Research and Development Of Silicon Nano wire: Faster Than Silicon Chip

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Abstract— Silicon nanowire (SiNW) is the renowned one dimensional material for future nanoelectronic applications. Nanowires are having unique capability to bridge the nanoscopic with macroscopic world and have already been demonstrated as main material for different energy conversion. Silicon nanowires (SiNWs) have been developed on the substrates of crystalline silicon, indium tin oxide and stainless steel, using a gold catalyst coating with a thickness of 200 nm via pulsed plasma enhanced deposition of chemical vapor. Also known as quantum wires, these connectors are used to connect tiny components together into very small circuits. SiNWs have been described as one of the promising building blocks for the nanodevices using in coming future such as field effect transistors, solar cells, sensors and lithium battery. During the past decade much progress has been made in this field and SiNWs have received much attention especially for applications in the semiconductor industry. There is no restriction how wide they can grow, but cannot grow more than a few nanometers in height.

Key words: silicon nanowire, silicon synthesize, VLS growth, OAG growth, physical and optical properties, SiNW in device application..

I. INTRODUCTION

Silicon-based nanowires including silicon, silicate and silicide nanowires are particularly attractive due to the central role of silicon to the semiconductor industry. Nanowires are simply very tiny wires. They are composed of metals such as silver, gold or iron or semiconductors. These nanowires are created by nanoparticles, which can have a diameter as small as 3 nanometers. It can also be defined as structures that have a thickness or diameter constrained to tens of nanometers or less and an unconstrained length. At these scales, quantum mechanical effects are important – which coined the term “quantum wires”. 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)[1]. Nanowires have been considered a promising contender for use on future logic chips because of their very small size and because they can be made without complicated lithography which refers to the art and science of writing at microscopic level “ They represent the smallest dimension for efficient transport of electrons and excitons, and thus will be used as interconnects and critical devices in nanoelectronics and nano-optoelectronics.“ (Charles M Lieber, Harvard University)

The nanowires could be used, in the near future, to link tiny components into extremely small circuits. It is in fact a promising framework for applying the “bottom up” approach for the design of nanostructures. By using decorated nanowires – for example, by varying composition at the nanometer scale, both axially and radially – the key nanoscale features may be built into the nanowires. SiNW research is a semi mature field, with studies being commenced during 1964 but new characterization and developing technologies have expended myriads of new research opportunities about half a century later. The bulk of recent studies on silicon nanowires are centered on their increasingly small diameters and their congregation into micro/nano electronic or photovoltaic devices. There is excellent flexibility in nanowires which permits their use in the assembly of nanoscale electronic devices. Due to its advantages, SiNWs is compatible with the current micro and optoelectronic technologies hence can be directly integrated onto silicon chips. SiNWs are good potential resource for the various applications in nanoelectric devices such as visible light emitters, photodetectors, battery devices, field effect transistors and optoelectronic devices.

II. NANOWIRE SYNTHESIS

The development of nanowire is similar to nanotubes. There is the need of using a catalyst particle in a heated reaction chamber. In order to develop nanodevices based on silicon nanowires, the basic issue is to analyze controllable synthesis of large scale high quality SiNWs. In 1964 Wagner and Ellis were the first to report the growth of Si whiskers[2]. Later Givargizov continued his efforts in this genre and in 1975 he clarified the growth mechanism of Si whiskers[3]. Hitherto yet several other methods have been introduced to synthesize large scale SiNWs such as template directed process, vapor-liquid-solid process, oxygen-assisted-growth, vapor-solid-solid and metal nanoparticles catalyzed chemical etching methods.

A. VLS Growth of Silicon_Nanowire:

Nanowires are typically obtained by the vapor-liquid-solid procedure in which a metal catalyst is applied for the congregating of the precursor species and nanowire growth. Most of the nanowires synthesis occurs via Vapor-Liquid-Solid

