DIAMOND – THE ULTIMATE SEMICONDUCTOR

Abstract:

Diamonds aren't just a girl's best friend – they promise to form the basis of the next generation of high-power, high-frequency semiconductors and amplifiers. Many companies believe that by synthesizing high-purity single crystal diamond, they have cracked one of the major problems that have prevented diamond from becoming a widespread semiconductor material. Diamond has a very wide band gap resulting in its extremely high breakdown voltage, very high saturation velocity, high carrier mobility, high thermal conductivity and making it extremely radiation hard. Diamonds can be synthesized in two ways:

1. By subjecting graphite to high pressure and high temperature, but the diamonds thus produced cannot be used in electronic devices.
2. Diamond films can be grown from carbon containing vapour in a process called Chemical Vapour Deposition (CVD).

The break-down voltage of silicon is 8KV-12KV whereas that of diamond is many times this value. In high-voltage applications, a thick section of silicon, 750µm. for 8000V is needed which makes the device quite resistive and hence high power dissipation when compared to that of diamond. Also diamond can deliver tens of watts of power at high frequency and this makes it extremely attractive for use in areas such as radar or satellite communications.

Keywords: *Chemical Vapour Deposition (CVD), single crystal diamond.*

Conclusion: 1.A single diamond device can replace multiple silicon devices stacked in series due to its high break-down voltage resulting in low power losses.

2. In most of the power circuits being manufactured, there are both switch and diode. If there is a more-efficient diode, this helps the other components to work more effectively. So a silicon transistor coupled with a diamond diode performs better than a silicon-only-device.
3. Diamond's high-frequency capabilities and its natural resistance to radiation damage make it a prime candidate for space communications.
4. The potential way of exploiting the properties of p-type diamond is to marry it with a high performance n-type semiconductor such as gallium nitride (or) silicon carbide, but it is proving extremely difficult to knit the two materials together at the atomic scale.

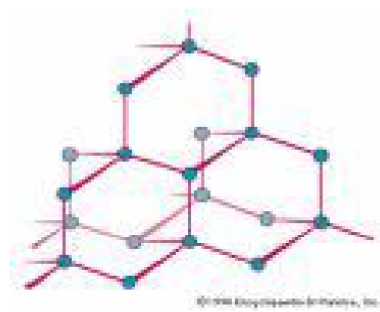
These are the conclusions, which prove that 'Diamond is the ultimate semiconductor'.

INTRODUCTION:

The diamond is generally regarded as the premier gem of the world. It came to prominence as a precious gem on account of its brilliance and hardness. Diamond is a chemical combination of carbon atoms in crystalline form. Due to its high refractive index and adamantine lusture, diamond is considered to be the 'prince of gems'. Also the extreme hardness of diamond makes it an excellent abrasive and cutting material. While pure diamond is an electrical insulator, diamond doped with small amounts of boron added is an electrical conductor, possibly allowing it to be used in new technology applications as a semiconductor material.

STRUCTURE OF DIAMOND:-

Diamond is the crystalline form of carbon. In diamond, carbon atoms are in tetrahedral arrangement. Each carbon atom is bonded to four others by covalent bonds. These strong and symmetrical bonds make diamond extraordinarily hard. It is a giant molecule with cage like units in its structure. The C-C bond length in diamond is 1.54A° and its density is 3.52gm/cc.



Structures of diamond

PROCESS INVOLVED IN PRODUCTION OF NATURAL DIAMOND:-

The diamond is generated naturally deep inside the earth under extreme pressure of about 50000atm. At temperatures above1000°C such conditions exist hundreds of kilometers deep in the interior of the earth, a zone referred as the 'upper crust'.

REQUIREMENTS OF A SEMICONDUCTOR:-

- The forbidden energy gap between valence band and conduction band is less than that of insulators.
- For a material to become a good semiconductor, chare density, conductivity and mobility must be high.

