Enabling Technology: Nanostructure and its Applications

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1. Introduction:

Nanotechnology is innovation on the nanoscale, one to one hundred nanometers. Scientists can change and observe atoms to revolutionize health care, materials science, and other practices or studies [1]. The newfound ability to manipulate “materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts” [1] has prompted ground-breaking research. This data can be used to improve biomedical devices, personalized medicine, energy production, energy storage, capacitors, and more.

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2. Structural Properties

What are Nanotubes?

Nanotubes are long chains of atoms or molecules, bonded together. To make such a structure, researchers at Penn State University used a large volume high pressure device to compress benzene at 200,000 atmospheres. This sudden, drastic pressure change polymerizes the benzene into thin strands of carbon atoms. In this case, the carbontube is the shape of a diamond, “hexagonal rings of carbon atoms bonded together, but in chains rather than the full three-dimensional diamond lattice” [2]. Carnegie researchers, Malcolm Guthrie and George Cody, have constructed diamond nanothreads, too. These benzene nanothreads have extraordinary properties, including strength and stiffness greater than that of today’s strongest nanotubes and polymer fibers” [2]. The shape of these nanothreads is completely unique to the benzene molecule.

Figure 1: Benzene carbontube [1]

Atoms and molecules may have different interactions on the macro and micro [or nano] scales. When benzene [C_6H_6] is compressed at high pressure, the hydrogen atoms envelop the diamond-shaped carbontube as it forms. “As the researchers slowly release the pressure, the benzene molecules unexpectedly react with each other forming new carbon-carbon bonds with the carbon configuration of diamond extending out as a long, thin, nanothread” [2]. Each thread has a diameter smaller than a nanometer.

States of Matter

Metal nanoparticles can take on interesting shapes and forms. “They appear, from the outside, to be liquid droplets, wobbling and readily changing shape, while their interiors retain a perfectly stable crystal configuration” [3]. This research, done at MIT, would change the way engineers construct electronic circuits on the molecular scale. The scientists gathered pure silver particles with diameters of less than 10 nanometers for the experiments.

The goal of the experiments (although not clearly described) was to learn how to consistently form shapes out of the silver molecules. However, the results contained inconsistent deformations when the liquid silver particles reacted with the test environment variables. The particle shapes changed often, and were unstable. Similar elements such as gold and tin, too, would not be a good option for a successful electrical connection medium.

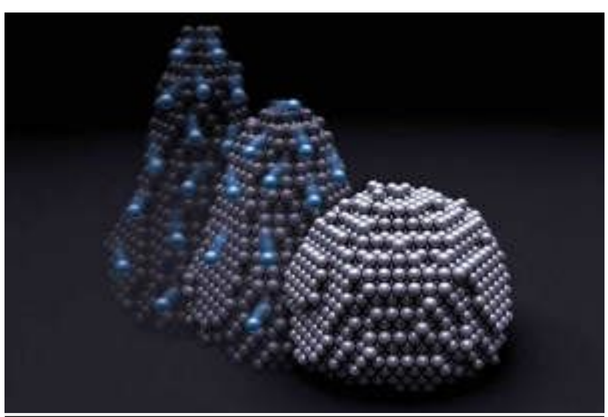

Figure 2: Detailed imaging of the metal nanoparticles [3]

To better understand the results of the tests, the researchers used a transmission electron microscope to observe the particle movements. The modeling processes used showed “while the exterior of the metal nanoparticles appears to move like a liquid, only the outermost layers — one or two atoms thick — actually move at any given time. As these outer layers of atoms move across the surface and redeposit elsewhere, they give the impression of much greater movement — but inside each particle, the atoms stay perfectly lined up, like bricks in a wall” [3]. This is yet another example of how different atom’s chemical and physical behaviors can be on a smaller scale; it’s distinctly unpredictable.

