

FUTURE OF NANOTECHNOLOGY IN MEMORY DEVICES

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ABSTRACT - Till now, there have been chips made from silicon, with innumerable transistors on it. But according to Moore's law, the silicon chips are now falling small for placing transistors. Therefore, the chip manufacturing has now switched over to nanomaterials, and has got success in finding several nanoscale substitutes of silicon in making chips. Substitutes like Indium Gallium Arsenide, Vanadium Oxide Bronze, carbon nanotubes etc. have been predicted by scientists, which have been discussed in detail. It has been found that these nanoscale substitutes have more information carrying capacity at much low power consumption in comparison to silicon, which also proves that they are more economical to use, with much faster speed. The synthesis techniques of these nanoscale substitutes has also been developed, which have also been discussed. Thus, within the next two decades, computer chips made from these predicted substitutes will completely replace currently used silicon chips. The future of nanocomputing is speeding up at an unexpected rate.

Keywords: Indium Gallium Arsenide, Carbon nanotube, transistors, nanowires, memory devices

1. INTRODUCTION

Nanoscience is the study of phenomena on a nanometer scale. The smallest structure humans have made was and will remain of size of a few nanometers, such as carbon nanotubes, graphene, nanotransistors etc. Manufacturing advances would allow the chip's transistors to shrink and shrink, so electrical signals would have to travel less distance to process information.

Till date, Silicon is being used in manufacturing of microchips used in computers. But, its use is getting limited as the integration of transistors on silicon chips is

becoming difficult, and the basic laws of physics are now imposing limits on this, according to Moore's law.

1.1 MOORE'S LAW: Moore's Law describes a long-term trend in the history of computing hardware. According to Moore's law, the numbers of transistors that can be placed on an integrated circuit will double every two years. This law has guided the semiconductor industry for over three decades, but now it's becoming difficult to follow this law with silicon. The reason why only Silicon is used for making chips amongst all the group 14 elements has been described.

1.2 GENERAL REACTIVITY

Carbon exists in two important allotropic forms, diamond and graphite. Diamond has an extended covalently-bonded structure in which each carbon atom is bonded to four others. This compact, rigid arrangement explains why diamond is both extremely hard and chemically inert.

Graphite has a layer structure. Planes of covalently-bonded carbon atoms are held together by weak van der Waals forces, and slide over each other easily. Chemically, graphite is more reactive than diamond but still does not react easily. However, it does oxidize at high temperatures, as a result of which there are chances that graphite might melt at high temperatures if used in making chips.

Silicon is chemically uncreative. Germanium is also uncreative, but it possesses good semiconducting properties, so it might be used in near future. Tin and lead are unreactive as well, but they cannot be used since tin has tendency to displace lead.

1.3 PHYSICAL LIMITATIONS OF SILICON BASED COMPUTERS:

The physical limitations of Silicon based computers as mentioned below [9]:-

SPEED AND DENSITY

All the conventional computers achieved high speed by reducing the distance between different IC chip components, shrinking the size of processing chip and transistors on it, so that instruction takes less time to travel from one component to another during execution. In doing so, the packaging of transistors on the IC chip becomes more and more dense, which is difficult for designers.

DESIGN COMPLEXITY

As a result of shrinking the IC chip size with doubling the transistors on it, chip manufacturing is becoming more and more complex, and if this trend continues, then designers will not be able to develop more advanced and fast chips and processors in future. Thus, Moore's law will face more complex design challenges.

POWER CONSUMPTION AND HEAT DISSIPATION

Power consumption and heat dissipation is a large obstacle for further advancement in Silicon based chips. High power consumption also inverts the effect of increased transistors on silicon chip. This large amount of power consumption boosts up heat generation, increasing danger that transistors interfere with each other. Although decreasing size of transistors provide an advantage of less power consumption by individual transistor, but the increasing number of transistors on an IC chip leads to large power consumption to drive all the transistors efficiently, thereby generating more heat.

These are the major limitations which traditional silicon based computers are suffering. Therefore, there is need of searching for new alternatives which can solve all computational problems.

