Nanowires

Application in Renewable Energy

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The global electrical industry has been witnessing major changes over the last few years owing to rapid expansion plans undertaken by governments across the world. However, with the energy resources being limited, renewable energy is perceived as a major source of alternative energy. As a result, the renewable energy sector is trying to figure out what more is needed to live up to the growing expectation.

Introduction of nanowires is one of the recent moves taken to meet the energy demand. However, use of nanowire is not only limited to the electrical industry. It can be seen as a revolutionary discovery that has the potential of changing the face of the technology world forever.

Discovery

The discovery of nanowires is closely associated with nanotubes, which was the brainchild of Japanese physicist Sumio Iijima. In 1991, Mr. Iijima proposed the manufacturing of tiny tubes of pure carbon, which are essentially sheets of graphene rolled up into cylinder.

Nanowires, which are made of solid crystalline fibres rather than the usual hollow tubes, gained popularity instantly after being introduced. The similarity between these two equipments lies in their slenderness of design and one-dimensional nature. Some experts opine that due to two of their dimensions being on the nanometre scale, they can be called quasi-one-dimensional.

Nanowires have a lateral size, which is limited to tens of nanometres or less. They also have an unconstrained longitudinal size. Since at such scales the quantum mechanical effects become critical, nanowires are sometimes also called 'quantum wires'. There are no restrictions on how wide nanometres can grow, but in terms of height they cannot be more than a few nanometres (10^−9 meters).

Synthesizing nanowires

Nanowire production or synthesis follows two basic approaches:

- » The Top-down approach
- » The Bottom up approach

The top-down approach follows the technique of reducing a large piece of material to smaller pieces, which can include methods like lithography and electrophoresis. On the other hand, the bottom-up approach combines constituent adatoms. Most laboratories today use the bottom-up approach.

Other common techniques used in laboratories today are suspension, electrochemical deposition, VLS growth and vapour deposition.

Researchers at the Harvard University have developed nanowires in their laboratories with the help of gallium-nitride, which can serve as a good example of how nanowires can be developed in labs through various experiments. The process involves flowing nitrogen gas and vaporised gallium through the reaction chamber which contains an iron target. Iron nanoparticles are vaporised from the target by using a laser that acts as the catalyst. Both gallium and nitrogen molecules get dissolved in the iron nanoparticle. As the particles start growing, they sweat-off of the surface. The molecules start precipitating on the surface where they combine to develop the nanowire.

The materials used to develop nanowire must be soluble in the catalyst nanoparticle. For example, while developing silicon nanowire, gold serves as catalyst nanoparticle because silicon is soluble in gold.

Types of nanowires

There are different types of nanowires available in the market today. Some of them are:

- » Metallic (Nickel, Platinum and Silver)
- » Semiconducting (Indium phosphide, Silicon, Gallium Nitride)
- » Insulating (Silicon Dioxide, Titanium Dioxide)
- » Molecular - Organic (DNA) and Inorganic (Mo6S9-xIx)

Metallic: Such nanowires are made of metals like nickel, platinum and silver. These metals are used as plasmonic materials for nanowire waveguides with diameters being as low as 5-nm-level. Such nanowires have high potential of revolutionising research in multiple fields like chemistry, electronics, medicine and optics because they exhibit unique electrical, optical, mechanical and magnetic properties.

Metallic nanowires have the ability of manipulating electromagnetic fields on the deep-sub wavelength scale by converting light to Surface Plasmon

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Polaritons (SPPs). Various types of metal nanowires have been proposed so far for guiding SPPs.

Semiconducting : These are quasi-one-dimensional structures having diameters in the range of 10s to 100s nanometres and lengths in the range of up to 100 microns. Often these semiconducting nanowires are large enough to ignore quantum size effects. Optically, these are high-quality one-dimensional waveguides consisting of rectangular, triangular, hexagonal and cylindrical cross-sections. One of the distinctive features of such wires is that there is high contrast between the refractive indices of the wires (which ranges between 2.5 and 3.5) and its surroundings, typically air. These high contrast wires, which are as small as a few nanometres, have very good optical waveguides.

Semiconducting nanowires are developed on the basis of the well-known vapour-liquid-solid mechanism. In this process, the growth of a single crystal depends on the initial existence of a catalyst, such as gold (Au). This Au film is either deposited or the nanoparticles are dispersed on the initial substrate. The absorption of the vapour phase semiconductor into the metal particles has the ability to significantly lower the melting point of the semiconductor-metal alloy. Liquid alloy droplets are formed at a moderately elevated temperature on a substrate.

Insulating : Another common type of nanowire is the insulating nanowire, which uses materials like silicon dioxide and titanium dioxide as insulators. In this process, nanowire bundles are constructed inside an insulating ceramic single crystal by using the process of unidirectional dislocations. The process is pretty elaborate, involving a two-step deformation technique and heat treatment.

