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Technology Review

Formation of DNA Nanotubes to Produce Nanowires

DNA makes an excellent tool for the creation of tiny structures with programmed topology due to its ability to self-assemble into regular structures. These tubes are created by encoding short unpaired sections of bases known as sticky ends allowing the tubes to self-assemble. In "DNA nanotubes self-assembled from triple crossover tiles as templates for conductive nanowires", Liu and colleagues use the properties of DNA to form nanostructures. They utilize both the inherent code of DNA base pairing and the ability to modify bases to require specific inter-strand interactions. These techniques produce small wires that are shown to carry electrical current suggesting possible future uses in developing small-scale computers.

Techniques

Knowledge of DNA base pairing rules had been previously used to form flat lattices of DNA tiles. DNA tiles are composed of multiple strands of DNA that form a number of double stranded regions of the tile and with single stranded ends that bind selectively to the single stranded sticky-ends of other tiles. By utilizing good algorithms for creating the unpaired regions to limit wrong tile pairings and optimizing the length of the sticky-ends, the tiles can be formed so they self-assemble into a predetermined, regular pattern. Liu et al. use this unique property of DNA to form 3-dimensional structures. Their process uses two different types of tiles, A and B. Both tiles are TAO tiles which contain three coplanar double-helices that are antiparallel at the strand exchanges with an odd number of half helical turns between these crossover points. The B tiles have two additional double-helical regions extending from the middle of the three coplanar helices. The two regions extend out of the plane of the three helices, one into and one out of the plane. An additional modification made to the B tiles was the addition of two thiol groups per tile to the region of the tile sticking out of the plane.

After the tiles were formed the A and B tiles were combined and allowed to self-assemble into regular structures. This was carried out by combining the individual strands that assemble to form the tiles which then assembled to form the lattices. The reactions were carried out by combining the strands at 95°C and then decreasing the temperature .1°C per minute for 12 hours. As the tiles assembled, they formed lattices of alternating A and B tiles. The thiol groups present on the B tiles reacted to form disulfide bonds causing a curvature in the lattice structure. Based on the bond length of the disulfide bonds, the tiles form a tubular structure with the thiol bonds inside the tube such that eight tiles make up the circumference of the tube, with alternating rows of A and B tiles.

After formation of tile nanotubes, a plating process is used to fabricate silver nanowires. The nanotube is seeded with silver particles by incubation with glutaraldehyde and TAE/Mg buffer. The DNA was set by overnight incubation in the TAE/Mg buffer. Then the DNA was incubated in AgNO3 and ammonia allowing for the seeding of silver onto the DNA. The gaps in the seeding were then filled in using the HQ

Silver process to completely encase the nanotube. This process formed nanotubes with lengths of up to 5 um, heights of 35 nm, and widths of 40 nm.

Scientific Applications

The scientific applications of this paper were to proof of concepts that nanotubes and nanowires could be formed. They succeeded in both objectives forming regularly patterned nanotubes that were observed by AMF. Measurements correlated well with expected dimensions of the tubules showing that the periodicity and construction were as expected. Additional tests included checking for the location of thiol groups which showed no misplaced thiol groups sticking out of the tubule. The nanowires were also shown to exist by examination with SEM. Conductivity tests demonstrated their completeness and their ability to carry a current. These tests show that these plated nanotubes are sufficient for carrying a current in a well formed, consistent tube. This proves that these nanotubes have potential in computing, however in this experiment all that was needed was to form a few nanotubes that worked. Because of this need for only a few nanotubes, there is high acceptable level of error in formation or the nanotubes. They can also be used as a basis from which to form future structures such as branched nanotubes or nanotubes anchored to specific locations. Why do you need these in science? Will you continue to have the same high fault tolerance?

Engineering Applications

The engineering applications of this paper are mostly future work. The ability of DNA to bind to specific locations makes it promising for self-assembly of nanotubules in specific locations for the formation of wires for electronics. Because these nanotubes are may/have the potential to

so tiny, they will provide a major step in the miniaturization of electronics. The paper also demonstrates how this method improves the conductivities of the nanowires, making them usable for electronics unlike previous attempts where the metal plating was far too irregular to allow for usage in a computing device. However, before any of the future engineering applications are able to be utilized, more work needs to be done to improve the accuracy and limit errors in the formations of the nanotubes and nanowires. Carrying a current through a system of nanotubes requires each nanotube to be error free, requiring an error rate much lower than one error in the number of nanotubes creating the system. Any wrong base pairing in the DNA structures will lead to large errors in nanotubule formation, affecting the properties of the nanowires that are formed. Because of the large numbers of nanowires that would be used in a single device, error must be almost eliminated in order to produce an acceptable number of error free devices. ↑More precision here

References

Liu D, Park S H, Reif J H, LaBean T H. DNA nanotubes self-assembled from triple crossover tiles as templates for conductive nanowires, PNAS January 20, 2004.