2. Results and Discussions

There are certain substances, whose constituents at the nanoscale are considered as substitutes for Silicon in manufacturing of computer chips. These are mentioned below:-

2.1 INDIUM GALLIUM ARSENIDE

MIT's MICROSYSTEM TECHNOLOGY LABORATORIES have created a 22 nanometer chip from Indium Gallium Arsenide, which is believed to have properties to replace silicon in microchips. InGaAs is already in use in fiber optic communication and RADAR technology. Researches have shown that it is possible to build tiny *metal oxide field effect transistor (MOSFET)* the type used in making processors, using InGaAs. Its use can take chip manufacturing beyond the use of silicon.

SYNTHESIS OF INDIUM GALLIUM ARSENIDE

The synthesis of Indium Gallium Arsenide (Jared J. Hou *et.al*) is explained below:

InGaAs was synthesized using a catalytic solid-source CVD method similar to the ones previously reported. Here, only the In-rich InGaAs NWs would be the focus to ensure the opening of the band gap without degrading the excellent carrier mobility as compared to the ones of InAs NWs. Since the vapor pressure of Ga is higher than that of In atoms, an equal weight of InAs and GaAs powders was mixed and utilized in this In-rich NW growth. In brief, during the growth, Au nano particles were used as catalysts. Then the subsequent growth temperatures, both source and substrate zones, as well as flow rate of carrier gas, H₂, were carefully adjusted to control the physical properties of NWs. This two- stepped method could significantly reduce the surface coating around nanowires.

The two stepped method is advantageous over single step method as, in the single-step growth, Au catalysts were first formed on the substrate during the annealing stage. Afterward, the temperature was cooled to the growth temperature and the precursor vapors were started to supply from the source zone. However, at this moment, the catalyst nanoparticles may not be homogeneous in the liquid or solid phase. This physical phase inversion within

the catalysts could hinder the growth rate of NWs at the catalyst NW interface and lead to the unevenly distributed growth rate. Thus, single step method is not preferred.

InGaAs NWs grown by the two-step method exhibit much more straightness as well as smoother surface (no over coating). The two-step grown InGaAs NWs are typically found to have a length exceeding 10 μm and an average diameter of 30 nm uniformly along the length of the NWs.

CHALLENGES TO InGaAs SYNTHESIS

One of the challenges in synthesizing high-performance nanowires is to control the NW stoichiometry uniformly and precisely to enable various devices fabrications. For ternary NWs such as InGaAs, this stoichiometric problem appears to be even more challenging because the chemically increased degree of freedom may easily induce atomic aggregation and clusters in the NW body, degrading the electrical properties of NWs. In this case, the elemental X-ray spectrometric elemental mapping of NW shows homogenous distribution of In, Ga and along the nanowire body. Thus, we can overcome this problem by two step method. The electrical performance of a representative FET consisting of an individual InGaAs NW as the channel material showed n- type conduction.

In order to further demonstrate the feasibility of large-scale integration of the NWs for electronic applications, the well-established NW contact printing method is utilized to fabricate InGaAs NW parallel arrays following the same device fabrication. Experiments showed that the calculated field effect mobility is similar to that shown by carbon nanotubes, hence proving their use in making nanochips.

2.2 VANADIUM OXIDE BRONZE

In [34], researchers have found *vanadium oxide bronze* with unusual electrical properties which could increase the speed at which information is stored and transferred.

Researchers have made nanowires from vanadium oxide bronze, which when exposed to an applied voltage at room temperature, transforms the nanowire characteristics from insulator to conductor. The insulator position act as 'off' and conductor position act as 'on' in the material. The ability to electrically switch these nanomaterials between

on and off state repeatedly and fastly makes them useful for computing.

The voltage induced phase transition in the material provides an alternative solution for silicon usage in chips, as silicon faces problems in switching fast speed. The material synthesized exhibits these electrical properties only in nano form. The wire's distinctive structure plays an important role in acting as a special conductor. In insulator phase, the positions of bronze molecules in nanowires' crystalline structure induces electrons to gather at certain locations within the wire, and are joined together on applying voltage, changing the phase to conductor phase from insulator phase, and allowing easy flow of electricity. Thus, they are considered to be one of the proposed substitutes for silicon in computing.

