Nanotechnology for Biomedicine: Past, Present and Future

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ABSTRACT
During the last few years nanotechnology has made many advances especially in the biomedical area. Some of the terminology is defined with illustrative devices under consideration discussed here with a view toward what will be coming up in the future.

Catagories and Subject Decriptors
K.4.1 Computer related health issues

General Terms
Design, Performance

Keywords
Nanotechnology, biomedical engineering

1. INTRODUCTION
Nano structures are ones whose length/width/height dimensions are on the order of nanometers, a nanometer, nM, being 10^{-9} meters. For those of us working with micron, µM, dimensions, which we thought to be small, the nM dimesions are the next step in miniaturization. Such a small length is rather hard to visualize, especially when one considers that the diameter of a human hair is on the order of 100 to 1000 nM in diameter, being made of over an hundred strands of 10 nM microfibril Keratin [1, p. 69]. To be able to construct in a controlled way such miniscule structures requires the means of ultra fine resolution and special instrumentation. At this stage little such is available but much is being developed and with the large scientific investments presently underway, such as the US Government's nanotechnology initiatives, the future looks very bright. This is especially true for the biomedical engineering field since nanoparticles can invade spaces previously unattainable, such as the wall of living cells. That being the case, the future looks bright for the cure of cancers, detection of DNA, and delivery of drugs through engineered viruses.

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2. NANO DEVICES
The technology is such that new components are required and with them new terminology, some of which uses familiar words but with very specialized meaning. Among the nano structures being considered by the research community and of interest to the medical community are nanoparticles, nanoshells, nanowires, nanotubes, quantum dots, mems nanobeams and molecular probes [2, p. 48].

Nanoparticles are nanosized devices which contain therapeutic molecules for delivery of drugs. The ones being developed contain a lipid shell which allows them to penetrate blood vessels. As such they can release drugs to desired areas, such as antibodies targeted to destroy cancer cells. Similarly, one can fabricate engineered viruses which can be used for many therapeutic purposes. Figure 1 shows on the top left a 12 nM particle which is an engineered virus with the inside shown on the right with a natural virus shown on the bottom [3].

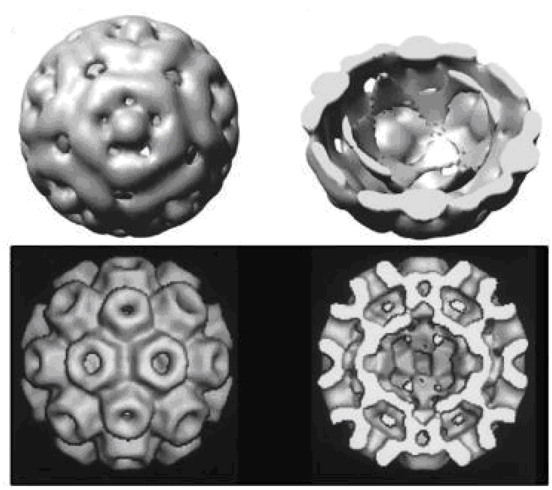

Figure 1. Engineered virus. Reprinted with permission from [3]. Copyright 2009 American Chemical Society.

Nanoshells are silica spheres with gold or other metallic coatings which can be sent through the blood stream to collect at a determined site. On being radiated they will absorb heat and serve as a very local heat source, which for example can be used to kill cancer cells.

Nanowires are nM diameter wires to which various particles, such as proteins or antibodies, can be attached such that complementary particles will be captured. Figure 2 [4] shows a cross section of nanowires coated with a therapeutic bead for drug delivery to the intestines.

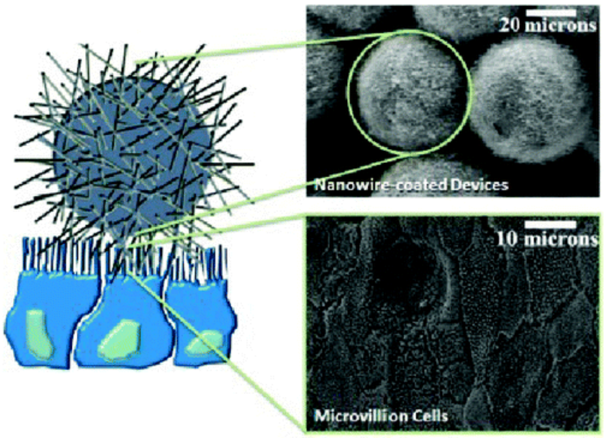

Figure 2. Nanowires. Reprinted with permission from [4]. Copyright 2009 American Chemical Society.

