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Developing a New Method to Maximize the Benefits of Nanowires

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Abstract

Nowadays, we are observing a very great interest in nano-structures such as quantum dots (zero-dimension) and wires (one-dimension). While there are some great advantages for the application of nanowires, there are some disadvantages of using them as well. The purpose of this study is to show the great application of nanowires in human life. To achieve to goal, first the importance and widespread use of nanowires is discussed; then, the advantages and disadvantages of using them in today's life is explained. Finally, it is shown how to use them in the correct way to reduce the disadvantages and get the most benefit out of nanowires.

Keywords: Nanowires, Nano-structure, Silicon, Electronics

1. Introduction

Nowadays, we are observing a very great interest in nano-structures such as quantum dots (zero-dimension) and wires (one-dimension) (Brewer, Zhang, Dong, Rutherford, & Tian, 2007). This tremendous interest caused by their size-dependent properties. One-dimensional (1D) semiconductor nanostructures are of particular interest because of their widespread applications in energy, electronic and environment. (Chu, Sasanipour, Saeedi, Baghban, & Mansoori, 2017) However there are a vast number of fields for 1D semiconductor nanomaterials to be applied, many areas require more development. (Grange, et al., 2009) In particular, the fabrication of desired 1D nanomaterials with fitted atomic structures and their assembly into functional devices are still major challenges for the scientist who are working in nanotechnology. (Hanrath & Korgel, 2003)

Nanowires are solid, rod-like materials with a diameters between 1 and 100 nanometer (10^{-9} meters). Many different types of nanowires exist, including metallic (e.g., Ni, Pt, Au), semiconducting (e.g., Si, InP, GaN, etc.), and insulating (e.g., SiO_2,TiO_2). Molecular nanowires are composed of repeating molecular units either organic (e.g. DNA) or inorganic (e.g. $Mo_6S_{9-x}I_x$). In the physics of nanoscale structures, quantum effects play an increasingly prominent role (Kolasinski K. W., 2006). Quantum wires have illustrated great electrical transport properties that have not been seen in bulk materials. The reason

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is because, in quantum wires, electrons could be quantum-confined laterally and thus could occupy discrete energy levels that are different from the energy bands found in bulk materials (Kolasinski K. W., 2006). As a result of low electron density and low effective mass, the quantized conductivity is more easily observed in semiconductors, e.g., Si and GaAs, than in metals (Kolasinski K. W., 2006). In addition to the opportunity to describe the new physics illustrated by nanowires, much effort has been devoted to fabricating high-quality semiconductor nanowires by employing different methods because of the importance of semiconductor materials to the electronics industry. Saeedi (2017) used a Meta-heuristic method to develop an integrated supply chain model (Saeedi, 2017).

On semiconductor nanostructures, etching processes always lead to significant surface damage, and thus surface states are introduced to the nanostructures (Torabi, Kiaian Mousavy, Dashti, Saeedi, & Yousefi, 2018). Such damage may not be serious for the structures in the micrometer range (Vizcaíno & Núñez, 2013). However, structures with dimensions in the nanometer range are very sensitive to the surface states or impurities induced by fabrication processes (Torabi, Kiaian Mousavy, Dashti, Saeedi, & Yousefi, 2018). One-dimensional (1D) nanostructures formed ‘‘naturally’’ (also called self-organized growth) without the aids of ex situ techniques, such as chemical etching, are desirable not only in fundamental research but also in future nanodevice design and fabrication (Kolasinski K. W., 2006).

2. Literature Review

In this paper, different applications for nanowires are reviewed. A well-known self-organized growth mechanism for creating nanowires is the vapor–liquid–solid (VLS) process (also known as metal catalytic growth) (Hanrath & Korgel, 2003). This technique can produce free-standing crystalline nanowires of semiconductor and metal oxide materials with fully controlled nucleation sites and diameters from pre-formed metal catalysts (Grange, et al., 2009).