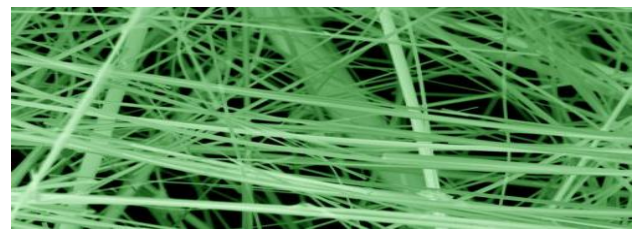


Fig-1:Vanadium Oxide Nanofibers

SYNTHESIS OF VANADIUM OXIDE BRONZE

V_2O_5 and Na_2SO_4 powders in the suitable proportion were dissolved in 10% H_2O_2 at 273 K. Then the solution was heated up to 333 K for the dissociation of the peroxide compounds. Produced gel was deposited on Ni substrate and dried in air at room temperature. Obtained xerogel of a dark-brown color was heated up to 580 K in air atmosphere for 2 h for the water removal from the xerogel. After this treatment, **the color of the films changed from dark-brown to dark-green**. XSAM 800 spectrometer (Kratos Analytical, UK) was used to record the X-ray photoelectron spectra. During the spectrum analysis the working pressure was below 10.7 Pa in the analysis chamber.

Using KRATOS DS800 data system the photoemission data has been collected and processed. The multiple photoelectron spectra were separated into several peaks setting the peak position: binding energy (BE), area (A), width (FWHM), and Gaussian/Lorentzian (G/L) ratio. After

the Shirley background subtraction, a non-linear least squares curve fitting routine was used for the analysis of XPS spectra. XPS spectra were measured for starting materials (V₂O₅ and Na₂SO₄ powders) as well as for vanadium-sodium oxide xerogel and bronze (after heat treatment).

The binding energies of V 2_{p1.5}, V 2_{p1/2} and O 1s peaks of V₂O₅ are typical for vanadium pentoxide [8]. Na 1s, S 2p_{3/2} and O 1s binding energies of Na₂SO₄ are similar as reported for sodium-sulphur-oxygen compounds [9]. V 2p_{3/2} and V 2p_{1/2} peaks of bronze and xerogel consists of two components which corresponds to V⁴⁺ and V⁵⁺ ions [8]. O 1s peak of xerogel consists of three components which corresponds to O²⁻, (OH)⁻ and H₂O [10, 11]. O 1s peak in the bronze consists only of one component — O²⁻ ions. Last fact means that after the heat treatment of the xerogel all water and hydroxyl groups were removed, i.e. the vanadium-sodium oxide bronze was formed. The presence of sulphur in the xerogel and bronze was not detected. Quantitative analysis shows that the composition of the bronze is Na_{0.35}V₂O_{4.96}.

2.3 CARBON NANOTUBES

Production of straight carbon nanotubes is generally achieved via electric arc discharge, laser evaporation, or chemical vapor deposition (CVD). Nanotubes obtained from electric arc discharge and laser deposition method are only straight nanotubes, while those obtained from CVD method contain coiled carbon nanotubes.

Very high growth temperature (>2000°C) required in arc discharge and laser evaporation method for vaporization of solid graphite for nanotubes' growth will result in higher mobility of carbon atoms and form perfect hexagonal graphite for growth of only straight nanotubes. Growth from CVD method (500- 1000°C) results in lower mobility of carbon atoms, favoring the formation of non-hexagonal carbon rings in the growing nucleus and resulting in a poor crystalline graphite structure.

Curvatures in the nanotubes originate from the introduction of pentagon- heptagon pairs in the hexagonal network on straight nanotube walls. This produces a coiled nanotube.

