IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 5, Issue 5, May 2016

Carbon: The Futuristic Semiconductor

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Abstract: Integrated Circuits form the backbone of all electronic and Computation Systems. Their working is based on the typical properties of semiconductor materials. Presently Silicon is ruling semiconductor but it will not be handle further miniaturization of devices and circuits. Carbon is focus of research for use in nanoelectronics. Carbon belongs to same group as that of Silicon and Germanium in periodic table. This motivation leads to study of various carbon allotropes that may have ability to sustain Moore's law. In this paper a review has been done of various carbon allotropes and techniques to analyze them.

Keywords: Allotropes, Carbon, Nanoelectronics, Spectroscopy.

I. INTRODUCTION

Carbon is a unique element in periodic table with atomic number 6 that has ability of bonding to itself .This feature leads to formation of rings, chains, networks of carbon that are key geometries in study. Carbon possesses this property due to two principles, first is Hybridization that is mixing of outer shell orbits to form hybrids and second is a direct transaction of atomic orbits to molecular one. The terminology carbon is basically derived from the charcoal and is diverse from other materials. The study of carbon in detail leads to the super lubricant, hardest crystal and to gas barriers and absorbers [1]. The structure of carbon atoms that is movement of electrons around nucleus and spin configurations are introduced by Schrodinger equation and Pauli principle and their study provides various properties and characteristics like atomic mass, atomic radius and ionization potential.

Though carbon belongs to same group as that of silicon and germanium but it is not used widely in electronics. It could be due to larger forbidden energy gap, lower mobility and lesser significant resistance. But as technology is evolving, various studies are being done in order to use carbon in electronics. The key motivation behind this is availability of crystalline form of carbon that can be doped to make it useful for various applications like FET's, sensors, switches and etc [2].

II. ALLOTROPES OF CARBON

There are various crystalline form of carbon available, the regularly ordered one are diamond and graphite but further amendments provides various other forms

A. Diamond

One of the natural allotrope of carbon is diamond, hardest material with great strength and high rigidity. Due to Scarcity and costlier behavior of diamond, various synthetic techniques are in practice. The different forms of carbon can be categorized as natural carbon (gemstone material), high pressure synthetic diamond (industry material), vapor phase diamond (laboratory material) and diamond like carbon (optics used material). The isotropic diamond itself has numerous polytypes [4]. But in spite of these features it does not attain the properties of semiconducting materials.

B. Graphite

The sp^2 bonding of c-c atoms leads to the formation of remarkable graphite that is basically designed as graphite fibers, excellent lubricant. The graphite structure on the basis of geometry is divided into structures namely graphitic carbons and non–graphitic carbons. On the behalf of their different properties and geometries these are used in distinct applications.The graphite structure is composed of parallel planes that can be arranged to form hexagonal graphite and Rhombohedral graphite [1].To examine the conductivity of graphite, it is structured into graphite nanosheets and various parameters like aspect ratio, percolation threshold are evaluated.

C. Amorphous carbon

A hydrogenated form of non crystalline carbon is called as amorphous carbon. It is called as amorphous as structure order is lost at higher ranges. This amorphous carbon sometimes known as diamond like hydrogenated carbon which is metastable state with sp^3 bonding [7]. The name diamond like carbon is given because of similarity of properties like hardness, elastic modulus between the two.

But the typical properties of DLC provides its application in MEMS, magnetic disks and protective coatings. The preparation methods of amorphous carbon includes ion beam techniques, mass selected ion beam, sputtering , cathodic arc, pulsed laser deposition ,PECVD. All these techniques provide their application in laboratory or in industry [7].

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D. Carbon Nanoallotropes

The research in the carbon family takes the researchers to the new type of carbon forms called as nanostructures carbon forms. These forms include fullerenes, Carbon nanotubes and graphene [3]. Fullerenes is the first ever discovery that provides path to the research of nanoallotrope. C_{60} is first fullerene isotrope and later on experimental results provide C_{76}, C_{82}, C_{84}. The structural characteristics of fullereme is defined by hexagons or pentagons and their hollow closed cage like structures. These are useful in applications in fields of industry, chemical and biology.

The efforts take this research next to 1D nanoallotropes called as carbon nanotubes. These carbon nanotubes have high aspect ratio structures of graphene sheets folded or fused to form cylindrical form. Based on the CNT coaxial walls, CNTs can single wall (SWCNT) or multiwall (MWCNT). The difference between the two is on the basis of the diameter. The structure of CNT on the placement of different hexagonal angle of carbon atoms attains the pattern like armchair, zigzag and the chiral one. Thus the advancements in the synthesis of CNT and purification process provides its use in electronics , batteries, films and coatings.

The 2D carbon allotrope that provides mostly its application in solar cells and electronic circuits after attaining different forms is graphene. The sp^2 hybridised graphene has honeycomb structure and this graphene geometry can be optimized to form single layer graphene sheets, multi layer graphene sheets and to the graphene nanoribbons. The properties of these various forms can be altered by the concept of bandgap engineering and by these alterations these are used in application like FETs, switches and sensors [5].