CAUSE FOR SYNTHESIS OF NATURAL DIAMOND:-

The best natural diamond has a carrier lifetime of less than 8nanoseconds-the charge carrier lives for 8ns. On an average before being trapped. Also, the mobility of carrier is

2000cm²/Vs. These values of carrier lifetime and mobility are far less than that of a good semiconductor. These arouse a necessity for the synthesis of a good semiconductor diamond.

SYNTHESIS OF ARTIFICIAL DIAMOND:-

Diamonds can be synthesized artificially in many ways of which the two main methods are:-

1. by subjecting graphite to high-pressure high-temperature and
2. by Chemical Vapour Deposition.

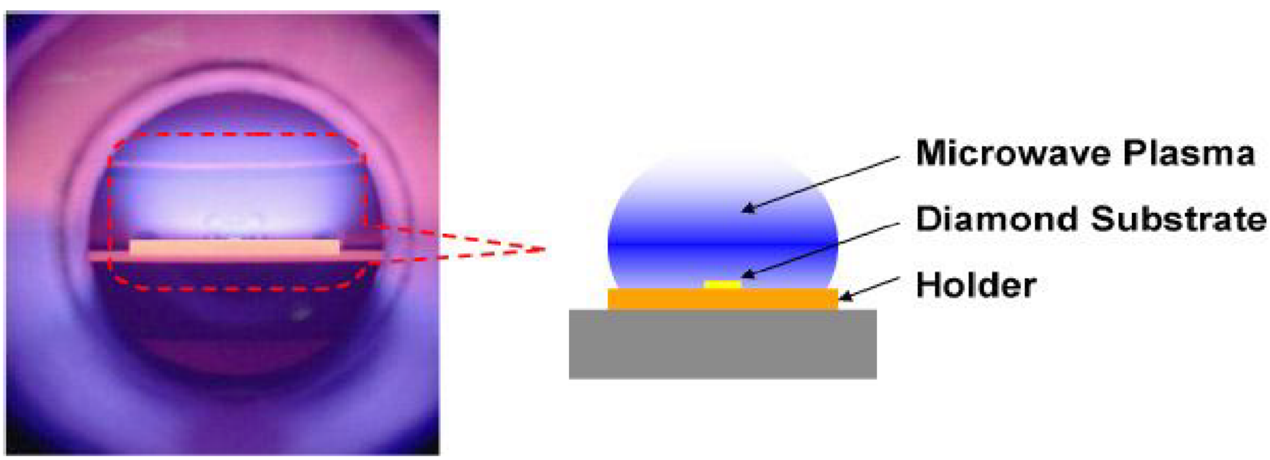
(1)HIGH-VAPOUR, HIGH-TEMPERATURE METHOD:-

This method uses large presses that can weigh a couple of 100tonnes to produce a pressure of 5GPa at 1500°C to reproduce the conditions that create the natural diamond inside the earth. However electronic grade diamonds cannot be produced in this process and the resulting diamonds are used for cutting and grinding.

(2)CHEMICAL VAPOUR DEPOSITION (CVD):-

It is a method of growing diamond by creating the environment and circumstances necessary for carbon atoms in a gas to settle on a diamond substrate in diamond crystalline form. This method of diamond growth has been the subject of a great deal of research since the early 1980's, especially due to its potential applications in the semiconductor and diamond-gem industry.

Here a mixture of carbon containing gas for example methane and hydrogen are passed into a quartz tube at a pressure of 0.05atm. Using microwaves the mixture was heated to 800°C, dissociating both the methane and hydrogen into elemental forms. The carbon is deposited on a substrate, the majority as graphite, but a very small proportion as diamond crystal. The graphite is removed by the hydrogen leaving a thin layer of diamond.



Apparatus showing synthesis of diamond using CVD technique

PROPERTIES OF DIAMOND THAT MAKE IT A BETTER SEMICONDUCTOR:-

- Its wide band gap results in high breakdown voltage.
- It has a very high saturation velocity, high carrier mobility of about 4000cm²/Vs, high thermal conductivity and is extremely radiation hard.
- Artificially produced single-crystal diamond has a carrier lifetime of more than
- 2000ns.