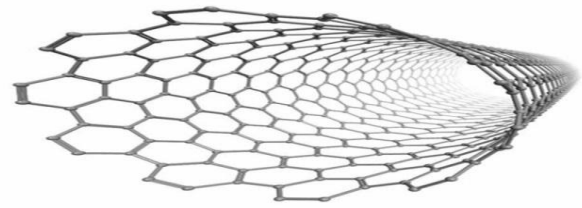


Fig-3:Carbon Nanotube

SYNTHESIS OF MULTI-COILED NANOTUBES BY SUBSTRATE CVD GROWTH METHOD

Synthesis of coiled carbon nanotubes by Chemical Vapour Deposition (CVD) [4] for multi- coiled nanotubes has been explained below:

CVD process involves the pyrolysis of a hydrocarbon (methane, acetylene, benzene, propane etc.) over transition metal catalysts (Fe, Co, Ni etc.) at high temperature (500-1000°C) to produce fullerene, carbon fibers, carbon nanotubes and other carbon *sp*² hybridization nano structures. The structure and size of nanotubes depend on the catalyst preparation and deposition conditions.

Coiled nanotubes and nanofibers were observed in the preparation of aligned carbon nanotube bundles by pyrolysis of solid organic precursors on laser patterned silica substrates. Melamine pyrolysis over aged Ni and Co catalysts could generate coiled nanotubes.

- Decomposition of acetylene over patterned Fe film coated Indium Tin Oxide (ITO) gave nanotube yield over 95% at 700°C temperature.
- Coiled carbon nanotubes were also synthesized through pyrolysis of a vapour mixture of Fe (CO)₅ and pyridine or toluene on a silicon substrate at temperature ranging between 1050- 1150°C under H₂ flow.

2.4 MOLYBDENITE (MoS₂)

Switzerland based team said that it can use **molybdenite (MoS₂)** in thinner layers than silicon, which is used in making electronic components. It said MoS₂ can make more flexible chips that used less energy.

A prototype microchip circuit was built using a very thin layer of MoS_2 , on which 6 serial transistors were attached and were tested to carry out simple logical operations, therefore proving that more complex circuits could be made with it instead of silicon chips. It's not possible to make thin layers/films of silicon since it's very reactive in comparison to MoS_2 . Also, its surface oxidizes, making its electrical properties to degrade in order to make a thin film.

As a result of the ability to make circuits with thin MoS_2 films, it's possible to make chips with it at least three times smaller than that made from silicon. A key advantage of having a thinner material is that we can also shrink the transistors, thereby dissipating less power. So, with the help of MoS_2 , we can make flexible and stiffened circuit chips, as molybdenite is as hard as stainless steel.

Advantage of using molybdenite over carbon nanotubes is that molybdenite can amplify electrical signals at room temperature, while graphene(carbon nanotubes) have to be cooled down to 70K. At room temperatures, graphene cannot amplify electrical signals. Instead, it may reduce the quality of signal if used at room temperature, while this is not observed in case of molybdenite and the signal goes into the processor after getting amplified.

SYNTHESIS OF MOLYBDENITE

Synthesis of molybdenite has been achieved from use of chemicals such as Trioctylphosphine oxide (TOPO) (technical grade, 90%), Molybdenum hexacarbonyl ($\text{Mo}(\text{CO})_6$) (98%), Elemental sulphur (S), 1- octadecene (ODE) (technical grade 90%), Toluene, ACS reagent 99.5%, Polystyrene, Polymethyl methacrylate (PMMA), Dichloromethane, Nominal M_w 192,000, Nominal M_w

996,000 and ACS 99.5% . The procedure of molybdenite synthesis [5] has been explained.

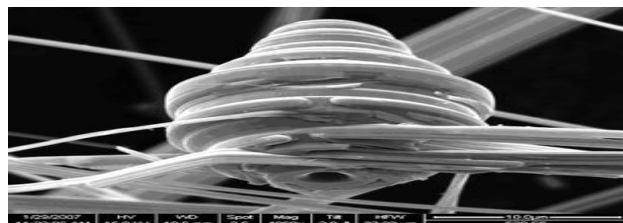


Fig-4:MOLYBDENITE NANOPARTICLE

MoS_2 NANOPARTICLES were synthesized via reaction of $\text{Mo}(\text{CO})_6$ with elemental sulphur in TOPO at 270°C using standard air- free techniques.