Nanotubes are wire-like tubes which are constructed as carbon nanotubes. These allow for electrical manipulation of particles around them as well as allowing the attachment behavior of nanowires. But since carbon nanotubes have electrical characteristics they can be used for electrical stimulations and manipulations. Figure 3 [5, cover] shows a carbon nanotube which serves as the gate of a field effect transistor. As the current-voltage characteristics of the transistor change with DNA attached to the polymer on the nanotube surface, one can characterize different DNA.

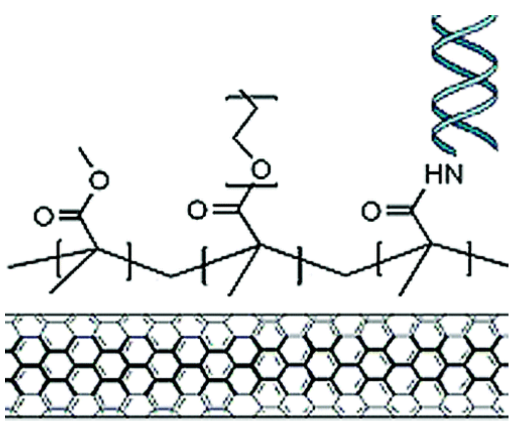

Figure 3. CNT FET gate. Reprinted with permission from [5]. Copyright 2009 American Chemical Society.

Quantum dots are nano size dots either embedded in semiconductors or free to move around, such as nanoparticles. These were initially designed to be embedded in silicon where they can be used to form single electron transistors. Unfortunately to date these really only have useful behavior at very low temperatures, near zero Kelvin. When free to move around at room temperature they have been constructed as small crystals which can fluoresce and as such become useful for sensing the location of various chemicals or particles. Probably the most prevalent of nano devices are the freely moving quantum dots. However, there is danger in letting them loose since they are so small they can infiltrate undesired locations and cause damage. Figure 4 gives an indication of a quantum dot configured to form a virus while Figure 5 illustrates the structural composition of similar devices [6,7].

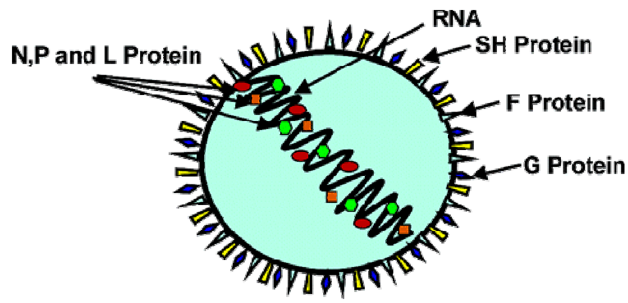

Figure 4, Quantum dot virus. Reprinted with permission from [6]. Copyright 2005 American Chemical Society.

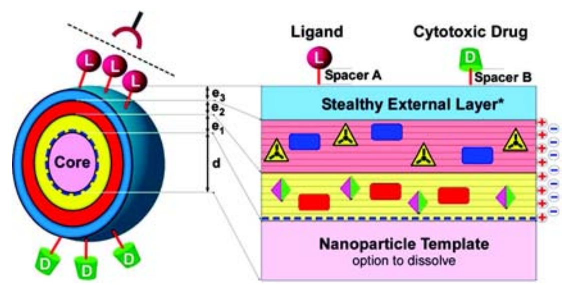

Figure 5. Structure of a possible nano dot. Reprinted with permission from [7]. Copyright 2009 American Chemical Society.

Mems (= micro electo-mechanical systems) nanobeams are beams embedded in semiconductor material. When they bend they can exhibit measurable changes, such as in attached capacitors, which allow the indication of something weighing them down. Thus, by attaching chemicals they can be used to detect the presence of complementary chemicals. As such they become useful for detecting pollutants. And with the incorporation on Systms on a Chip, SoC, they allow for the processing of signals for alerts or other uses. Although the sensors on them may be nano the full SoC is at present certainly at the micron level.

The words “molecular probes” at present generally mean probes for DNA. Usually these would be attached to other structures, such as mems beams such that complementary strands of DNA can be detected for either medical or forensic uses.

3. FUTURE TECHNOLOGIES

The design of nano-structures is a very challenging field. There is the difficulty of fabrication where even a speck of dust is bigger than the structures of interest. And then there is the difficulty of measuring and using the result. Thus, considerable research effort will be needed to make the use of nano devices common place. Standards will be needed in order to prevent damage and to achieve interoperable systems [8].

