Study of Metal Contact on Silicon Carbide Semiconductor Substrate

A Thesis Submitted in Partial Fulfillment of the requirements

For the degree of

Masters of Science in Physics

By

MANISH RAO

from

Lingaya's Vidyapeeth, Faridabad, Haryana, INDIA. Pin -121101

Worked with

Solid State Physics Laboratory (DRDO), New Delhi, INDIA

Under the Guidance of

PRAVEEN SAHO (SSPL)

DR. DIPIKA NANDA (LINGAYA'S VIDYAPEETH)

Declaration

I declare that the thesis on "*Study of Metal Contact on Silicon Carbide Semiconductor Substrate"* has been composed by myself and that the work has been submitted only for Partial Fulfillment of the requirements for the degree of Masters of Science in Physics. I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in any submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

This certify that M.Sc. (Physics) project report entitled *“Study of Metal Contact on Silicon Carbide Semiconductor Substrate”* submitted by *“***Manish Rao***”* to *Lingaya’s Vidyapeeth* is a record of Bonafede work carried by him under our supervision. The project report submission in partial fulfilment of the requirement for the award M.Sc. in Physics in the department of Physics in Lingaya’s Vidyapeeth (Haryana).

PRAVEEN SAHO	**DR. DIPIKA NANDA**
Scientist-E	**Assistant Professor**
(SSPL D.R.D.O)	**(LINGAYA’S VIDYAPEETH)**

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Abstract

Metal contacts on Silicon Carbide (SiC) semiconductor substrate has played a vital role in improving the physics and technology of electronic devices. Metals are deposited on SiC to attain conduction with semiconductor or to get electrical interconnection among devices of same integrated circuit. As We know SiC carbide has played a great role in improving semiconductor technology as it is easier to work with SiC semiconductor devices at extreme conditions but that is almost impossible unless the metal contacts donot fail at those conditions. Reliability and durability of metal contacts are the main issues narrowing the possibility of operating electronics at high temperature.

Almost 30% of all electricity is lost in channeling, modification, distribution and conversion between power point and point of use. So to over come all these, we need a better semiconductor where It has been found that SiC as semiconductor can fulfill all these needs as It offers high power densities, low energy losses and high breakdown strength. They are considered as third generation materials in the semiconductor industry after Silicon and Germanium.

In the last decade, the metal to SiC contacts has been studied and gave important results and even now it is an interesting topic for research as improving metal contacts technology can improve the semiconductor electronics technology as metal/semiconductor contacts are the building blocks of electronic devices. By improving metal semiconductor contacts we can improve the performances of simple devices and complex integrated circuits. In this, this thesis aims to peak some applicable characteristics related to metal/semiconductor contacts to SiC, both on n-type as well as p-type semiconductor contacts. Here we will discuss the metal contacts on SiC semiconductor substrate, their growth techniques and methods of characterizations which would help to predict future aspects of applications of using SiC as a semiconductor with different metal contacts.

Contents

Chapter – 1

Chapter-2

Methods of Silicon Carbide Growth and Characterization

Chapter-3

Silicon Carbide Semiconductor Contacts

Chapter-4

List of Figures

List of Tables

Chapter-1

Introduction to Semiconductors

Semiconductors are the class of elements having conductivity in between conductors and insulators. The value of conductivity for semiconductors lies in between 10^{-5} to 10^{0} Sm^{-1} and of resistivity between 10^{5} to 10^{0} Ωm. Semiconductor materials can be classified mainly in two parts as single-crystal semiconductors and Compound semiconductors. Single crystal semiconductors can be available in natural form as Silicon (Si) and Germanium (Ge) and Compound semiconductors are made by compounding the metals where the semiconductors can be further classified as Inorganic semiconductors (example- CdS, GaAs, InP), Organic semiconductors(example as anthracene) and organic polymers semiconductors(example polypropylene, polyaniline, etc.) Germanium (Ge), Silicon (Si) and Gallium Arsenide semiconductors are most frequently used in construction of electronic devices.

1.1 Germanium

Germanium was used exclusively in first few decades after discovery of diode in 1939 and transistor in 1947. Ge with atomic number 32 and mass number 74.64u have energy band gap of 0.67eV which is suitable to act as a semiconductor. Germanium was relatively easy to find, available in relatively large quantities and obtain very high levels of purity. But diodes and transistors developed by using Ge as a base material did not proved to be a good semiconductor as it suffered from low levels of reliability due to its sensitivity to for a range of temperature.

1.2 Silicon

Silicon was found to be a better temperature sensitive semiconductor. First, Silicon transistor was introduced in 1954 and was not even less temperature sensitive but also one of the most available materials on earth and about which we donot have any concern of its presence in nature whereas refining process for the production of Silicon of very high levels of purity was still in development and still there were issues of speed, systems were not working at higher level of performance.

1.3 Gallium Arsenide

Gallium arsenide was found as much better semiconductor than Silicon and Germanium which can give better results for the issues of sensitivity, speed. GaAs transistors was first developed in early 1970s and in field of electronics it became increasingly sensitive to issues of speed and had speed of operations upto five times that of silicon. Some of the properties of Si, Ge and GaAs are given in the table below:

Properties	**Silicon**	**Ge**	**GaAs**
Crystal Structure	Diamond	Cubic	Zinc Blende
Energy gap E_g(eV)	1.12	0.67	1.43
Electron mobility (cm^2/V.s)	1400	400	400
Break down field E_B (V/cm)x 10^6	≈0.3	≈0.1	≈0.4
Thermal conductivity at 300K (W/cm)	1.5	0.6	0.5
Relative permittivity	11.8	16.0	12.8

Table 1.1: key electrical properties of Si, Ge and GaAs [3]

1.4 Silicon Carbide

1.4.1 History

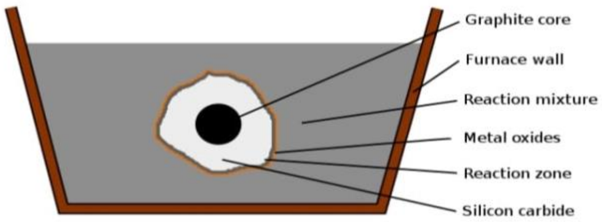
SiC also known as Carborundom was found by Henri Moissan in 1893 while observing a meteorite in Arizona. Earlier it was mistakenly found that it is a diamond but after found to be as Silicon Carbide. It is one of the rarest mineral on earth but present in large amounts in space. As it’s structure is similar to diamond and it is the third hardest material known after diamond and boron Carbide so first it was used as an abrasive and then later was used for cutting, grinding glass, making grinding wheels, knife or as preservatives of eggs and in soap industry too.

