NANONETS: two dimensional random networks of nanowires. The value proposition

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Introduction

Novel materials are beginning to emerge as attractive alternatives to silicon, metals and transparent conducting oxides that presently dominate the electronic materials and technology landscape. These include polymers and composites, often coupled with simple, room temperature and bottom-up fabrication approaches. Together, they offer opportunities in areas broadly defined as flexible and transparent electronics, passive and active matrix displays, simple electronic circuits, and components of solar cells.

We have also witnessed the emergence of nano-scale "wires": long and thin bulk wires, tubes, belts, nanofibers and other forms with a large aspect ratio. These are built of inorganic materials, such as silicon, polymers such as polyaniline and also new forms of matter such as carbon nanotubes. As illustrated on Fig.1.the diameter of these wires is small, smaller than the smallest structures that are currently fabricated using lithographic techniques,

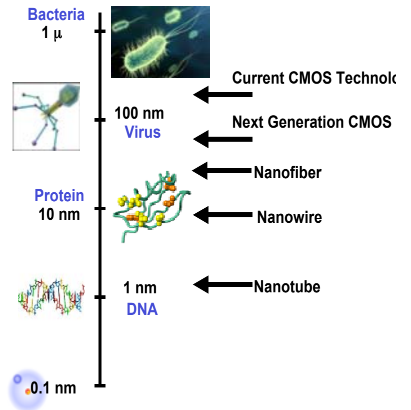

Fig.1. The size scale of nanoscale metallic, semiconducting wires with high aspect ratio, as compared with fabricated (CMOS) structure sizes.

Nanoscale wires: the building blocks

A variety of organic and inorganic wires have been fabricated. Inorganic nanowires, such as silicon, together with carbon nanotubes are the most prominent examples, but metallic wires have also been produced. At the same time, nanofibers of conducting polymers are also rapidly emerging.

Architecture

The fundamental device architecture is that of a random molecular nanowire network that serves as the conducting channel. The architecture is illustrated on Fig.2. An appropriate analogy of the device architecture is that of an interconnected network of freeways, providing a fast transport medium for cars – potentially significantly faster that a uniform, but lower conductivity medium (analogous to surface roads or the terrain itself). The same concept applies for electrically conducting structures – given of course the assumption that the network is built of highly conducting nanoscale wires. A larger aspect ratio leads to more superior properties, for example conduction occurs at lower surface coverage.

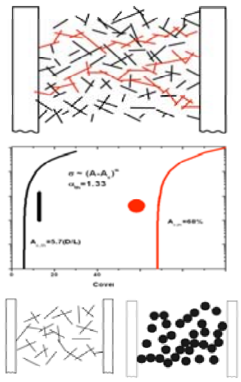

Fig.2. The concept of two dimensional random nanowire network (upper part), conduction versus coverage (middle part) and networks built of wires and dots (lower figure)

Fabrication avenues

The individual elements are grown by a variety of techniques, a fact not surprising in the light of the broad variety of nanowires. Appropriate solubilization, and deposition technologies of such wires (while avoiding bundling) are essential to arrive are a random structure. These have been solved in certain cases, for example significant effort has been devoted to carbon nanotube solubilization and deposition. These issues have also been successfully addressed for a variety of wires, as illustrated with a few examples on Fig.3. Direct growth on substrates has also been attempted.

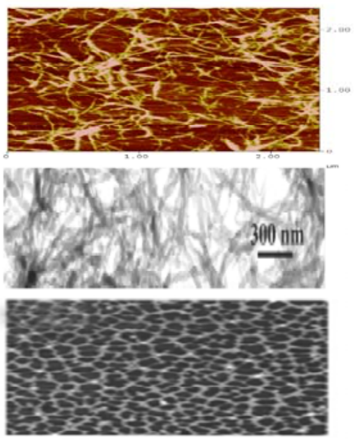

Fig.3. A carbon nanotube, polyaniline nanofiber and gold nanowire network.

The value proposition

The issue at hand is the value propositions associated with such a construction, in comparison with other structures – such as thin films for example. Several advantages are of importance.

Conductance: the freeway analogy. This value proposition assumes that the conductivity of the wires is large; the larger the nanowire conductivity, the better the network conductance. Factors like nanowire-nanowire interconnects are also playing a role here and have to be addressed.

Transparency. A network of highly one dimensional wires has very high transparency – approaching 100% for truly one dimensional wires. The advantage is illustrated on the lower part of Fig.2: a wire network with a conducting channel has much higher transparency than the same construction using dots.

Flexibility – the spider web analogy. A random network of wires has, as a rule significantly higher flexibility that a film of comparable surface coverage, making the architecture eminently suited in particular for flexibility-requiring applications.

Fault tolerance. Breaking a conducting path leaves many others open, and the electron pathways will be rearranged. The concept is called fault tolerance, and is used in many areas, from internet networks to networks of power lines. The concept applies here as well.

The individual components: the ability to make highly perfect (so-called single crystalline) wires – with quality superior than that of thin films for example. Single crystal silicon wires can be grown – and then deposited onto a surface, while growth of single crystal silicon thin film is a rather difficult enterprise. Note also that, as an example, there is significant difference between the mobility (factor of about 500) of single crystalline and amorphous silicon, and a random network is expected to retain at least some of the advantage of the former.

Application opportunities

With the architecture coupled to room temperature, simple fabrication avenues, a variety of applications will benefit from the technology. They include transparent electronics, where transparent conducting coatings are needed, plastic or macro-electronics where mechanical flexibility is essential, new generation of photovoltaics, solid state lighting and the construction has also advantages for cheap, disposable sensors.