E. Glassy carbon

In 1950's, a new type of carbon form is introduced named as glassy carbon. The name Glassy carbon indicates glass like carbon. The structure of glassy carbon is sometimes assumed as similar with fullerene. The sp^2 hybridized glassy carbon possesses ceramic properties . These glassy carbons basically fabricated as Glassy type electrodes for which electromechanical properties are studied. Glassy carbon also called as vitreous carbon . These can be fabricated as microstructures as they possess density lower than that of graphite and diamond. For those microstructures they are yielded at high temperature from 1000-3000°C. The enormous properties of glassy carbon like low density, low friction, and low thermal resistance make it a potential candidate for MEMS.

F. Q-carbon

In 2015, researchers lead to the discovery of new type of carbon allotrope. This allotrope named as Q-carbon. The formation of Q-carbon is by the process of quenching using laser pulses of high power. This Q-carbon allows the direct conversion of carbon to diamond. Q-carbon exhibit more hardness than diamond and quenching of it provides the nanodiamonds, microneedles, thin films, microdiamonds. The attractive phase of Q-carbon is its ferromagnetism, conductivity, hardness and Enhanced field emission [8]. Q-carbon is under research phase to examine its use in electronics.

III. METROLOGY TECHNIQUES TO CARBON ALLOTROPES

The study of structures of various allotropes needs a detail investigation of its composition, surface and its characteristics at various scales. For this there are various techniques available that are optical spectroscopy, electron microscopy, X-Ray Diffraction, Raman Spectroscopy and surface techniques.

A. Optical Spectroscopy

One of the oldest techniques to carbon nomenclature is optical spectroscopy. Optical spectroscopy uses light beam as a probe. The arrangement of optical spectroscopy includes specimen tray, analyzer, mirror and polarizer. In between analyzer and specimen there is half wave retarder. The operation in this includes the beam of light is either transmitted or reflected in order to form an image. The image itself includes features of the specimen that is phase, color, brightness, and florescence. The resolution of image formed is dependent on the wavelength of light [9]. However, in optical microscopy there is always a challenge of distance and resolution of image for which new techniques are developed**.**

B. Electron Microscopy

Advancement to the optical microscopy in terms of resolution and magnification is achieved by electron microscopy. In this technique, beam of electron is used for probing, which has wavelength much less than of light , as a result of which there is more resolution of image. Electron microscopy is divided into two types one is Scanning Electron microscopy (SEM) and other is Transmission Electron microscopy [13].

SEM (Scanning electron microscopy) is a technique based on the principle of scattered electron . For SEM, sample can be prepared by etching or ion bombarding. The image generated of the sample has 3D characteristics and used this technique generally used for polished powders structures whereas the TEM technique of electron microscopy is widely used for study of carbon materials because the 2D image generated by this technique has better resolution than SEM. But this technique requires special sample preparation. In this larger sample is cut into thinner pieces. Thus transmitted electrons of TEM analyze small samples as compare to SEM.

C. X-Ray Diffraction

A new tool in chemistry and material science in order to study important characteristics of a crystalline compound is X-Ray Diffraction. This technique extracts the shape and size of compound unit cell by using probe of X-ray. X-Ray beam on illumination on specimen get diffracted by an angle ϴ. This diffracted beam is noted on the film or on a meter called as diffractometer [11]. The sample prepared for this technique is in powder form and is

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spreaded over the sample holder. The use of this technique provides good resolution as wavelength of probe beam is also small and is widely used to determine the lattice parameters, phase composition and phase purity.

D. Raman spectroscopy
A highly sensitive technique to study the carbon morphology made of c-c bonds is Raman spectroscopy. This technique is most commonly used technique to study carbon nanoallotropes that are CNT and graphene because this method is highly efficient to determine a minute change in carbon structures [12]. This technique sometimes called as molecular morphology technique for the characterization of carbon forms as it deals with the raman band and corresponding vibrational frequency of carbon-carbon bond.

E. Surface Spectroscopy techniques
Surface spectroscopy techniques are the methods developed to study surfaces and films of various compositions. The commonly used surface techniques are X-ray photoelectron (XPS), Auger electron (AES), ion scattering (ISS) and secondary mass ion spectroscopy (SIMS). The difference between these spectroscopic techniques is on basis of use of different probe. XPS uses X-ray as probing signal, AES uses electron beam whereas other two uses ion bombarding. In spite of different detection techniques, all these are different from each other as all have different sensitivity and provides different information of chemical composition.

IV. CONCLUSION

Carbon is an abundantly present element that exists in many forms. It is a key element from human body to day to day life materials .The various allotropes of carbon namely graphite, diamond, amorphous carbon, Fullerenes, Carbon nanotube, graphene, glassy carbon can be used in many fields virtue of different structure and bonding patterns between the carbon atoms .These structures and unique properties of carbon forms are studied by means of several techniques. In this paper the various techniques are reviewed so as to understand their importance in analyzing carbon.

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