Figure 1.1: Silicon carbide [Wikipedia]

1.4.2 Production (Bulk Growth)

Edward Goodrich Acheson in 1890 discovered a method for the production of SiCas he was trying to prepare artificial diamonds. He patented the method for making Silicon carbide powder in February 1893. As natural Carborundom is extremely scarce, so most of the SiC is synthetic.

The most common process used to produce silicon carbide is to combine silica sand and carbon in an Acheson graphite electric resistance furnance at high temperature inbetween 1600^0C and 2500^0C.



Cross-section of an Acheson furnace for producing bulk silicon carbide or graphite

Figure 1.2: Acheson furnace [Wikipedia]

But this process was not succeeded as it was not capable for controlled crystal growth technique
In 1955, J. A. Lely invented a new important crystal growth technique which almost made controlled crytal growth possible which resulted a series of research activities on SiC in a very short time but after 1958 no high quality SiC substrate were available to time.[1]

First, SiC wafers were produced by two Russian scientists Tairov and Tsvetkov by the process known as Seeded Sublimation Growth and finally In 1987, Epitaxial growth of SiC was possible by the discovery of another technique known as ‘Step controlled epitaxy’ which commercialized the power of Electronic Devices based on SiC such as Schottky diode and MESFETs produced by Cree in and Infineon.[1]

1.4.3 Properties of SiC

SiC is a compound semiconductor made up of Silicon and Carbon. It is the third hardest material known after Diamond and Boron Carbide. It offers high power densities and low energy losses. It is a good heat conductor and bears so many properties which makes it suitable to use as a semiconductor in the field of electronics.

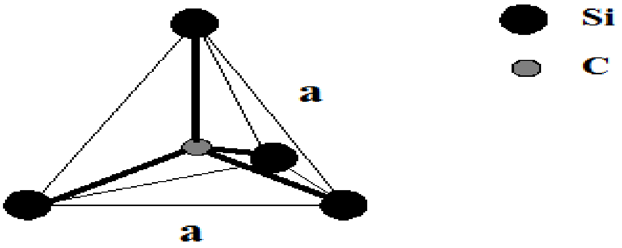


Figure 1.3: Basic structure of silicon carbide. [3]

It is a wide band gap semiconductor biocompatible material which is capable to improve advanced biomedical applications. SiC withstands higher electric field which allows high voltages or same voltages but smaller devices and It's breakdown strength is 10 times more than Silicon. Basically, majority of electronics equipment's like TV, ICs etc are using semiconductors of Silicon and Germanium. Using these semiconductors in advanced gadgets which are used in harsh conditions like rockets, space gadgets have to work in extreme conditions is not practical.

As Silicon devices do not perform at high temperatures above 250^0C whereas SiC devices are capable to work in between 300^0C to 600^0C and can block voltages in the range of 300V to 1200V. These properties of SiC made it to develop high power devices and have many applications in power electronics like in Aerospace, geothermal wells, information technology (IT) nuclear power instrumentation, laptops, Military systems, sensor systems, solar power invertors, wind turbines, high efficiency product for Biocompatible and long term vivo application.

Silicon carbide has high thermal conductivity 4.9W/cm/kelvin which exceeds only by diamond and Have low values of densities and high value of hardness. Some more properties of SiC are given below over other semiconductors [2]

Properties	**Silicon**	**4H-SiC**	**GaAs**	**GaN**	**6H-SiC**
Crystal Structure	Diamond	Hexagonal	Zinc Blende	Hexagonal	Wurtzite
Energy gap E_g(e)	1.12	3.26	1.43	3.5	3.26
Electron mobility (cm^2/V.s)	1400	900	400	200	470
Break down field E_B (V/cm)x 10^6	0.3	3	0.4	3	3.2
Thermal conductivity (W/cm)	1.5	4.9	0.5	1.3	4.9
Saturation drift velocity V_s(cm/s) x 10^7	1	2.7	2	2.7	2
Relative permittivity	11.8	9.7	12.8	9.5	10.3