The MIT researchers also noticed, similar to the benzene molecule, that when solid, the nanostructure’s “interior is crystalline... the only mobile atoms are the first one or two monolayers” [3]. However, if the state of matter changed the silver droplets to liquid, the crystal structure deteriorates completely. This deformation is pseudoelastic: the material returns to the original shape after stress is removed [3]. With this knowledge, MIT has dedicated another team of researchers that develop nanocircuits and other tools that can work with elements that change structure along with state. They have discovered that “if the nanoparticles are protected by even a vanishingly thin layer of oxide, the liquidlike behavior is almost completely eliminated, making stable circuits possible” [3]. Research and future experimentation with noble metals is also a possibility. With a covalent bond between a noble gas and metal, the “formation of an oxide layer is destabilized” [3]. Since most noble gas elements have smaller atomic radii, one would believe the bonds will have higher strengths, giving greater stability to the shapes of the nanostructures that they form. In nanochemistry, this is not the case. At such small sizes, the nanotubes can be weak, especially “at about 10 nanometers at room temperature” [3].

Grand Challenge Area & Social Impacts: Health

MIT’s work with the silver particles contributes to the Grand Challenge area of health. The different interactions of the molecules on the nano scale can be applied to drug development for patients, especially with personalized medicine. Creating new pharmacy products that can combat tumors and viruses would solve cancer and illesses on a wide-scale, changing the health care world for better. Treatments would become more successful, and perhaps more affordable and accessible. Then, people in third-world countries would be able to receive the medical attention they deserve, and global health would increase to comfortable, safe level. However, not all countries have the funding nor the qualified employees to administer these medical solutions. Being economically aware and charitable might help developing countries. Furthermore, societies must be respectful of others’ cultures. Some cultures do not accept modern medicine, in conjunction with current religious practices and beliefs that are upheld in the area. Learning more about their ways and negotiating with their leaders might lead to successful implementation, and healing for all.

Grand Challenge Area & Social Impacts: Energy

The MIT research project results could also be applied to the Grand Challenge area of energy. The nanomolecular structural observations could be used to create more powerful resources and circuits. Not a Joule is wasted when transferring energy; batteries do not overheat and drain out. Power lines transmit the electrons quickly between anode and cathode, and power resources can recharge quickly. This would not only increase the lifespan of the typical smart phone battery, but also put electric cars back on the market as a viable transportation option. To further expand on the development, if engineers made circuits that stored the potential energy, or even produced their own energy, then products would be completely self-sustainable. Smart phone cases that are self-charging already exist, but what if every electronic device maintained its own battery level at a constant one hundred percent? Sustainable devices are in the near future.

3. Custom-Shaped Applications

Using DNA

Researchers at the Wyss Institute for Biologically Inspired Engineering at Harvard University have taken nanotechnology to the next level. Using DNA, they created small, three-dimensional metal nanoparticles. Instead of using gold or silver, these researchers are using bits and pieces that are always accessible (and free!)-- our cells! The precision in the three-dimensional structures that these particles make "has the potential to advance laser technology, microscopy, solar cells, electronics, environmental testing, disease detection and more" [4].

In 2012, the Wyss team used computer aids to create "hundreds of different self-assembling one-, two- and three-dimensonal DNA nanoshapes with perfect accuracy" [4]. Harvard students and researchers plan and design the framework using a very similar digital program that designs arbitrary nanostructures. The challenge to this process is to input organic material (DNA) and output inorganic material (metal particles). The Wyss team used the hollow, empty spaces within the DNA double helix structure. Within these gaps, the researchers could make changes and use the DNA as foundries, or molds [4]. "The concept can be likened to the Japanese method of growing watermelons in glass cubes. By nurturing watermelon seeds to maturity inside cube–shaped glass boxes, Japanese farmers create cube-shaped mature melons that allow for densely–packed shipping and storage of the fruit. The Wyss researchers similarly planted a miniscule gold "seed" inside the hollow cavity of their carefully designed cube–shaped DNA mold and then stimulated it to grow. Using an activating chemical solution, the gold seed grew and expanded to fill all existing space within the DNA framework, resulting in a cuboid nanoparticle with the same dimensions as its mold, with the length, width and height of the particle able to be controlled independently" [4].

