic code, but to Sandia researchers, it is just another polymer that happens to be utilized *in vivo*. Because of its importance in nature, DNA has been the subject of or used in more than one million technical publications and countless books. As a result, DNA has become a material with an enormous commercial and technical infrastructure to mine, and its synthesis, functionalization, and use have been rather well studied. Could DNA be used as an engineering material and maintain its sequence-specific nature? After all, with Sandia's historical interest in unique signatures and codes, why not the genetic code? As a material, DNA is relatively inex-

pensive and can be ordered with remarkable purity. It is a robust biomolecule and is commercially available with a variety of chemical functionalities. DNA can be purchased in short chains (called "oligonucleotides") of controlled size and base sequence order (A, T, G, and C) unlike most other polymers or macromolecules. Because of its controlled dimension and specificity towards a complementary sequence, oligonucleotides can be thought of as true nanoscale building blocks, which when used in tandem with other techniques (lithography) or nanoparticles, will result in a powerful "toolbox" for doing nanoscience or nanotechnology.

The initial focus of this exciting, new research has been on forcing the DNA to take on the geometric patterns of microfabricated structures and to allow it to integrate with traditional microfabricated materials and structures. The figure below shows how researchers have photochemically patterned surface function-



Light creates a strong acid that catalyzes a reaction with an epoxysilylated silicon wafer and a fluorinated glycidyl ether (upper right) to create hydrophobic regions. The wafer is exposed to a 5'-aminated DNA strand (bottom left) that reacts predominantly in unexposed areas. The DNA is

now fixed in a specific geometry to the wafer. The entire wafer is exposed to the complement with either a fluorescent tag or nanoparticle tag for signal transduction in fluorescence (upper image) or reflectance (lower image) after silver deposition.



alities on a standard silicon wafer. Where the wafer is exposed to light, inert, hydrophobic molecules are reacted to the substrate. In a subsequent step, oligonucleotides with 5'-primary amine is then reacted with the available, hydrophilic surface functionality to form covalently attached DNA structures. Once the DNA is placed on the surface, the complementary strand is hybridized to the immobilized DNA—creating the double stranded base pair. If the complementary strand has a fluorescent dye attached to it, then the pattern can be imaged in a fluorescence microscope. Alternatively, a complementary DNA sequence tagged with gold nanoparticles can be hybridized with the immobilized oligonucleotides. Once the gold nanoparticle is in place, a whole regime of new possibilities unfold. Electroless silver reduction on the gold nanoparticles can be used to form DNA-directed wires, mirrors, gratings etc. as shown in the figure.

Silver patterns will form only when complementary DNA is present. In addition, the researchers now have geometric control over the DNA patterns. If electrical signals are passed through the materials formed by DNA-directed assembly, then signal transmission will be critically linked to the presence of the correct sequence. In that case, it will be a bio-inspired event instead of mechanical or electrical switch—but the outcome will be the same.

New sensors, detectors, and assays will likely evolve from this work. Most chip-based, DNA assays are stuck with either dots or squares because of their fabrication approach. One goal is to utilize the geometric control of the DNA for new sensing or detection technologies. The area of interest with the most potential impact is in using oligonucleotides as a template for assembly of nanoscale devices. Because of its ability to be obtained in a range of specific sizes (length scale) and base sequence (codes for assembly), DNA as a material is ideally suited for the assembly of complex nanoscale devices and sensing



*In 1990, Paul Dentinger (right) received his B.S. in chemical engineering from the University of California, at Santa Barbara. From 1990-1992, he taught chemistry and math in the Peace Corps in Ghana, West Africa. His Ph.D. in materials science was awarded in 1998 from the University of Wisconsin where he studied reaction mechanisms in X-ray exposed photoresist materials. In 1998, he joined Sandia as a Senior Member of the Technical Staff, and has worked in EUVL and various customer-driven materials chemistry programs.*

*Srikanth Pathak (left) completed his Integrated Master's in Physical Chemistry from the Indian Institute of Technology, Kanpur, India in 1997. He obtained a Ph.D. in Inorganic and Materials Chemistry in 2001 from the University of Southern California. His thesis research was primarily based on understanding the surface of metal and semiconductor nanoparticles for optical, catalytic, and biological applications. Srikanth was awarded the 2001 outstanding graduate research award by the chemistry department for his work on quantum dot based bioassays. He is currently a post-doctoral scientist at Sandia and is working on DNA-based patterning and assembly of useful micro and nanoscale devices.*

assemblies. Fortunately, because of the enormous commercial infrastructure already in place, many of the fabrication methodologies are already established, and in some cases, it's simply a matter of implementing well known steps. This fabrication blueprint allows much more time to be spent on envisioning interesting new applications using DNA as tool for nanoassembly.