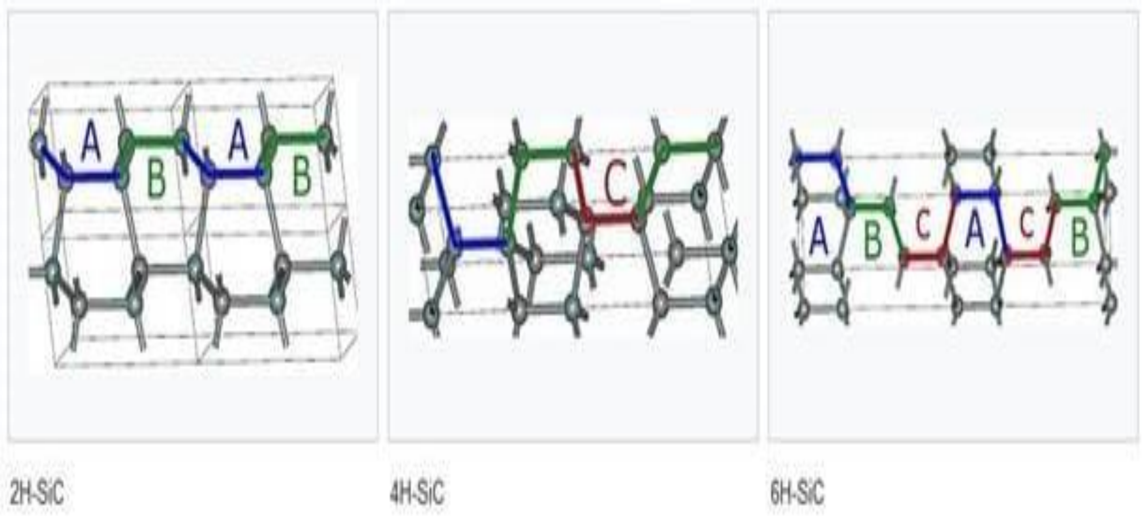
Table 1.2: Electrical properties of SiC vs. Si, GaAs, GaN [3].

1.4.4 Polymorphs of SiC

There are near about or more than 250 polymorphs of Silicon Carbide had found but 2H-SiC, 4H-SiC, 6H-SiC and 3C-SiC are used among all.

3C-SiC has highest electron drift velocity per unit electric field and saturation velocity. Among these 3C-SiC, 6H-SiC can be prepared easily and easier to study, while 3C-SiC and 4H-SiC polytypes are founded much better than other polymorphs these offers better electronic properties.
The α-SiC polytypes 2H, 4H and 6H can be represented in the Ramsdell classification scheme where number tells about the layer and the letter explains the Bravais lattice.

- **2H SiC** structure is wurtzite type structure and its elements A and B are stacked as ABABAB.
- **4H SiC** unit cell is two times longer and its second half is curled compared to 2H SiC, 4H Sic has hexagonal lattice with 4 layer repeated structure arranged in ABCB stacking.
- **6H SiC** cell is 3 times longer than2H, and assembled as ABCACB.
- **Cubic 3C SiC** is also known as β-SiC and it is stacked as ABC, the number 3 refers to 3 bilayer periodicity of assembling and letter C denotes cubic symmetry of 3C. It is only cubic polytype [1]



2H-SiC 4H-SiC 6H-SiC

Figure 1.4: Basic structure of SiC polytypes: 2H-SiC,4H-SiC and 6H-SiC [Wikipedia]

POLYMORPHS	BAND GAP
3C-SiC	2.3Ev
2H-SiC	3Ev
4H-SiC	3.2eV
6H-SiC	2.3eV

Table 1.3: Band gaps of polymorphs [5]

Polymorphs	Thermal conductivity
3C-SiC	3.6 W/cm-k
4H-SiC	4.9W/cm-k
6H-SiC	4.9W/cm-k

Table 1.4 : Thermal Conductivities of polymorphs of SiC [5]

Chapter-2

Methods of Silicon Carbide Growth and Characterization

2.1Growth Techniques

Since from time, It was an issue to produce SiC as a semiconductor as it is not found on earth in natural form and can be synthesized only. So many methods have been introduced for the the production of SiC as a semiconductor.

2.1.1 Bulk Growth

2.1.1.1 Physical Vapor Transportation technique

Physical Vapor Transportation method (also known as modified Lely method) is widely used now a days for the commercial production of SiC as a semiconductor and is preferred much more than other growth techniques. this method performs the sublimation at above 1800°C. However, PVT SiC cannot be grown commercially, as systems are not available so the growth industries develop systems in-house and optimize the growth conditions. It operates at high temperatures 2100–2500° Cd due to its complex behaviour. An air-tight graphite crucible is used for the growth process. As it operates at high temperatures, so it is not practical to observe the opacity of the graphite crucible or observe experimentally the exact thermal conditions in the growth zone.[14]

2.1.1.1.a Sublimation Growth Principle

Growth by sublimation mechanism is started to convert SiC powder in gaseous form. Then it is transported from the source to the growth front followed by diffusion and advection and then that gaseous species is fused into the surface layer of the growing crystal

2.1.1.1.b Sublimation Growth Furnance

According to reference 14, The growth furnace is fitted in a double-walled quartz glass tube that is cooled with water. an HF generator (power 50 kW, frequency 250 kHz) is used to heat the suspector with the help of induction coil. Two different Pyrometers are used to calculate the hotness of the graphite crucible located at the top and at the bottom as shown in figure. Pressure is maintained through needle valve which creates platform to fill the crucible with non reacting or dopant gas at low pressure.[14]

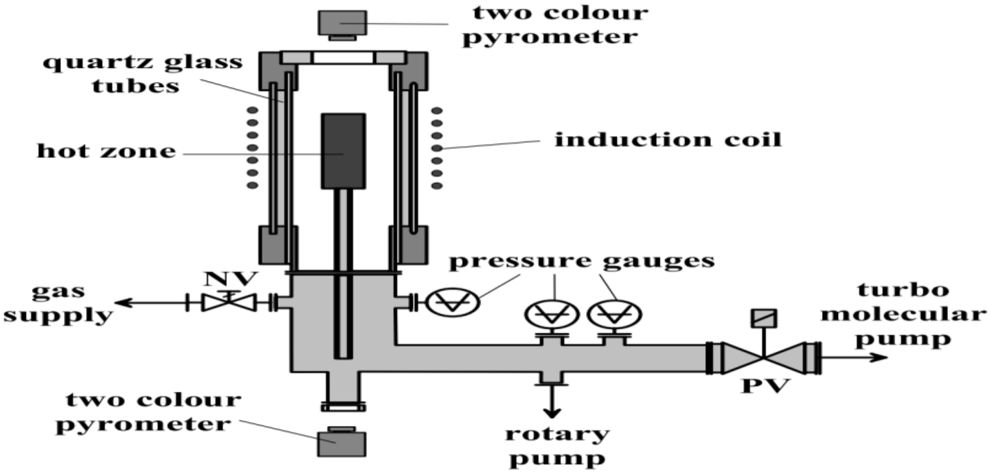


Fig 2.1-Sublimation furnace for the growth of SiC single crystals by PVT method [14]