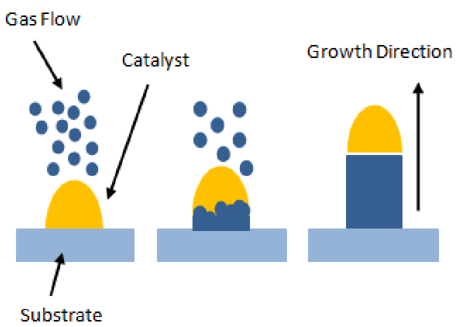

Fig. 1: Nanomaterial synthesized by VLS Mechanism

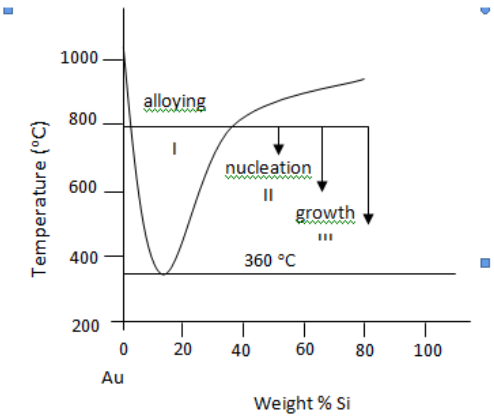

Fig. 2: Binary Phase Diagram Si-Au Alloy

(VLS) process. It is a mechanism for the growth of one-dimensional structures, such as nanowires, from chemical vapor deposition [4]. The majority of its applications involve applying solid thin-film coating to surface, but it is also used to produce high-purity bulk materials and powders, as well as fabricating composite materials via infiltration techniques[5]. As shown in *Figure 1* in the VLS reaction metal particles, such as gold particles on silicon substrate, are generally used as the mediating solvent to direct the growth of silicon nanowires. These processes make amend of a liquid catalyst to draw components out of a vapor phase and deposit them in a solid phase. This process has been described such because the silane [6] semiconductor vapor phase reactants usually taken as the source of silicon will alloy with gold nanoparticles which are in the melted state when heated. The silane will decompose at the bottom of the gold nanoparticles and silicon will dissolve into the liquid gold nanoparticles if temperature rises higher than the eutectic temperature of the binary system as shown in *Figure 2*. The size of the as grown silicon nanowire is analyzed by the dimensions of gold nanoparticles. Kinking and bending defects of growth are observed. The growth direction can be prejudiced by the principle of thermodynamics.

B. Oxide Assisted Growth:

C.S.Lee and co-worker proposed another way to synthesize silicon nanowires without using metal catalyst [7]. Oxide-assisted-growth technique is capable of producing large quantities of high-purity silicon nanowire with a preferential growth direction, uniform size, and long length, without the need for a metal catalyst [8]. They proposed OAG with gold catalyst to grow SiNW with better dimensional control and predicted it by laser ablating a mixture of silicon and silicon dioxide. Generally the oxide assisted growth model applied to a laser ablation system where Si, O and Ca are present, can account for the growth of nanochains. In this oxide assisted process the key intermediate was the vapor phase of Si_xO which was generated by laser ablation. We can also consider the formation of silicon through the following steps:-

Si_xO $Si_{x-1} + SiO(x>1)$

$2\,SiO$ $Si + SiO_2$

The SiO_2 component in the shell might help to decelerate the side long growth of each nanowire. The precipitation, nucleation and growth of silicon nanowire always occurred in the region closest to the cold finger suggesting that the temperature gradient was the driving force for the nanowire growth.

C. Chemical vapor deposition:

This cost effective method is a chemical process used to produce high-purity, high-performance solid materials. In typical CVD, the wafer or substrate is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit [9]. Here for the growth of Si nanowires SiO particles are used as source material. In crucible of a tube furnace SiO particles are taken. To the tube furnace inert gas supply is given. Near about 1350°C temperature is given to the furnace. By it Si gets evaporated and flows from hotter end to the cooler part to the substrate and Si nanowires are formed. Chemical vapor deposition is a process mainly used for deposition of solid thin films on silicon wafer surfaces and other substrates. The substrate is heated to an elevated

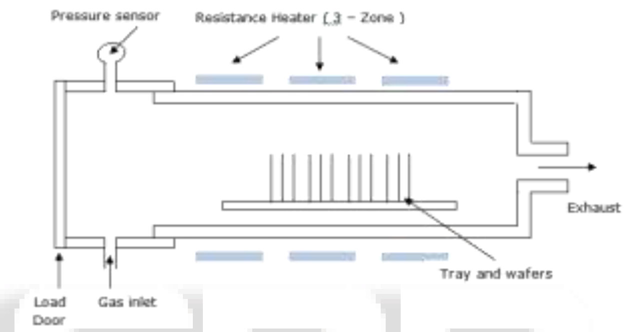

Fig. 3: Chemical Vapor Deposition Reactor

D. Metal nanoparticles catalyzed chemical etching:

There is still one benign mechanism which defines the electrochemical reaction in the synthesizing process of nanomaterials. Peng and co-workers defined electroless metal deposition (EMD) and electroless etching in the synthesis of silicon nanowire. Fabrication of nanowires take place after having several continues reaction in the aqueous solution so it is called aqueous method. The elements that are used for deposition for the etching method are silver (Ag), gold (Au), copper (Cu) on Si substrate. These metals attract the electron from the Si substrate.