250g TOPO and 15g (56.8 millimole) $\text{Mo}(\text{CO})_6$ were added to a 1000 mL three necked round bottomed flask fitted with a flow control adapter, a stopper and an air condenser. The system was brought into inert atmosphere by alternatively applying vacuum and flushing with argon three times. Reaction temperature was then increased to 250°C under argon atmosphere and system was kept for 16 hours.

Then, the sulphur precursor solution was prepared by dissolving 3.64g of elemental sulphur in 75mL of 1-octadecene at 130°C under argon atmosphere. When a clear solution was obtained, the system was cooled to 60°C . Then, the temperature of molybdenum- TOPO solution was increased to 270°C and sulphur solution (at 60 deg.) was added drop-wise with a pipette in batches of 5mL maintaining the argon atmosphere in both the flasks.

After the addition was complete, the reaction temperature was maintained at 270°C for 48 hours to complete the nanoparticle synthesis. The reaction system was then cooled to 60°C and 60mL toluene was injected into the system to prevent solidification of mixture. The dispersion was subsequently cooled to room temperature. After that, MoS_2 nanoparticles were isolated by using an excess of methanol (1.5 L) followed by centrifugation. The particles were purified by washing with methanol to remove excess TOPO and then dried in oven at 70°C for 16 hours to yield molybdenite.

2.5 ANIMAL DNA

DNA computing is a method of solving computational problems with the help of biological and chemical operations on DNA strand. DNA is a basic storage medium for all living cells. The main function of DNA is to transmit or absorb the data of life. If we assume DNA as software and enzymes as hardware, then the way in which these molecules undergo chemical reactions with each other allows simple operations to be performed as a byproduct of the reactions. These operations can be controlled by controlling the composition of DNA software molecules. DNA computing has the potential to overcome the limits imposed on the processing power on silicon based computers.

DNA COMPUTING

DNA molecule has a double helix structure composed of two sugar phosphate backbones formed by the polymerization of deoxyribose sugar. Placed between two backbones are pairs of nucleotides Adenine, Cytosine, Guanine and Thymine. DNA computers use single strands of DNA to perform computing operations. DNA computing focuses on the use of massive parallelism, or the allocation of tiny portions of a computing task to many different processing elements. The structure of the DNA allows the elements of the problem to be represented in a form that is analogous to the binary code structure.

One form is DNA computing in which information is processed by making and breaking bonds between DNA components. DNA computers can solve variety of problems and it has proved its worth by solving some complicated problems like the HAMILTONIAN PROBLEM. Another form is DNA chip which is being used by scientists in their research for self-treatment of diseases. Efforts are under way to create tiny robots that could reside in cells and interact with different processes of living organisms. Researchers are developing genetic 'computer programs' that could be introduced into and replicated by living cells in order to control their processes. Research has already produced engineered sequences of genetic material that can cause the living cell in which it is implanted to produce one of two possible genes. This would be effectively analogous to the computer programs and can serve as

'switches' to control the chemicals that living organisms synthesize.

ADVANTAGES OF DNA COMPUTING

- **Gigantic Memory Capacity:** They provide extremely dense information storage. For example, one gram of DNA, which when dry would occupy a volume of approximately one cubic centimeter, can store as much information as approximately one trillion CDs.
- **Low Power Dissipation:** DNA computers can perform 2×10^{19} (irreversible) operations per joule. Existing supercomputers aren't very energy-efficient, executing a maximum of 109 operations per joule. Here, the energy could be very valuable in future. So, this character of DNA computers can be very important.
- **Clean, Cheap and Available:** Besides above characteristics, clean, cheap and available are easily found from performance of DNA Computer. It is clean because people do not use any harmful material to produce it and also no pollution generates. It is cheap and available because you can easily find DNA from nature while it's not necessary to exploit mines and that all the work you should do is to extract or refine the parts that you need from organism.