Graphite foam is used to make the thermal insulation cylinder and rest of the parts are made of solid graphite. The crucible is heated by radiation of susceptor which absorbs the electrical HF field. The temperature slope is adjusted by the discs and the position of the coil. Source and seed are separated by near about 30 mm and the inner diameter of the crucible is 25 mm in our furnace. A solid dopant source is used to dope Aluminium (Al) or Phosphorus (P). The dopant source is placed at lower temperature because of the high vapour pressure of all the suitable Al and P compounds. The evaporating dopant gas is connected to the growth front by tubes drilled through the graphite walls.[14]

2.1.2 Epitaxial Growth

2.1.2.1 Chemical vapor deposition (CVD)

A plating process that uses thermally induced chemical reactions at the surface of a heated substance, with reagents supplied in gaseous form. This method can produce structural controlled materials with high levels of purity at atomic or nanometer scale level. In this method, the required material is deposited on the surface of wafer after converting it into gaseous form at high temperatures (near about 1700^0C) and unwanted by-products are out of the CVD chamber.

Precursor gases like Silane and and hydrocarbons are mixed by heating and then decomposed on the Surface of Silicon Carbide substrate in presence of gaseous hydrogen as a carrier gas for the epitaxial growth of Silicon carbide.[7]

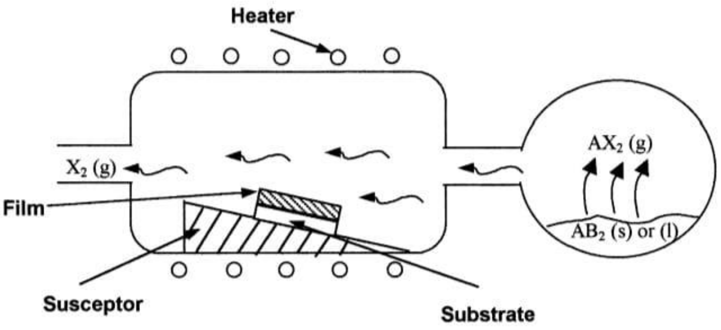


Fig. 1. A schematic diagram of the CVD coating.

Figure 2.2: A schematic diagram of CVD coating [7]

2.2 Characterisations

2.2.1 X Ray Diffraction Technique

This technique is widely used for the study of properties of generated polymorphs of SiC. X-Ray Diffraction is a technique which is used to gather detailed information about the internal structure of the a unit cell of Crystal. Statistics about the bond length, unit cell dimensions, bond angles and details of site ordering of a crystal lattice can be determined by this technique
X-Ray diffraction is based on the the principle of crystalline sample and constructive interference of monochromatic X-Rays.

this method comprises of three parts, X-Ray tube, a sample holder and an X-Ray detector Cathode ray tubes are used to produce X-Rays of monochromatic radiation aimed towards the sample. These rays produces constructive interference when conditions satisfy Bragg’s law($n\lambda = 2d\sin\theta$), It gives the relation between wavelength of electromagnetic radiation and the diffraction angle. These diffracted X-rays are then analysed by changing the position and angle of crystal which is placed for observation and on the basis of that the properties of the crystal can be determined.[10]

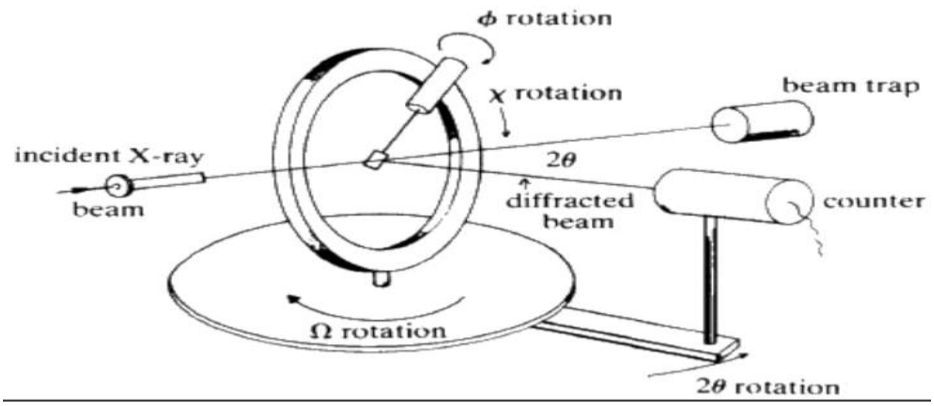


Figure 2.3: A four circle diffractometer, angles between the incident ray, detector and sample [10]

2.2.2 Raman Spectroscopy

Raman spectroscopy is a technique used to study vibrational modes, chemical structure, phase and other characterisations of a molecule. It was named after an Indian Scientist Dr. C. V. Raman. An present, Raman spectroscopy is a fast and contact free method used for the study and characterization of SiC and its defects. This method is useful in detection of the defects in single crystals. This technique is based on the study of interaction between light and matter where light is inelastically dispersed. In this, Sample is targeted by monochromatic light and the scattered photons from the sample are collected after the interaction of photons with matter, Its wavelength is shifted either lower or higher and a spectrum is generated from the scattered photons which is analysed for properties.[15]

2.2.3 Scanning Electron Microscopy (SEM)

In this technique, image of SiC is formed with the help of electrons. The electrons are scanned in a raster pattern over the sample of SiC and then emitted electrons are detected. A number of signals are produced from which Secondary electron detectors are considered as one of the best equipment in all SEMs and a single machine cannot trace all types of signals. It has some range.