Molecular : Molecular nanowires are composed of repeating molecular units that can be both organic and inorganic.

» Organic : One of the most commonly used processes to develop organic molecular nanowires is the direct printing method (liquid-bridge-mediated nanotransfer moulding), which enables the simultaneous synthesis, alignment and patterning of the nanowires from molecular ink solution.

» Inorganic: These nanowires have sulphur terminated ends that help them to bond easily with golden nanoparticles.

Incorporating into industrial application

In order to integrate nanowire technology into industrial application, researchers have developed a technique of welding nanowires together. In this process, one sacrificial metal nanowire is positioned close to the pieces that are to be joined. An electronic current is applied to fuse the wire ends. Scientists have recently discovered that single-crystalline ultrathin gold nanowires with diameters within the range of 3-10 nanometre can be 'cold-welded' together within just a few seconds through the process of mechanical contact, under considerably low applied pressure.

Normal usages of nanowire

Research groups employed in developing and experimenting with nanowires have come up with new and innovative concepts on how nanowires can be used for betterment of human life. Two such areas or devices where nanowires can be suitably used are in transistors and memory devices. Researchers at Hewlett-Packard (HP) and the University of California have proved that memory cells can be created at the intersection of two nanowires. They have also used a somewhat complicated array of nanowires to develop a transistor-like device called crossbar latch. There are various other such memory devices that use indium oxide nanowires. The prediction from researchers at the University of South California and NASA Ames research Center are that the device will be able to store 40 gigabits per square centimetre, which is a lot of data by any standard. The process of developing transistors and memory devices used in computer chips from materials that are almost of the width of a nanometre, such as nanowires, is called molecular electronics.

Due to their miniscule size, manufacturers can use millions of nanowires on a single microprocessor. The computer speed can be increased considerably as a result.

Nanowires also have the ability of becoming superconductors due to their proximity effect. Researchers have been able to control the superconductivity of nanowires by running various amounts of voltages through the substrate under the wires.

Nanowires can also be used in nano-size devices like nanorobots that can be used for medical purposes. Such devices can help in treatment of diseases like cancer.

Special nanowires created by using piezoelectric material can be used to generate electricity from kinetic energy. Researchers in Japan are working on developing atomic switches that make use of nanowire to replace semiconductor in electronic devices. Nanowires are also being widely used today to generate renewable energy. Solar photovoltaic (PV) cells specially make use of coaxial nanowires that help to improve the energy efficiency of solar cells.

Using nanowires to generate renewable energy

When equipped with the right kind of electrical properties, nanowires have the ability to become tiny solar cells, thereby transforming sunlight into electric currents. Nanowires are being widely used in solar PV cells. Researchers have developed solar technology by integrating nanowires that have the ability to capture large quantities of light and produce energy with incredible efficiency at a much lower cost. In spite of the size constraints, nanowires have tremendous potential. This crystalline cylindrical structure, which is about 10,000 times thinner than a single human hair, can concentrate sunlight up to 15 times than normal intensity. Researchers feel that this discovery is revolutionary as this can help to increase the amount of solar energy produced every year across the world by a significant percentage.

The mechanism

While creating nanowires for solar PV

cells, certain techniques are followed. One such technique is the 'vapour solid growth'. The nanowires need to be uniform having a specific diameter and length in a certain pitch. Having the right size is absolutely critical as the nanowires are entrusted with the task of absorbing as many photons as possible. Even if they are just a few tenths of nanometres too small, their function can be significantly hampered. Nanowires generally concentrate the sun's rays into a very small surface area within the crystal (by up to a factor 15). As the diameter of the nanowire crystal is smaller than the wavelength of light coming from the sun, it has the ability to cause resonance in the intensity of light in and around the nanowires. The resonance therefore allows the concentration of sunlight. Here the energy is being converted, giving higher conversion efficiency of the sun's energy.

Researchers have found that efficiencies of up to 13.8 percent can be achieved using the technique of resonant light trapping with the help of 180 nanometre diameter nanowires, which covers only 12 percent of the surface area. The share of sunlight tapped into the photocurrent is 71 percent, which is six times higher than the limit in a simple ray optics description.

Costing

As the use of nanowires in solar PV cells helps to boost their efficiency by up to 25 percent, the improvement can be channelised to boost output at lower costs, improving the economy for module manufacturers in the process. It also helps to reduce the total installed cost by about 15-20 percent, which can be financially more viable. Also, an array of nanowires can use at least 10,000 times lesser gallium arsenide freeing up this costly material, which can then be used in other industries.

Future prospect

Researchers are optimistic that the nanowire technology can help to exceed the current efficiency levels of solar PV cells. However, the full commercialisation aspect of this technology still remains a doubt. It will be interesting to see how much research and development effort is invested in the near future to squeeze out more efficiency from the solar panels. Even by just incrementally improving current technology and trying to make it cheaper through economies of scale and more efficient production processes, a significant benefit can be provided to human civilisation

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