DNA Directed Formation of Nano-scale Wires and their Use in a DNA Identification System

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Fabrication of nano-scale electronics can be greatly facilitated using smart materials which can self-assemble devices. DNA is uniquely suited to function as a scaffold for the formation of nano-scale devices because (1) of its ability to carry information needed to direct assembly of complex structures and (2) the readily available array of enzymes that can be used to manipulate the DNA substrates.

DNA strands attach to on another following a set of well understood rules which allows for the synthesis of sequences which will form organized structures. Seeman et al. showed that DNA could be used to fabricate complex three dimensional structures with a high degree of precision. More recently, Braun et al. at the Technion Institute in Haifa demonstrated a method for developing a coating of metal on DNA substrates to form conductive wires. Positively charged metal ions are attracted to the negatively charged phosphate backbone of the DNA. The metal ions are then reduced and metal is developed over these nucleation sites. A strand of DNA can be completely coated in metal forming a conductive wire. The resulting wires have a length determined by the DNA template used and have a diameter between 40 and 200 nanometers.

Lithography can be carried out to pattern materials on DNA, using DNA binding proteins to block regions of the DNA during the coating process. This allows for the formation of electrical circuit elements. The DNA template is designed with specific binding sites for proteins. The DNA biding proteins are attached to the DNA, a coating is applied and the blocking protein is removed leaving a region of the DNA exposed. A second material can then be coated on the exposed region. This process has been used to produce self-assembling transistors on a DNA template. By protecting the ends of the DNA template during coating, the resulting components have tails which can direct their assembly with other components.

Using the metal deposition technique, we have been able to develop an electronic sensor which can detect even a single copy of a specific DNA sequence bound to the sensor. A set of interdigitated electrodes is patterned on a silicon chip. Two sets of DNA capture probes, specific for a particular target sequence are attached to the wires. The two probes are specific for regions of the target DNA molecule spaced far enough apart to span the gap between the electrodes. The chip is then sealed in a microfluidic card. A sample is treated to release DNA from any organisms present and DNA is sheared to a length needed to form bridges. If a target DNA is in the sample which is homologous to the capture probes, it can bind to the two sets of electrodes and form a bridge between the electrodes. The resulting bridge is then coated in metal and the presence of a target DNA molecule is determined by measuring completion of an electrical circuit. One DNA bridge between the electrodes reduces the resistance between the electrodes by more than 1,000 fold. Identification of virulent anthrax strains has been carried out using the DNA electronic sensors with a high degree of reproducibility.

Keywords:
DNA: Deoxyribonucleic acid; a nucleic acid that consists of two long chains of nucleotides twisted together into a double helix and joined by hydrogen bonds between complementary bases adenine and thymine or cytosine and guanine.

Self-assembly: the process by which a complex macromolecule or a supramolecular system spontaneously assembles itself from its components.

Lithography: A process in which a material to be coated is rendered on a surface where some areas are available to retain the coating material while the other areas are protected from the coating material.