We can get better images by using cathode for emission of electrons under very high electric field. Image result is obtained from interactions of the electron beam with atoms at various depths within the sample.

The path covered in solid matter can be maintained by varying energies of secondary electrons ranging about 50eV. Consequently, SEs escape from the few nanometers of the surface of a sample. The signal is highly localized at the point of impact of the primary electron beam which collect images of the sample surface with a resolution of less then 1 nanometre.

Narrow electron beam of SEM micrographs give a large depth of field which makes it to possible to produce characteristic 3-D appearance of crystal and become easy to understand the surface structure of a sample. It produces highly magnified images from about 10 times (about equivalent to that of a powerful hand-lens) to more than 500,000 times, about 250 times the magnification limit of light microscopes.[17]

2.2.4 Transmission electron microscopy (TEM)

Transmission electron microscopy (TEM) also transmits a beam of electrons through an ultra-thin specimen sample and an image is formed from the interaction of the electrons transmitted through the specimen. This method is also used to study properties and structure of SiC. Later the image is formed and magnified on a imaging device as on photographic film and then it is to be detected by a sensor. Observations taken by TEM gives useful information about samples of SiC that cannot be obtained by other.[16]

Instrumentation:

From the top down, the TEM have an emission source, which may be a tungsten filament, or a lanthanum hexaboride (LaB6) source. This will be of the form of either a hairpin-style filament, or a small spike-shaped filament for tungsten filament. LaB6 sources adjusts small single crystals. By connecting this gun to a high voltage source (typically ~100–300 kV) the gun will start to emit electrons either by thermionic or field electron emission into the vacuum at sufficient current. This extraction is usually aided by the use of a Wehnelt cylinder. Once electrons are emitted, the formation of electron probe of required size and location is allowed by upper lenses. Manipulation of the electron beam is performed using two physical effects. Magnetic field will make the electrons to flow according to right hand rule, thus allowing for electromagnets to

manipulate the electron beam. The use of magnetic fields allows for the formation of a magnetic lens of variable focusing power, the lens shape originating due to the distribution of magnetic flux. Additionally, electrons are deflected through constant angle with the help of electrostatic fields. The shifting of beam path is done by Coupling of two deflections in opposing directions with a small intermediate gap.[16]

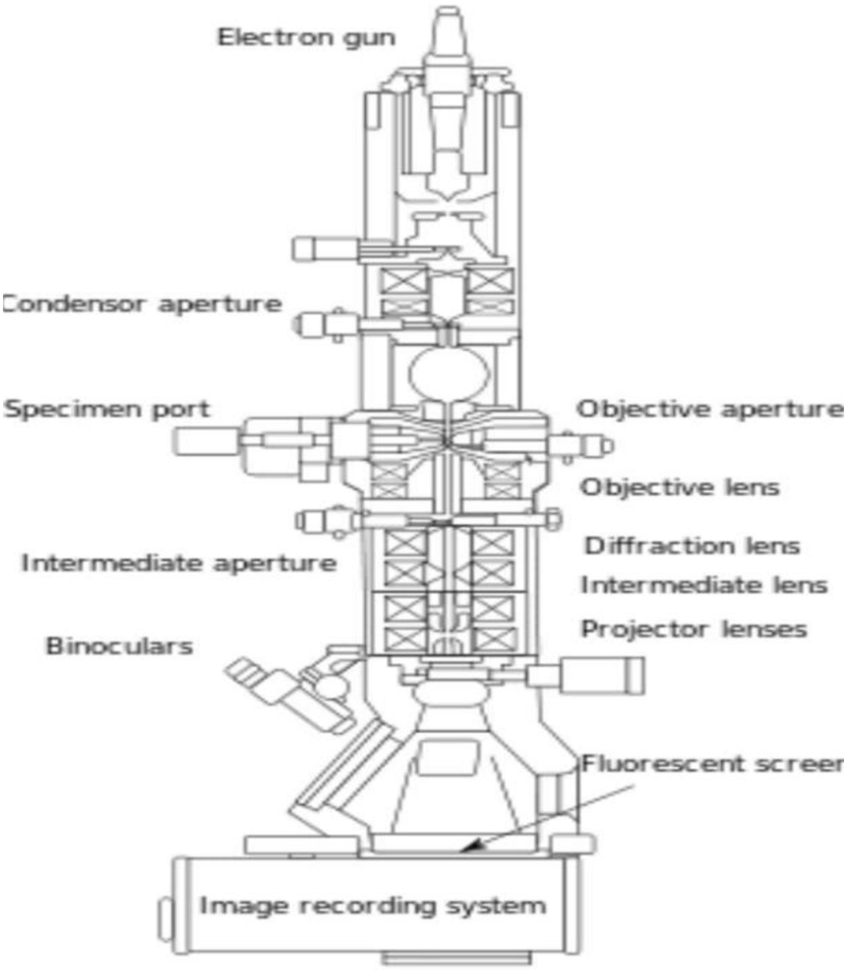


Figure 2.4 Layout of optical components in a basic TEM [16]

Chapter – 3

Silicon Carbide Semiconductor contacts

3.1Metal Semiconductor contacts:-

Metal semiconductor contacts are the components which consists of a thin barrier on the substrate through which carriers can move.

As it is already mentioned that SiC devices can work at extreme conditions but it is not possible unless the metal contacts do not fail at these conditions. Reliability and durability of metal contacts are the main issues narrowing the possibility of operating electronics at high temperature. Metal contacts are essential part of semiconductor devices. Metal are deposited on SiC to attain conduction with semiconductor or to achieve electrical interconnection among devices of same integrated circuits.