Since the 1960s, semiconductor whiskers grown by this method have been extensively studied. In recent years, different new methods have been developed and studied to realize one-dimensional nanostructures, like laser-assisted chemical vapor deposition (CVD), oxide-assisted CVD (without a metal catalyst), thermal CVD, metal-catalyzed molecular beam epitaxy (MBE) and chemical beam epitaxy (CBE) (Chu, Sasanipour, Saeedi, Baghban, & Mansoori, 2017). Although the number of different types of 1D nanostructures fabricated via various methods grows significantly every year, our realization of the basic process of one-dimensional nanostructure formation has not reached maturity. How to fabricate desired nanowires with fitted atomic structures and how to integrate functional nanostructures into devices are still challenging issues for nanotechnologists (Brewer, Zhang, Dong, Rutherford, & Tian, 2007). For 1D semiconductor nanomaterials to have wide practical applications, however, many areas require more pursuing.

3. Importance and Applications of nanowires

In these days, there are several applications where nanowires may become very important in electronic, opto-electronic and nanoelectromechanical devices, as additives in advanced composites, for metallic interconnects in nanoscale quantum devices and as leads for bimolecular nano-sensors. Some categories of these applications are as below:

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3.1 Electronic Equipment

Nanowires are still being developed in laboratories. However, they may complement or replace carbon nanotubes in some applications. Some early experiments have illustrated how they can be applied to make the next generation of computing devices.

In order to create active electronic elements, the first key stage was to chemically dope a semiconductor nanowire. This has already been done to individual nanowires to create p-type and n-type semiconductors.

The next step was to find a way to generate a p–n junction, one of the simplest electronic devices. This was reached in 2 different methods. The first method was to physically cross a p-type wire over an n-type wire. The second way involved chemically doping a single wire with various dopants along the length. This technique created a p-n junction with only one wire.

After p-n junctions were built with nanowires, the next logical step was to build logic gates. By connecting several p-n junctions together, scientists have been able to make the basis of all logic circuits: the AND, OR, and NOT gates have all been generated from semiconductor nanowire crossings.

In August 2012, scientists reported constructing the first NAND gate from undoped silicon nanowires. This avoids the problem of how to reach precision doping of complementary nano-circuits, which is unsolved. They were able to control the Schottky barrier to achieve low-resistance contacts by placing a silicide layer in the metal-silicon interface.

It is possible that semiconductor nanowire crossings will be important to the future of digital computing. Although there are some other applications for nanowires beyond these, the only ones that actually take benefit of physics in the nanometer system are electronic.

Nanowires are being studied to be applied as photon ballistic waveguides as interconnects in quantum dot/quantum effect well photon logic arrays. Photons travel inside the tube, electrons travel on the outside shell. When two nanowires acting as photon waveguides cross each other the juncture acts as a quantum dot.

Conducting nanowires offer the possibility of connecting molecular-scale entities in a molecular computer. Dispersions of conducting nanowires in different polymers are being investigated for use as transparent electrodes for flexible flat-screen displays.

Due to their high Young's moduli, their application in mechanically enhancing composites is being studied. Since nanowires appear in bundles, they may be used as tribological additives to boost friction characteristics and reliability of electronic transducers and actuators.

Because of their high aspect ratio, nanowires are also uniquely suited to dielectrophoretic manipulation, which suggests a low-cost, bottom-up approach to integrating suspended dielectric metal oxide nanowires in electronic devices such as UV, water vapor, and ethanol sensors.

This advantage of nanowires in electronic section have caused scientists and companies to apply this 1D nanostructure in several fields of energy and electronics as you can see below:

