Alternative to Silicon for Semiconductor-based Electronics

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ABSTRACT

This is paper focuses on an alternative to silicon as a material for semiconductor-based electronics. For the purpose of understanding alternatives to silicon, it's essential to understand the impact of silicon in the semiconductor industry, the effective usages of silicon in multiple devices along with that, it's essential to understand the shortcomings of the material and look at other alternative materials which not only overcomes the shortcomings but also helps in developing better applications.

1 INTRODUCTION

Semiconductors run the world, in other words, most of the devices that we use like computers, mobile phones, cameras the critical components in these devices are semiconductors. Even If we think about everyday usage items live ovens, refrigerators, automobiles, etc. have some kind of semiconductors operating them. It would be very hard to find a device that is connected to electricity that doesn't have a semiconductor circuit in it. Firstly, we want to understand what a semiconductor material is, semiconductors as the name suggests are the materials that conduct electricity at some temperatures but not others unlike most metals which are conductive at all temperatures, and insulators like glass, plastic, and stone which usually don't conduct electricity. The most important property of semiconductors when constructed properly, these materials can modify the electricity moving through them, including limiting the directions it flows and amplifying a signal. The combination of all these properties is the basis of diodes, transistors which make most of the latest gadgets. Why silicon is mostly used as the material for semiconductors is the relatively easier way of manufacturing and also the availability of the material on earth.Silicon also has very good properties and it was the go to material for over 70 years in the semiconductor industry. This abundance availability and relatively good mobility made silicon the first choice semiconductor material. But even with abundance availability and good conductive properties silicon also has some limitations. Doubling of the computational power of integrated circuits (as Moore's law), has been slowing down and it could come to an end soon. With the current methods, it's pretty much impossible to etch these many materials into silicon-like transistors below 3 nanometers (15 atoms) in their smallest dimension adding to that, it has technical limitations for processing light and also to use in devices where high electron mobility is required. So, the industry is in search of other materials which could replace silicon or at least combine with it to increase its capabilities.

To overcome these challenges researchers are experimenting with different kinds of materials such as graphene, black phosphorus, and boron nitrate nanosheets. These materials are 2D materials that look like a flat sheet only one atom or two thick.

Rest of the paper is organised as follows:

- Section 2 presents about the devices that run on silicon and silicon compounds and the limitations of the silicon.
- Section 3 presents about the Graphene as a semiconductor
- Section 4 presents about Graphene for latest applications
- Section 5 talks about can Graphene replace Silicon

2 DEVICES BASED ON SILICON

Its evident that Silicon is one of the most used semicondutor in th 20th century, i would like to present the properties of silicon and few of the many devices that are made out of silicon and the limitations of silicon.

Silicon is a semiconductor material whose number of free electrons is less than conductor but more than that of an insulator. For having this unique characteristic, silicon has a broad application in the field of electronics. There are two kinds of energy band in silicon which are conduction band and valence band. A series of energy levels having valence electrons forms the valance band in the solid. At absolute 0oK temperature the energy levels of the valence band are filled with electrons. This band contains maximum amount of energy when the electrons are in valence band, no current flows due to such electrons.

Conduction band is the higher energy level band which is the minimum amount of energy. This band is partially filled by the electrons which are known as the free electrons as they can move anywhere in the solid. These electrons are responsible for current flowing. There is a gap of energy between the conduction band and the valence band. This difference of energy is called forbidden energy gap. This gap determines the nature of a solid.

Whether a solid is metal, insulator or semiconductor in nature, the fact is determined by the amount of forbidden energy gap. Partially there is no gap for metals and large gap for insulators. For semiconductors, the gap is neither large nor the bands get overlapped. Silicon has forbidden gap of 1.2 eV at 300oK temperature.

We know that in a silicon crystal, the covalent bonds exist. Silicon is electrically neutral. When an electron breaks away from its covalent bond, a hole is created behind it. As temperature increases, more and more electrons jump into the conduction band, and more holes are created in the valence band.

2.1 Silicon based materials

- **Electronics**
  High-purity silicon is made by thermally breaking down the ultra-pure trichlorosilane. This prepare is taken after by silicon's recrystallisation, which is utilized to form numerous sorts of gadgets, counting semiconductors, transistors, printed circuit sheets, and coordinates circuits. For transistors, the fabric is doped by including a little pollution which empowers the electrons to move around, conduct power, and make

dependable semiconductors for voltage. When warmed into a liquid state, silicon can be shaped into semi-conductive wafers to serve as the base for coordinates circuits, or microchips.

- **Solar panels** For the foremost portion, solar powered cells and sun powered boards are made utilizing silicon wafers, basically since of their semiconducting properties, as well as their plenitude. Silicon contains a sun based band proficiency of 1.1 eV, which makes it a sensible alternative to be used.
- **High Power Lasers**
  The foremost capable silicon-based laser is able to rack up a record 111°C temperature, with a edge current per unit region of 200 A/cm2 and an yield control of 100 mW. It's likely that silicon-based hardware has likely come to its limits, but silicon photonics has moreover been a source of intrigued, which combines the photonics and hardware to make ultra-fast optical information processing.