CHALLENGES TO DNA COMPUTING

- In some cases the type of genetic sequences that would have to be synthesized to make fully functional genetic robots would be expensive using current methods.
- Despite their capability for massively parallel calculations, the individual operations of DNA computers are quite slow in comparison to those of their silicon based computers.
- DNA computing requires quantity of DNA that can only be used once as reuse can contaminate reaction vessels and lead to less accurate results. DNA computing is prone to errors at a level that would be considered unacceptable by silicon based computer industry.
- The DNA molecules can fracture. Over the six months you're computing, your DNA system is

gradually turning to water. DNA molecules can break – meaning a DNA molecule, which was part of your computer, is fracture by time. DNA can deteriorate. As time goes by, your DNA computer may start to dissolve. DNA can get damaged as it waits around in solutions and the manipulations of DNA are prone to error.

FUTURE ADVANCEMENTS IN DNA COMPUTING

It may be possible that DNA computing technology can be integrated with more traditional approaches to create DNA/silicon hybrid architectures or within software. Since software is more flexible and suited to rapid adaptation than hardware, we may see DNA computing benefits being implemented and exploited by in software first, leaving hardware to play catch up.

2.6 QUANTUM DOTS

In [18], circuit elements made of individual atoms, electrons or even photons would be the smallest possible. At this dimension, the interactions among the elements are governed by quantum mechanics—the laws that explain atomic behavior. Quantum computers could be incredibly dense and fast, but actually fabricating them and managing the quantum effects that arise are daunting challenges. Atoms and electrons have traits that can exist in different states and can form a quantum bit, or qubit. Several research approaches to handling qubits are being investigated. One approach, called spintronics, uses electrons, whose magnetic moments spin in one of two directions. The two states can also coexist in a single electron, however, creating a unique quantum state known as a superposition of 0 and 1. With superposition states, a series of electrons could represent exponentially more information than a string of silicon transistors that have only ordinary bit states.

SYNTHESIS OF SILICON QUANTUM DOTS:-

➤ “FLYING PARTICLES” METHOD

Nanomaterial	BAND GAP (eV)
InGaAs	0.783 (when In content is 50%)
Si	1.12
Graphene	0.1
CNT(Diameter as 4.7 nm)	0.16

In [16] and [17], a method called the “flying particles” process is used to deposit quantum dots on the surface of a flexible substrate. The substrate is formed into a cylinder and covers the inner wall of a sealable cylindrical chamber. A gas of a required pressure fills the chamber. Quantum dots of different sizes are prepared in a colloidal solution and placed in a rotating crucible located in the interior of the chamber. The crucible is rotated, and the quantum dots move radially outward because of centrifugal forces, while partially evaporating under the effect of laser irradiation. While the solution evaporates, the quantum dots fly out of the rotating crucible. Each dot experiences a resistance force that depends on its size. Therefore, the time at which each particle hits the substrate and the position of each particle is different. The nanofilm formed therefore contains layers arranged in sequence and corresponding to quantum dot size. If low-cost materials such as silicon, germanium, cadmium telluride, cadmium selenide, and cadmium sulfide are used to make the quantum dots, then the obtained multi-layer nanofilm is inexpensive and also highly efficient.

➤ USING GRIGNARD REAGENT:-

In [17], the silicon source material is SiCl₄, which is readily reduced by hydride reducing agents. The use of hydride reducing agents produces silicon particles with surfaces terminated by silicon-hydrogen bonds. The reaction is catalyzed by platinum and produce silicon particles whose surfaces are capped by strong covalent Si-C bonds. This approach offers options and advantages unavailable to chloride-terminated particle surfaces by reaction with Grignard reagents or from formation of Si-O-R bonds.

The Grignard approach provides silicon particles whose surfaces are capped with alkyl chains without other functionality. However, if particles with surfaces suitable for use in biological applications are required the limited availability and the synthetic difficulty of producing suitable Grignard reagents become important. Capping with Si-C bonds has provided silicon quantum dots with a variety of surfaces that now include hydrophobic and hydrophilic particles.

Table -1: Band Gap energies at nanoscale (eVolts)

3. CONCLUSIONS

Substitutes for Silicon in manufacturing of computer based transistor chips have been proposed. We have tried to compare the available band gap energies of all the possible compounds, along with mentioning about any of the ongoing research work in any of the Institutes across the world. We can conclude that CNTs based cores are the best suited as an alternative to Si, followed by Indium Gallium Arsenide. Thus, the future of computing can be improved through the substitutes proposed in this paper.

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