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- Nanotechnologists at MIT have developed a solar cell using graphene coated with zinc oxide nanowires. The researchers believe that this technique will make them able to produce low cost flexible solar cells at high enough efficiency to be competitive.
- Sensors powered by electricity made by piezoelectric zinc oxide nanowires. This little sensors could allow small, self-contained, sensors powered by mechanical energy such as tides or wind.
- Nanotechnologists are applying a method called Aerotaxy to grow semiconducting nanowires on gold nanoparticles. They plan to use self-assembly methods to align the nanowires on a substrate; forming a solar cell or other electrical equipment. The gold nanoparticles replace the silicon substrate on which conventional semiconductor based solar cells are built.
- Researchers at the Niels Bohr Institute have done a study which illustrate that sunlight can be concentrated in nanowires due to a resonance effect. This effect can lead to make solar cells with more efficiency that allowing higher rate of the energy from the sun to be converted to electricity.
- Researchers at Lawrence Berkeley have illustrated an inexpensive process for producing solar cells. These solar cells are composed of cadmium sulfide nanowires coated with copper sulfide.
- Researchers at Stanford University have developed silicon nanowires on a stainless steel substrate and illustrated that batteries using these anodes could have up to 10 times the power density of conventional lithium ion batteries. Using silicon nanowires, instead of bulk silicon fixes a problem of the silicon cracking. That has been seen on electrodes using bulk silicon. The cracking is caused because the silicon swells it absorbs lithium ions while being recharged, and contracts as the battery is discharged and the lithium ions leave the silicon. However the researchers found that while the silicon nanowires swell as lithium ions are absorbed during discharge of the battery and contract as the lithium ions leave during recharge of the battery the nanowires do not crack, unlike anodes that used bulk silicon.
- Applying electrodes composed from nanowires that would enable flat panel displays to be flexible as well as thinner than current flat panel displays.
- Applying nanowires to make transistors without p-n junctions.
- Applying nanowires made of an alloy of iron and nickel to create dense memory devices. By applying a current magnetized sections along the length of the wire. As the magnetized sections move along the wire, the data is read by a stationary sensor. The name of this technique is race track memory.
- Applying silver nanowires embedded in a polymer to make conductive layers that can flex, without damaging the conductor.

3.2 Sensing of proteins and chemicals by applying semiconductor nanowires

In an analogous way to FET devices in which the modulation of conductance (flow of electrons/holes) in the semiconductor, between the input (source) and the output (drain) terminals, is controlled by electrostatic potential variation (gate-electrode) of the charge carriers in the device conduction channel, the methodology of a Bio/Chem-FET is based on the detection of the local change in charge density, or so-called “field effect”, that determines the recognition event between a target molecule and the surface receptor.

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This change in the surface potential influences the Chem-FET device exactly as a 'gate' voltage does, leading to a detectable and measurable change in the device conduction. When these devices are fabricated using semiconductor nanowires as the transistor element the binding of a chemical or biological species to the surface of the sensor can result in the depletion or accumulation of charge carriers in the "bulk" of the nanometer diameter nanowire i.e. (small cross section available for conduction channels). In addition, the wire, which serves as a tunable conducting channel, is in close contact with the sensing environment of the target, leading to a short response time, along with orders of magnitude increase in the sensitivity of the device as a result of the huge S/V ratio of the nanowires.

While several inorganic semiconducting materials such as Si, Ge, or metal oxides (e.g. In2O3, SnO2, ZnO, etc.) have been used for the preparation of nanowires. Silicon nanowires are usually the material of choice when fabricating nanowire FET-based chemo/biosensors.

This advantage of nanowires have caused scientists and companies to apply this 1D nanostructure in several fields that you can see many examples as below:

- Several examples of the use of silicon nanowire sensing devices include the ultra sensitive, real-time sensing of biomarker proteins for cancer.
- Detection of single virus particles.
- Detection of nitro-aromatic explosive materials such as 2,4,6 Tri-nitrotoluene (TNT) in sensitive superior to these of canines.

4. Limitations of sensing with Silicon nanowire FET devices

Generally, the charges on dissolved molecules and macromolecules are screened by dissolved counterions, since in most cases molecules bound to the devices are separated from the sensor surface by approximately 2–12 nm (the size of the receptor proteins or DNA linkers bound to the sensor surface). Due to the screening, the electrostatic potential that arises from charges on the analyte molecule decays exponentially toward zero with distance. Therefore, for optimal sensing, the Debye length must be carefully selected for nanowire FET measurements. One approach of overcoming this limitation employs fragmentation of the antibody-capturing units and control over surface receptor density, allowing more intimate binding to the nanowire of the target protein. This approach proved useful for dramatically enhancing the sensitivity of cardiac biomarkers (e.g. Troponin) detection directly from serum for the diagnosis of acute myocardial infarction.