E. Cold water chemical vapor deposition:

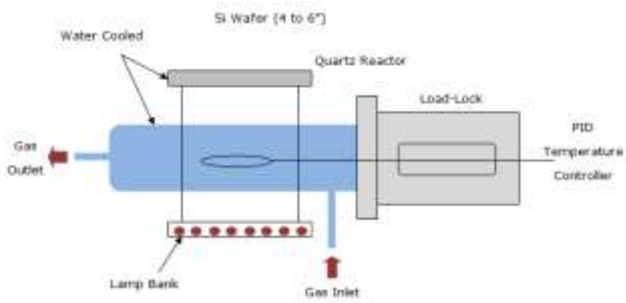

Fig. 4: Schematic of the cold-wall chemical vapor deposition reactor

We carried out the growth experiments of SiNWs in the lamp-heated cold-wall chemical vapor deposition reactor as shown in *Figure 4*. Lamp heating enables fast heating and cooling rates during the growth, and the quartz reactor is cooled both by water and air, which minimizes the deposition over the chamber wall. The reactor is connected with reactant gases (SiH_4 and GeH_4), dopant gases (B_2H_6 and PH_3), and carrier gases (H and Ar) so that both homogeneous and heterogeneous semiconducting SiNWs and GeNWs can be synthesized.

III. CHARACTERIZATION METHODS

Silicon nanowires had quite different structural characteristics if it grown on discrete substrates. Such characterization results have technological implications as they direct that it is very important to select the appropriate substrates for the growth of silicon nanowire depending on the specified applications. SiNWs have been grown on crystalline silicon, indium tin oxide and stainless steel substrates using gold catalyst via pulsed plasma enhanced CVD and duly characterized using scanning electron microscope (SEM) which used two different scanning microscopes; one for observing nanowires and one for observing in the lithographic pattern, X-Ray Diffraction (XRD), XPS and Raman analysis. Its surface characteristics are similar to all the substrates. Scanning electron microscope is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. Transmission electron microscope was used to examine the crystal structure of SiNWs. Its working principle is like projector. The electron gun in the TEM projects a beam of electron through the sample.

IV. PROPERTIES OF SINWS

Depending on what it's made from, a nanowire can have the properties of an insulator, a semi conductor or a metal. Nanowires possess certain amazing properties due to the small scale. The main properties of SiNWs are as follow:-

A. *Electronic & Electrical Properties:*

The most obvious use for nanowires is in electronics. The small sizes of SiNWs make their electronic and electrical properties strongly dependent on growth direction, size, morphology and surface reconstruction. A well known example is the size dependence of the electronic band gap width of SiNW irrespective of wire direction [10]. As the wire diameter decreases, the band gap of the nanowire widens and deviates from that of bulk silicon gradually. The orientation of the wire axis and the surface has a great effect on the electronic properties of SiNWs.

B. *Optical Properties:*

SiNWs grown along most of the crystallographic orientations have a direct band gap, meaning that the maximum of the valence band and the minimum of the conduction band occur. This property has allowed envisage the use of SiNWs as optically active materials for photonics applications [11]. The possibility of controlling the band gap width is tremendously attractive for optoelectronics applications not only SiNWs can have a direct band gap but its width can in principle be tuned.

C. *Physical Properties :*

The nanoscale diameter puts the radial dimension of nanowires at or below the characteristic length scale of various interesting and fundamental solid state phenomena [12]. The physical properties including electrical, photo-electrical, and mechanical properties of these regular SiNWs employed as building blocks in aforementioned nanodevices will be removed briefly. The high carrier mobility is essential for fabricating high performance FETs.

V. SINWS IN DEVICE APPLICATIONS

Lithium-Ion battery capacity depends on the lithium holding capacity of the anode. Silicon is a good candidate and silicon nanowire based Lithium-Ion batteries could boost battery life 10 times. In these batteries, the lithium ions react with silicon nanowires and make lithium silicide which has much greater capacity. In this process when energy is used up, the lithium silicide turns back into silicon, so batteries are rechargeable. It increases the storage capacity with growth temperature by a factor of three as the temperature varies from 525ºC to 575ºC.