When a metal like Al, Ti, Ni etc and a semiconductor are attached or contacted, a depletion layer is formed between them whose breadth or width of depletion layer depends on doping levels of semiconductor and explain about the type of contact that has formed.[11]

Metal and semiconductors are chosen very carefully because their work function plays an important role. If the work function ϕ_m of metal is greater than the that of semiconductor (ϕ_s), then electrons will move from semiconductor to metal by creating a voids or depletion region over a width W in n-type semiconductor.

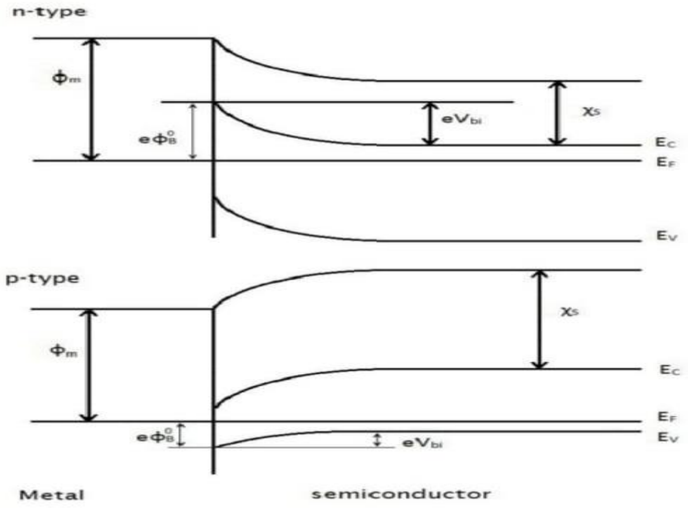


Figure 3.1: Energy band diagram of metal-semiconductor contact [1]

3.1.1 Ohmic and Schottky contacts:

After attaining thermodynamic equilibrium, movement of electrons stops and both hold outs the same fermi level. After the formation of depletion region, electrons in the metal will experience a barrier I travelling to semiconductor. This work function is called Schottky Barrier.

An ohmic contact is formed when depletion region between these two is narrow and Schottky contact is formed for wide depletion region. So in this way metal contacts are divided mainly into two parts-Schottky contact and Ohmic contacts.

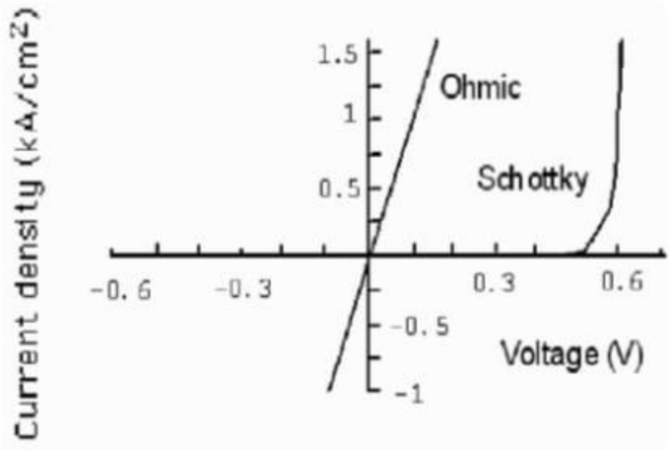


Figure 3.2: Ohmic and Schottky I-V Curve [12]

Ohmic and Schottky contact’s properties can be studied by drawing graph between current and voltage or by studying I-V characteristics. From the above figure it can be analyzed that the contacts which follow ohms law or give a straight line as output while observing I-V characteristics. The ohmic contacts are formed to n-type SiC then the contact formed is called Ohmic contacts to n-type Silicon carbide and the contacts formed with p-type Silicon carbide are known as Ohmic contacts to p-type Silicon Carbide.

If graph does not give the straight line then the contacts formed are known as Schottky contacts.

The Schottky contacts formed with n-type Silicon Carbide are called Schottky contacts to n-type Silicon Carbide and to p-type contacts are known as Schottky contacts to p-type Silicon carbide.

3.2 Contact Resistivity and annealing

As discussed above we can make different types of contacts depending upon the needs and requirements. So, to compare the properties we need a good method, and comparing the resistivities was found one of the appropriate method. By this method, The standard or grade of ohmic contacts have been estimated or checked by the behavior of this main characteristic parameter. It can be measured as the product of contact resistance R_C and contact area S. It is one of the useful method for comparision between the contacts of unequal sizes as it depends on the area of contact whereas contact resistance depends. Some of the methods for contact resistivity measurements are

1. Two probes method
2. Differential method
3. Extrapolation method
4. Method of interface probes

As we know SiC is a wide band gap semiconductor material with special properties which can be used to operate at high temperature and in high power semiconductor devices. But One of the disadvantage of SiC is that it requires high temperatures for electrical activation of contacts formed at its Surface. So , for manufacturing of contacts on surface of SiC, the furnances used for production of different metals contacts on SiC wafers should be capable to work at high temperatures. These furnances are used to produce the SiC semiconductors devices with desired properties. This process is known as Annealing, As a heat treatment process in which a given material is heated to change the microstructure of a material to get required mechanical or electrical properties.