COMPARISON OF PROPERTIES BETWEEN CONVENTIONALLY USED SEMICONDUCTOR MATERIALS AND DIAMOND:-

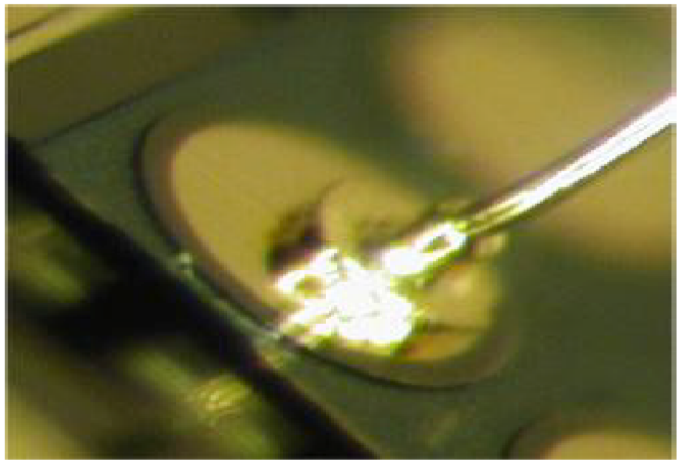
Till now silicon has been considered as an advisable semiconductor material for electronic devices. But the properties of single-crystal diamond produced by CVD technique when compared with that of silicon make it clear that it is a better semiconductor material than silicon for electronic devices. They are as follows:-

PROPERTY	SILICON	DIAMOND
Band gap	1.1	5.5
Breakdown field(MV/cm)	0.3	20
Electron mobility(cm^2/Vs)	1450	4500
Hole mobility(cm^2/Vs)	480	3800
Thermal conductivity(W/cmK)	1.5	24
Breakdown voltage(KV)	8-12	Very high

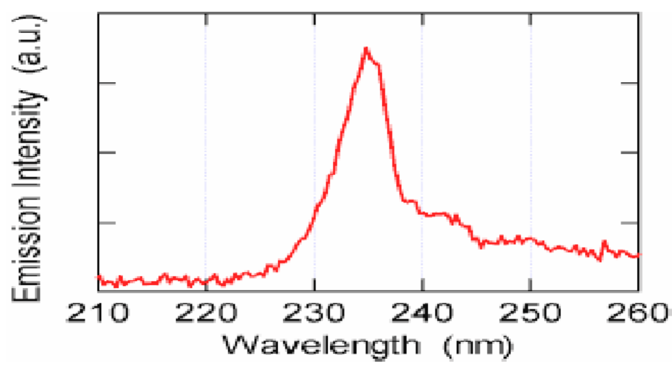
APPLICATIONS:-

Diamond has and could have a wide ranging impact in many fields.

- Diamonds have long been used in machine tools, especially when machining non-ferrous alloys. While natural diamond is certainly still used for this, the amount of synthetic diamond is far greater.
- The most common usage of diamond in cutting tools is done by distributing micrometer sized diamond grains in a metal matrix, hardening it and then referred to in industry as 'PCD' diamond. PCD tipped tools are often used in mining and in the automotive aluminium cutting industry.
- The diamonds can detect redox reactions that cannot be ordinarily be studied and in some cases degrade redox reactive organic contaminants in water supplies. This is because diamond is almost completely chemically inert and can be used as an electrode under conditions that would destroy traditional materials.
- For the above reasons, waste water treatment of organic effluents, as well as production of strong oxidants have been published.
- Diamond is used as a potential radiation detection device.
- Due to its radiation hard and wide band gap properties it is employed in applications such as BABAR detector at Stanford.
- Diamond transistors are functional to high temperatures and are resistant to chemical and radioactive damage where silicon transistor fails.
- A chip made of diamond could do with a far less robust cooling mechanism and run at unheard of frequencies without damage.
- When a p-n junction diode is used in UV emitting device, and when current is fed into it, emission of UV radiation of 235nm. has been confirmed.



UV-emitting Device employing diamond diode



Graph emission intensity and wavelength of UV-radiation emitted by UV-emitting device using diamond diode