It appears that nano particles can be manipulated by light pressure, so the development of laser means for moving the particles into place seems to be at hand [9]. Likewise, since many diseases can be detected or monitored via blood samples, nano bar codes to catalog protein presence have been developed [10]. And at present polymer coated silica nanoparticles have been used to repair damaged cells in the brains and spinal cords of injured guinea pigs [11], opening the way for many types of damages previously not healable. In any event ingenious fabrication techniques will be called upon [12] with the need for much more sophisticated laboratory equipment.

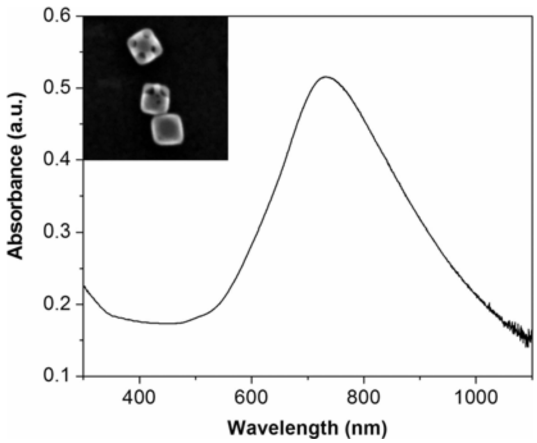

Figure 6. Spectrum for Au nano-cage. Reprinted with permission from [13]. Copyright 2009 American Chemical Society.

Means of accessing and making measurements at nano dimensions raises particular problems. One approach is to use light to detect or monitor, as shown in Figure 6 [13].

Over time the electrical behavior has become more tractable so that we can create nanotubes in predictable designs for given characteristics as illustrated in Figure 7 [14].

And with the advent of good computational models and electronics to handle them, systems on a chip should become available to control things like mitosis [15].

Some promising devices for the future are magnetic nanoparticles. Those of [16] use an iron oxide core surrounded by polyethylene oxide. By applying a magnetic field the devices heat up and in so doing can apply local heat. But one can imagine steering them into position using magnetic fields. Another interesting area could be the use of Zinc Oxide nanowires [17]. Since ZnO is a piezoelectric material they could be used in many creative ways. They should be especially useful since their diameter is about one-third that of a carbon nanotube.

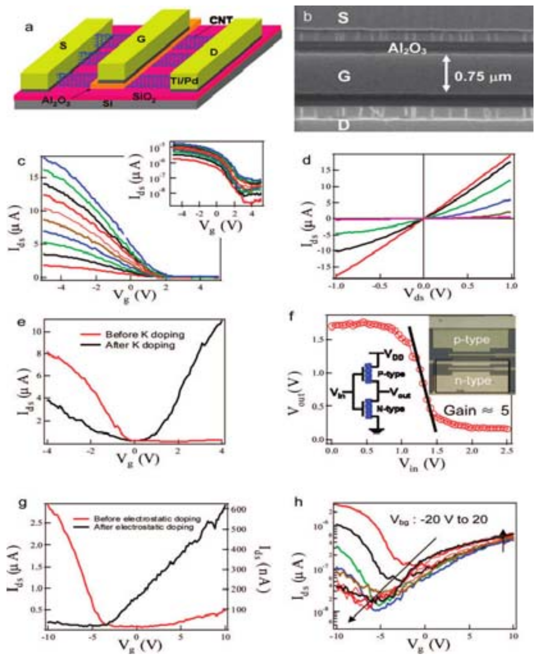

Figure 7. Nanotube I-V designs. Reprinted with permission from [14]. Copyright 2009 American Chemical Society.

4. DISCUSSION

The field of nanotechnology has been of interest for some time in the electronics industry since it represents one means to increase the density of transistors. There it is somewhat routine these days to fabricate transistors in the 10-100 nM feature size. Still the field of nanotechnology is a rather new one, especially with applications to medicine where there isconsiderable activity world wide. That being the case , along with numerous articles in standard journals, such as Nature, it has spawned a number of new journals targeted specifically to the field, among which are Nanomedicine, International Journal of Nanomedicine, Nanotechnology, Nanoscale Research Letters, IEEE Nanotechnology Magazine, Nanostructured Materials, Nanotechnology Law and Business, Nano Today, etc. One I like is NANO Letters, because it has at the front of each article pictures portraying the key ideas, a number of figures of which are used in this paper. Many nanotechnology articles are devoted to topics other than medicine but the number of ones specific to biology appears to be increasing and certainly they represent very creative uses of nano devices.

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