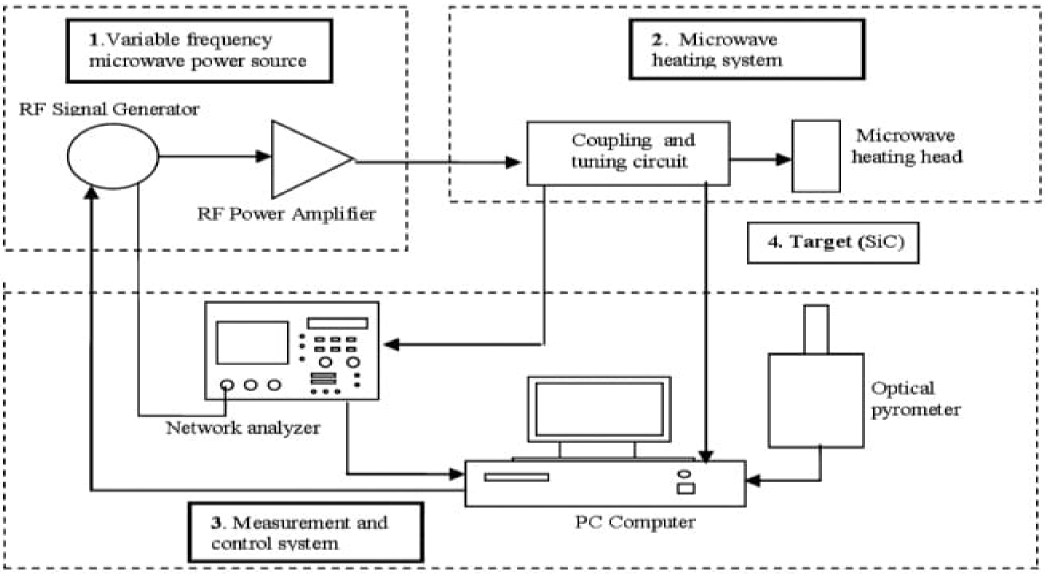


Figure 3.3: Block diagram of the solid-state microwave annealing system[13]

3.3 Metal contacts to n-type SiC

The Ohmic contacts with contact resistivity of the order of 10^{-6} Ωcm^2 have been formed with n-type SiC. Some metals and their compounds like Ni, Ti, Mo, TiN, Ta etc have been found appropriate for ohmic contacts with resistivity range (10^{-2}to10^{-6}) Ωcm^2

In this, Nickel is found to be the one of the best /suitable metal for gadgets/device application. Nickel and some other metals like W, Mo and Co forms silicide's in the metallization communication.

During growth of Nickel contacts on n-type SiC at high temperatures, Carbon is released during annealing of these contacts whose gathering in the contact layer degenerate the contact reliability, whenever a device works and make it unable to work with its full capability so in order to finish this undesirable effect. A contact system having multilayered Ni/Si films in the ratio 2Ni: Si, has been suggested at place of pure nickel.

After annealing, at 950^0C for 10 min, Ni/Si and Ni creates n-type ohmic contacts with very low resistivity SiC. Observations describes that contacts with the same substrate doping level of 1.8×10^{18} cm^{-3} have depletion layer width (potential layer width) within in range of (1.08 to 1.11) x 10^{-6} cm.

Resistivity depends on substrate doping concentration. Increasing doping concentration of 8×10^{18}cm^{-3} decreases resistivity by 2.7 x x 10^{-5} Ωcm^2.

3.4 P-Type contacts to SiC

P-type SiC creates high barrier formation at communication metal/ p-SiC, which strictly hinders developing ohmic contacts with low resistivity. Al, Boron, Gallium, Indium can be used in present semiconductor technology for obtaining p-type semiconductor contacts. Aluminum is most appropriate dopant growth of p-type SiC. It is first metal preferred for any p-SiC ohmic contact.

Al based contacts are formed by Al and its alloys or forming many layers of Aluminum. Al diffuses into SiC by which p-type concentration in communication layer rises and which results decreased depletion layer and p-type barrier can tunnel effectively through potential barrier.

However, the use of pure Al metallization is resisted as pits are formed during annealing which damage contact properties like morphology and conductance and hence reduces its working ability. That is why

Al/Si (1-2 wt%) composition has been suggested to avoid this problem. The presence of titanium in metallization scheme prohibits the Al oxidation and allows its diffusion into SiC. Upper thick Ti layer acts as a barrier for Al volatilization which is detected during contact annealing.

Ti/Al contact is most actionable p-type contact in SiC devices. With a thickness of 1µm and a carrier concentration of 3×10^{19} cm^{-3}, Contacts are created on p-type 4H-SiC epitaxial layers.[2]

The Au/Ti/Al and Au/Al/Si contacts are of many layers and films are continuously deposited. The thickness of Si, Ti & Al component films were nano scaled & chosen according to ratios:-

Si(2wt%) in Al/Si

Ti(70 wt% & 30wt%) in Ti/Al

&Al(30 wt% & 70wt%) in aTi/Al

Width of these films is 100nm before annealing. A 100 nm thick Au film is coated as cap layer in all contact types and Contact resistivity acquired for Al-based contacts annealed at optimal temperature are

Au/Al/Si - $2.5 \times 10^{-4}\ cm^2$

Au/Al/Ti - $6.4 \times 10^{-5}\ cm^2$

Au/Al(30%)/Al(70%) - $1.4 \times 10^{-5}\ cm^2$

Palladium is also an another metal suitable for ohmic contacts to p-type semiconductors. The work function of Pd is 5.12eV. Pd forms silicide's by reacting with SiC at temperature of 500^0C which decreases barrier height. Now a days, Pd is widely used in SiC metal and gas sensors planning to operate at high temperatures. Earlier Palladium was found to be very appropriate metal for producing p-SiC ohmic contacts with low resistivity. Ohmic contacts for Au/Pd attains resistivity of $7.2 \times 10^{-4}\ \Omega cm^2$

After annealing at 600^0C, after that contact resistivity decreases with increase in temperature upto 850^0C and attains resistivity of $4.2 \times 10^{-4}\ \Omega cm^2$, after annealing at 700°C they become ohmic with high contact resistivity of $3.3 \times 10^{-3}\ \Omega cm^2$.

To create good quality of fabricated electronic devices we need appropriate metals which can be used as contact materials. To produce high power electronic devices that can work at high frequencies like MOSFET and MESFET, low resistance ohmic contacts are required and annealing is done at very high temperatures. Although we have very few options of metals with which we can produce both ohmic and Schottky contact devices.