This advantage of nanowires have caused scientists and companies to apply this 1D nanostructure in several fields in the environment that you can see many examples as below:

- Applying silver chloride nanowires as a photo-catalysis to decompose organic molecules in polluted water.
- Applying an electrified filter composed of silver nanowires, carbon nanotubes and cotton to kill bacteria in water and filtered water.
- Applying nanowire mats to absorb oil spill.

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5. Conclusion

Overall, it is shown that there have been lots of studies on the recent properties of 1D nanomaterials in the last few years. In addition to the opportunity to describe the new physics demonstrated by 1D nanostructures, much effort has been devoted to fabricating high-quality semiconductor and oxide nanoscale wires based on the bottom-up, self-assembly process by employing different techniques. These methods are promising to produce desired 1D nanomaterials with tailored atomic structures and to integrate functional nanostructures into devices. 1D nanostructures grown by these technologies have been seen to exhibit interesting and sometimes unusual growth phenomena. With the extensive studies throughout the years, our understanding of the basic process of 1D nanostructure formation (nucleation, growth, defects, junctions and interfaces) has been greatly enhanced. For 1D semiconductor and oxide nanomaterials to have wide practical applications, however, many areas require more development. Most 1D nanostructures are formed under non-equilibrium state and controlled by kinetic processes. Theoretical works have helped our realization of the mechanism of some growth and provided certain prediction on recent structures. Much more efforts are still needed for more complicated systems involving new structural morphologies and new processes.

6. References

Brewer, M., Zhang, T., Dong, W., Rutherford, M., & Tian, R. Z. (2007). Future Approaches of Nanomedicine in Clinical Science. Med Clin N Am, 963–1016.

Chu, Z.-Q., Sasanipour, J., Saeedi, M., Baghban, A., & Mansoori, H. (2017). Modeling of wax deposition produced in the pipelines using PSO-ANFIS approach. Petroleum Science and Technology, 1974-1981.

Grange, R., Choi, J., Hsieh, C., Pu, Y., Magrez, A., Smajda, R., . . . Psaltis, D. (2009). Lithium niobate nanowires: synthesis, optical properties and manipulation. Applied Physics Letters.

Hanrath, T., & Korgel, B. A. (2003). Supercritical fluid-liquid-solid (SFLS) synthesis of Si and Ge nanowires seeded by colloidal metal nanocrystals. Advanced Materials, 15(5), 437-440.

Kolasinski, K. W. (2006). Catalytic growth of nanowires: Vapor–liquid–solid, vapor–solid–solid, solution–liquid–solid and solid–liquid–solid growth. Current Opinion in Solid State and Materials Science, 182-191.

Kolasinski, K. W. (2006). Catalytic growth of nanowires: Vapor–liquid–solid, vapor–solid–solid, solution–liquid–solid and solid–liquid–solid growth. Current Opinion in Solid State and Materials Science, 182–191.

Saeedi, M. (2017). Developing an Integrated Closed-Loop Supply Chain Model By Considering Social Responsibility and Solving the Model Using Meta-Heuristic Methods. International Journal of Scientific Study, 394-403.

Torabi, A., Kiaian Mousavy, S., Dashti, V., Saeedi, M., & Yousefi, N. (2018). A New Prediction Model Based on Cascade NN for Wind Power Prediction. Computational Economics.

Vizcaíno, J. P., & Núñez, C. A. (2013). Fast, effective manipulation of nanowires for electronic devices. SPIE Newsroom.

Received:12 January 2018/Accepted:18 April 2018/Published:1 June 2018

Wang, N., Cai, Y., & Zhang, R. Q. (2008). Growth of nanowires. Materials Science and Engineering, 1-51.

Xia, Y. (2003, March). One-dimensional nanostructures. Advanced Materials, 15.

Received:12 January 2018/Accepted:18 April 2018/Published:1 June 2018