2.2 Limitations of Silicon

For the most part, solar cells and solar panels are created using silicon wafers, simply because of their semiconducting properties, as well as their abundance. Silicon has a solar band efficiency of 1.1 eV, which makes it a reasonable option to be used. The immense social impact silicon has had on countries where it is abundant. Large electronics manufacturers and corporations have rushed into these regions, bringing with them economic opportunity. However, the opaqueness of this supply chain is a large issue.

The second major impact produced by silicon mining and manufacturing is its damage to the environment. This impact is immensely sourced from the mining process, but also in the manufacturing of electronic devices. Pure silicon does not naturally occur, so its formation must be induced artificially, leading to the creation of carbon monoxide. Other rare earth mining operations produce environmentally harmful waste.

Technical properties includes, the silicon wafer to be stable its needs to be a little thick , if its not thick enough the device would be brittle. Silicon is also not very effective in processing light.

3 GRAPHENE AS SEMICONDUCTOR

Among various 2d materials such as graphene, boron nitrate, etc., graphene has received extensive research and attention in the last 2-3 decades. The discovery of graphene provided an immense boost up and new dimension to materials research and nanotechnology. Graphene has a wide range of applications from health to aerospace. Graphene is treated as one of the interesting discoveries in the field of science and technology.

Graphene is a hexagonal crystalline single layer of graphite (having a C-C bond distance of 0.124 nm) that has received massive attention in the field of sensors, biomedicals, composite materials, and microelectronics. ([1],[2],[3]). A wide range of applications such as transparent conductive films, ultra-sensitive chemical sensors, thin-film transistors, quantum dot devices, and anti-corrosion coverings has been tested and is well established ([4],[5]). However, the production of graphene is a challenging process, and it has been improved recently ([6]).

Graphene exists in several forms like graphene nanoribbons, nanosheets, and 3D graphene. Each carbon atom in graphene is sp2 hybridized, having three bonds, related to different neighbor carbon atoms. (Fig. 1). In the hexagonal phase, graphene consists of one free electron in the p-orbital which essentially plays a vital role in the chemical and physical behavior of the material. The presence of a zero bandgap is a drawback of graphene but new methods discussed in [6] helps in manufacturing graphene with a bandgap similar to silicon.

Due to the tight packing of atoms in the crystal lattice of graphene, its highly stable (until 20nm).

3.1 Structure and properties of Graphene

It is interesting to note that the structural holes in graphene allow phonons to travel without any obstruction. This property is not observed on graphene oxide or other subsidiaries of graphene owing to the difference in the bandgap. The classification of graphene as metal, non-metal, or semimetal is still a matter of wrangle debate. But, due to the nearness of metallic layers with exceptionally low bandgaps, it can be treated as a semimetal. As an entirety, it has various surprising characteristics that are not watched for other non-metallic materials.

The properties of graphene exclusively depend on the number of layers and the defects within the graphene layers. For illustration, the surface region of perfect graphene is 2630 m2/g which is much higher than the surface zone of carbon black(850–900 m2/g), carbon nanotubes (100–1000 m2/g).

On the other hand, the surface area of a number of layers of graphene, graphene oxide, and numerous other subsidiaries is much less in comparison to single-layer graphene. Due to these extraordinary properties, graphene acts as an idealized material for numerous cutting-edge electronic applications.

Since the charge carriers in graphene behave as semi-metals, commonly massless fermions, graphene shows a half-integer Quantum hall effect. The quantum hall effect in graphene is unique and it shows exceptional relation between charge, thickness, and speed of charge carriers. It also has been found that graphene sheet has much less electrical resistance compared to silver which makes it favorable for electronic applications. Graphene is also strong material, a single layer of graphene can withstand stress upto 42N/m of stress with Young's modulus of 1 TPa.

4 GROWING GRAPHENE WITH SIMILAR BANDGAP AS SILICON

For all of graphene's astounding electronic capabilities, it has not made much of an affect as a substitution for silicon in advanced rationale applications. This deficiency is to a great extent due to its need of an inborn bandgap that's required in computing applications to begin and halt the stream of electrons.

Whereas strategies for building a bandgap into graphene have been around for a long time, these approaches have been recognized as blemished arrangements. They have included basic costs and complications to utilizing the fabric and compromised the appealing electronic properties that made graphene a alluring substitution for silicon within the to begin with put.

Now researchers in Spain have devised an inexpensive way to grow graphene with the same bandgap that exists in silicon (1 electron volt), and in so doing, may have reopened graphene's potential as an alternative to silicon for digital logic.