Ni/Ti/Al triple layer can be used to produce Schottky contacts on n-type 4H-SiC at 800^0C. By using this combination, size of the devices can reduced and can have better fabrication process. [1]

Chapter-4

Results and Conclusions

In this thesis, through theoretical study of the metal contacts on Silicon carbide as semiconductor substrate. In starting we discussed the history of Silicon carbide and how it was produced with different techniques. SiC is a wide band gap semiconductor which actually improved the Technology behind electronics exponentially. First it was used as a semiconductor for producing LEDs in 1907 and after that many talks, researches and discussions were there on its use in the field of electronics but the main problem was the production as it was typical task to produce because of its rare presence on earth. And finally two Russians scientists discovered a technique for its manufacturing after that it came in use. SiC can be used as a semiconductor because it can work at extreme temperatures and at harsh conditions while other semiconductors like Silicon and Germanium were uncapable to do. Although, more than 250 types of its polymorphs has been found, but very few are in use in the field of electronics. Their applications includes in avionics, radars, space instruments, satellites, high power devices, geo thermal wells, etc.

Here in this thesis, we discussed its production in two parts first in bulk growth and then epitaxial growth which includes Chemical Vapor Deposition, Etching. Many elements can be contacted on the SiC surface as precursor but we found very few elements which gives good quality of semiconductor contacts and can be further divided in two parts -Schottky and Ohmic contacts.

Ohmic contacts are the contacts which give a straight line on graph of I-V characteristics while Schottky contacts does not. Here in this we discussed the methods for characterization of these contacts as it is important to know about the properties of of contacts formed. XRD technique has been discussed in this paper.

We found that Ti/ AL/ Ni and Pd contacts on SiC substrate offers better characteristics in durability and reliability to and offer better options to produce electronic devices with better properties.

Although the manufacturing of these contacts is not an easy task but can be completed with the help of annealing process and by some advanced techniques like ion implantation. Ion implantation technique is the most preferable technique now a days because it does not requires very very high temperatures and produces better quality of wafers. But we can test a multiple metallization stacts on the surface of Silicon carbide surface for the production of better devices that can work with more higher temperatures.

Now a days, there is no doubt that Silicon carbide has attracted the minds of Scientists for more research as it can give better results with some more modifications. It may have wide number pf applications in the sector of Aviation space and power module industries. As it is already discussed that Almost 30% of all electricity is lost in channeling, modification, distribution and conversion between power point and point of use, so to over come all these we need a better semiconductor where It has been found that SiC as semiconductor an fulfill all these needs as It offers high power densities, low energy losses and high breakdown strength. They are considered as third generation materials in the semiconductor industry after Silicon and Germanium.

Refrences:-

1. Muhammad Yousuf zaman; Modelling and characterization of metal/Silicon SiC interface for power device applications; Department of Applied Science and Technology in Politecnico di Torino; Dec 2012.
2. Lilyana kolaklieva and Roumen Kakanakov; ohmic contacts of high power and high temperature microelectronics; Central Laboratory of Applied Physics, Bulgarian Academy of Sciences, Bulgaria; December 2009
3. Krishna Chaitanya Kundeti; The properties of SiC Barrier Diodes Fabricated with Ti Schottky Contacts; Youngstown State university; May 2017
4. V. A. Izhevskyi, L.A. Genova, J. C. Bressiani, A. H. A. Bressiani; Review article: Silicon Carbide. Structure, Properties and Processing; Instituto de Pesquisas Energeticas e Nucleares, C. P. 11049,Pinheiros, 05422-970, S. Paulo, SP, Brazil; Ceramica vol.46 n.297 S$\tilde{a}$o Paulo Jan./Feb./Mar.20000
5. Zheng Huang[1], Tie-Yy L$\ddot{u}$[1], Hui-Qiong Wang[1,3] and Jin-Cheng Zheng[1,2,3,a)];thermoelectric properties of the 3C, 2H, 4H, and 6H polutypes of wide-band-gap semiconductors SiC, GaN, and Zno; AIP Advances 5, 097204 (2015);2015
6. Govindhan Dhanaraj, Balaji Raghothamachar M. Dudley;Growth and characterization of Silicon Carbide Crystals;Springer Handbook of Crystal Growth; January 2010.
7. K. L. Choy*;Chemical vapour deposition of coatings;department of materials, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2BP,UK.; October 2000.
8. Hitoshi Habuka; Etching of Silicon Carbide Using Chlorine Trifluoride Gas; October 2012
9. Mark Goorsky; Ion Implantation; May 2012
10. Christine M. Clark, Eastern Michigan University, Barbara L. Dutrow, Louisiana State University; Single crystal X-Ray diffraction
11. Fabrizio Roccaforte, Marilena Vivona , Giuseppe Greco ,Italian National Research council; metal/semiconductor contacts to silicon carbide;June 2018.
12. Tanner Web Rice; Ohmic contact metallization for Silicon Carbide in future Transportation and Aviation System; University of Arkanas; May 2020.
13. Siddarth G. Sundaresan, Mulpuri V. Rao, Yonglai Tian, John A. Schreifels, Mark C. Wood, Kenneth A. Jones and Albert V. davydov;Comparison of Solid-state microwave annealing with conventional Furnance annealing of Ion- Implanted SiC;2007.
14. Growth of SiC polytypes by the physical vapour transport technique; K Semmelroth, N Schulze1 and G Pensl ;6 April 2004
15. Investigation of SiC polytypes by Raman Spectroscopy; G. Chikvaidze1 , N. Mironova-Ulmane1 , A. Plaude1 , O. Sergeev2;July 2015.

16. Transmission electron microscopy-an overview; Rukari Tushar G, Alhat Babita R; 25/08/2013
17. Scanning Electron Microscopy (SEM)- A Review; Azad Mohammed, Avin Abdullah; January 2019