Silicon nanowire could be used for making *solar cells*. It is having several advantages such as improved charged transport in comparison to other

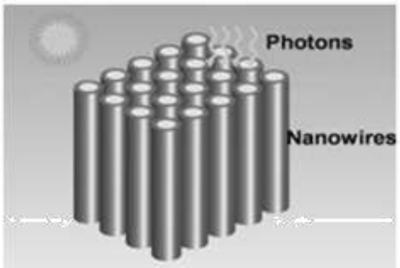

Fig. 5: Solar cell

nanostructures. They tend to absorb a large portion of the light incident upon them and they form a highly textured surface when grown on an otherwise flat substrate. These properties indicate silicon nanowires are good candidates for use in solar cells. It is having improved efficiency comparative to crystalline silicon with lower costs. SiNW solar cells consists of arrays of radial p-n junction nanowires as shown in *Figure 5* where the darker outer shell is compared of n-type silicon, to which the electron acceptor phosphorus has been added. The lighter inner core is p-type silicon.

Silicon nanowire *field effect transistors* have been fabricated, where direct metal contacts formed the source and the drain. SiNWs-related FETs have been demonstrated as one of the promising building blocks for next generation circuit and have attracted much interest. Methods of synthesizing high quality SiNWs along with the traditional techniques of electron beam lithography (EBL) and photolithography lay the foundation for FETs. Traditional FET structures have p-n doping. As shown in *Figure 6*. The current from the source to drain is turned on and off by the voltage applied to gate. Because the gate in nanowires is surrounding the channel, it can control the electrostatics of the channel more efficiently than the conventional metal-oxide-semiconductor field-effect-transistors (MOSFET).

Fig. 6: Nanowire FET

Silicon nanowire could play a vital role in future nanoscale electronic devices. A *non volatile memory device* was fabricated. "Non-volatile" memory, meaning stored information is not lost when the device is without power. In such devices, nanowires are integrated with a higher-end type of non-volatile memory that is similar to flash, a layered structure known as semiconductor-oxide-nitride-oxide-semiconductor (SONOS) technology. Such devices showed better stability at higher temperature and combine silicon nanowires with a more traditional type of data storage. A self alignment technique is used to position the silicon nanowires, which could allow for lower production cost than current flash memory card. Their hybrid structure may be more reliable than other nanowire-based memory devices recently built and more easily integrated into commercial applications.

A. Reduce size of microchips :

SiNWs can help to further reduce the size of microchips. In its never-ending quest to develop more powerful microchips, the semiconductor industry is constantly advancing the miniaturization of circuits. Currently the transistors lie on the surface of the substrate. Vertical silicon would reduce the space requirement considerably. Such nanowires are suitable for applications in the micro-chip industry, unlike nanowires which form of gold, the material that has mostly been used as a catalyst material up to now.

B. Nanowire Sensors:

Sensing is the discrete area in which the application of nanowires is likely to have a great influence. Nanowire sensors have showed that can detect the presence of many gases, including oxygen, hydrogen, NO_2 and ammonia, at very low concentrations. Nanowires also have been used to detect ultraviolet light changes in pH. The sensing capabilities of nanowires may be enabled by selective doping or by surface modifications that enhance their affinities for certain substances

VI. Challenges and Risk

Adequate oversight of new technologies will depend on our ability to forecast the risks the technologies pose. Forecasting the risk involves basic scientific information about the technology, test data on specific products and risk assessment. Costs reflect the limits of our resources and abilities. High costs indicate scarce resources and difficult goals. Nanotechnology research requires cutting-edge tools and highly experienced technical and research manpower. It will also require some consolidation and coordination of the research effort as well as improved linkages between public sector researchers and industry to accelerate the innovation in this field. In the future scientists working on it will likely encounter issues that will require sound ethical deliberation and decision-making. Maintaining infrastructure and international engagements is much needed for the cause.

VII. Conclusion

It is the structure that has an incredibly length-to-width ratio. It can be nonpareil thin and it's possible to create a nanowire with the diameter of just one another nanometer, though researchers are delving into this genre to create nanowires that are between 30 and 60 nanometers wide. They hope that they will soon be able to use it to create the smallest transistors, even though there are some pretty tough obstacles in the way. Over the past few years significant progress has been made in investigation into the synthesis of nanowires of various materials, as well as their application to nanometer scale electronics, optical devices and sensing systems. The era is coming very soon when we will see the transition from synthesis of nanowire to the production of the same and incorporation into various devices and systems enabled by nanowire.

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