In the research done by Catalan Insititute of Nano Science and Nano Technology,has employed bottom-up manufacturing techniques to assemble nanoporous graphene in such a way that the pores have the size, density, and morphology to create a perfect bandgap for digital electronics. The researchers then made a field-effect transistor (FET) device using this material.

Apart from that , by increasing the distance between the strips the band gap can be controlled. The fabrication method is relatively simple and can be extended to wafer-scale growth.

Currently, the main methods to induce a bandgap into graphene involve chemical doping or adding pores, or reducing it into nanoribbons—processes known as nanostructuring. For all of graphene's amazing electronic capabilities, it has not made much of an impact as a replacement for silicon in digital logic applications. This shortcoming is largely due to its lack of an inherent bandgap that's needed in computing applications to start and stop the flow of electrons.

While methods for engineering a bandgap into graphene have been around for years, these approaches have been recognized as imperfect solutions. They have added critical costs and complications to using the material and compromised the attractive electronic properties that made graphene a desirable replacement for silicon in the first place.

The bottom-up synthesis approach allows the fabrication of one-dimensional graphene nanoribbons and, nanoporous structures with atomic precision and with lateral dimensions in the order of 1 nm, this is the crucial ingredient to obtain a sizable and homogeneous gap.

The semiconducting gap is, in fact, related to the finite lateral size of the graphene sections that are between the pores. The individual nanoribbons are already semiconductors before coupling with each other to form pores.

The size of the graphene sections between the pores will define the absolute value of the gap, and variations on this size will induce inhomogeneities in the gap value.

5 REALTIME APPLICATIONS WITH GRAPHENE

In this section we would discuss few of the applications that can be made with graphene and the properites of those applications.

5.1 Biomedical

- **Medical Science** Graphene based materials counting flawless graphene sheets, few-layer graphene d, and graphene oxide offer a assortment of one of a kind, flexible and tunable properties that can be used for biomedical applications. such as , transport (conveyance) frameworks, sensors, tissue building and organic specialists (for illustration antimicrobials).
- **Drug Delivery** A sheet of graphene oxide can be transformed into liquid crystal droplets spontaneously—like a polymer—simply by placing the material in a solution and manipulating the pH. The graphene droplets change their structure in the presence of an external magnetic field. This finding raises the possibility of carrying a drug in graphene droplets and releasing the drug upon reaching the targeted tissue by making the droplets change shape in a magnetic field. Another possible application is in disease detection if graphene is found to change shape at the presence of certain disease markers such as toxins

5.2 Electronics

- **Tranparent Conducting Electrodes** Graphene has higher electrical conductivity and high optical transparency which makes it an ideal candidate for transparent conducting electrodes. These have applications in touch screens , liquid crystal displays , photovoltaic cells etc., which is a big boost compared to silicon. The mechanical strength of graphene is higher and flexible compared to indium tin oxide.
- **Hall Effect Sensors** Graphene has extremely high electron mobility, which would help in production of highly sensitive hall effect sensors, and potential application of such sensors are with DC transformers. The sensors made of graphene are two times better than Si based sensors.
- **Other Areas** There is an extensive research going on for creating different applications using graphene such as in opto electronics, quantum dots, oraganic electronics etc.,

5.3 Sensors

- **Bio Sensors** Graphene does not oxidize in air or in natural liquids, making it an appealing material for use as a biosensor.A graphene circuit can be arranged as a field effect biosensor by applying organic capture particles and blocking layers to the graphene, at that point controlling the voltage distinction between the graphene and the sample. Of the different sorts of graphene sensors that can be made, biosensors were the primary to be accessible for sale.
- **Pressure Sensors** The electronic properties of graphene can be altered by changing the distance between the layers by applying external pressure, this leads to atomically thin pressure sensors. In 2016 researchers demonstrated a biocompatible pressure sensor made from mixing graphene flaxes with polysilicon.

6 CAN GRAPHENE REPLACE SILICON

Graphene certainly has the potential to supplant silicon in gadgets, but it'll be subordinate on a few distinctive variables, counting the eagerness of end-users to embrace graphene over the status quo (and, in turn, alter all their manufacturing strategies). It'll moreover depend on the graphene industry to supply sufficient high-quality graphene for the electronic devices—as as it were high-quality graphene is appropriate for electronic applications.

Graphene will also have to show that it offers a better value proposition in the long term, whether this is improved performance or long-term stability compared to the cost.

The substitution of silicon will be profoundly subordinate on companies on both sides of the industry encouraging graphene appropriation on a large-scale. Indeed on the off chance that graphene does not supplant silicon in all gadgets (particularly lower-end cheap hardware), it is likely that the long run of specialist electronics, such as printable, wearable, and adaptable hardware, will be administered by graphene. Typically since few choices can compete with the synergistic impacts of both the conductive and auxiliary (flexibility/strength) graphene properties for these gadgets

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