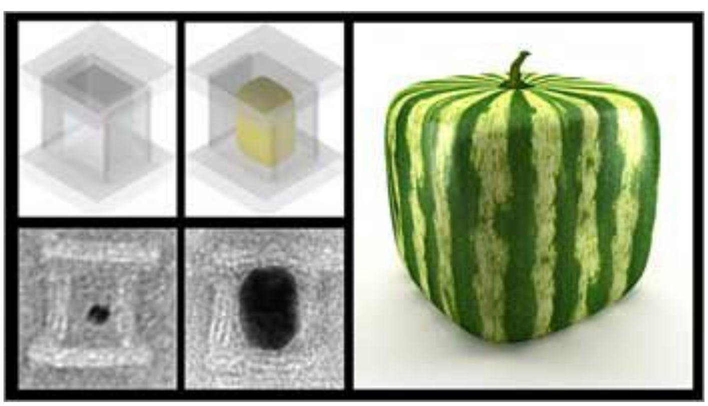

Figure 3: Japanese cube-shaped melons [4]

In summary, once the computer identifies the mold and orders for the DNA to be manipulated, everything changes. The shape is built out of linear DNA sequences, “which attract and bind to one another in a predictable manner” [4] based on the biological patterns of base pairing. The result inorganic particles are smaller than twenty five nanometers. The precision is less than five nanometers [4]. This is incredibly accurate, even more so than using gold or silver as input for such desired nanoparticles [4].

Shapes

Havard researchers explored “varied 3D polygonal shapes, spheres, and... 3D Y–shaped nanoparticle and... a cuboid shape sandwiched between two spheres” [4]. The positive results of these stable, diverse shapes supports the idea of using complex DNA mold designs. Unlike inorganic nanotubes, the DNA molecules are stronger when they are smaller. DNA maintains its structure exceptionally well under pressure [4]. Researchers have also discovered that “there is a wide range of inorganic nanoparticles that can be forcibly shaped through this process of DNA nanocasting”; it is not limited to just gold or silver [4].

As the shape grows under pressure, the nanoparticle products form around the DNA molds. This allows scientists to make any last minute changes (like I am with this paper) to the surface of the particle, with high precision on the nanoscale. These changes could affect “highly-sensitive, multiplex methods of detecting early–stage cancers and genetic diseases by combining the chemical specificity of the DNA with the signal readout of the metal” [4]. In the electronic world, the DNA framework could be used to produce pure metal wires and connectors for more efficient power and data processing.

Grand Challenge Area & Social Impacts: Health

Wyss and Harvard’s projects contribute to the Grand Challenge area of health, as well. The various shapes of the molecules formed with the DNA molds can be used to create new drugs for patients, likewise with states of matter. “‘The properties of DNA that allow it to self assemble and encode the building blocks of life have been harnessed, re–purposed and re–imagined for the nano–manufacturing of inorganic materials,’ said Don Ingber, Wyss Institute founding director” [4]. With regards to personalized medicine, using individuals’ DNA to make the nanoparticles might be an idea that doctors would consider. The drugs have to be made with the DNA, and once injected into the target, the drugs will have a lesser chance of reacting negatively in the environment. The concept of personalized medicine, however, is not something that many people feel comfortable with. Although patients can discuss solutions with their doctors, they may not always have options that reap desired results, such as life. Another element to consider is the cost of implementing personalized medicine research and techniques across the entire nation, in every health care center. When the solution goes abroad, again, scientists must be considerate of other communities’ culture and ethics.

4. Conclusion

Nanotechnology includes some of the tiniest, most important engineering solutions of this century. Researchers are learning more about atomic and molecular interactions on the nano scale, one to one hundred nanometers. Inorganic atoms and molecules can be weak and unstable, while organic compounds, particularly DNA, can be very strong and create stable shapes. This data can be used to change the health and energy industries. With new innovations in health care practice and ethics, personalized medicine just might become an option within the next few decades. Longer lasting batteries are also in the near future. The world is changing, in ways that cannot be seen, but rather measured by societal contributions and responses.

References

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