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A Review Study on Fundamentals of HEMT Device and Technology

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***Abstract*— This review paper includes review study of the fundamentals of HEMT device and technology. The working principle of the HEMT device has been explained. The major advantage of HEMT device is high mobile electrons concentration in the channel. The various semiconductor materials properties such as InP and GaN also explained briefly. InP is one of the useful materials for optoelectronics and electronic devices. Due to wide band gap, high thermal stability and high critical field, the GaN-based material system are very attention-seizing for electronics domain application.**

Keywords*— HEMT, Heterojunction, High Electron Mobility Concentration, InP, GaN.

I. INTRODUCTION

HEMT stands for High Electron Mobility Transistor. HEMTs are one of the most encouraging devices for millimeter and sub-millimeter wave application. HEMT device offers high electron mobility concentration. It works on much lower noise. Explosive research is done on HEMT device. The different type of semiconductor material system has been searched. The structure of HEMT consists PN junction. It is known as heterojunction. It consists of a junction of different band gaps materials. This heterojunction contains a doped wide band gap energy material. It also contains an undoped narrow energy band gap material. The most common materials used in HEMT device are Aluminium Gallium Arsenide (AlGaAs) and Gallium Arsenide (GaAs). The major advantage of Gallium Arsenide is it offers a high electron mobility. Silicon is not used because it has low electron mobility. The principle of HEMT device is the heterostructure with modulation doping. HEMT device forms a junction between two different band gaps materials as the channel which is used in the standard MOSFET. This junction is called heterojunction. The HEMT is also known as a heterojunction FET. Initially most common material used in manufacturing of HEMTs device was GaAs (Gallium Arsenide). After that InP(Indium Phosphide) was started using in HEMT based device. Now a days GaN(Gallium Nitride) based HEMT device are commonly used. In this review paper, the fundamentals of HEMT device and technology have been discussed. Section II describes the principle of HEMT device and Technology. Section III describes overview of HEMT device. Section IV describes the material system used in HEMT devices and summary have been discussed in section in V. In the last reference are given.

II. PRINCIPLE OF HEMT

The basic principle of HEMT is the heterojunction with modulation doping. This heterojunction is formed by different band gaps semiconductor. A doped material having wide band gap and undoped material having narrow band gap forms heterojunction. The wide band gap material has surplus amounts of electrons in conduction band as it is doped with donor atoms. The narrow band gap material has conduction band material as it has states with lower energy. Therefore, electrons will diffuse from wide band gap material to the adjacent lower band gap material where they occupy a lower energy state. Due to movement of electrons potential is changed and there are produced an electric field. This electric field drifts electrons back to the conduction band of the wide band gap material. The drift and diffusion process continue until they create equilibrium junction like p-n junction.

III. HEMT DEVICE OVERVIEW

The major advantage of HEMT device is high mobility electrons concentration over the channel. The high electron mobility is due to the formation of heterojunction. The heterojunction is formed by material having different gaps.

A HEMT device has epitaxial material layer. The material layer of device has different types of layers as- a cap layer, a barrier layer, a spacer layer, a channel layer, buffer layer, and substrate from top to bottom respectively. Substrate is formed during wafer growth. Two common methods are used for the epitaxial material growth. They are Metal Organic Chemical Vapor Deposition (MOCVD) and Molecular Beam Epitaxy (MBE).

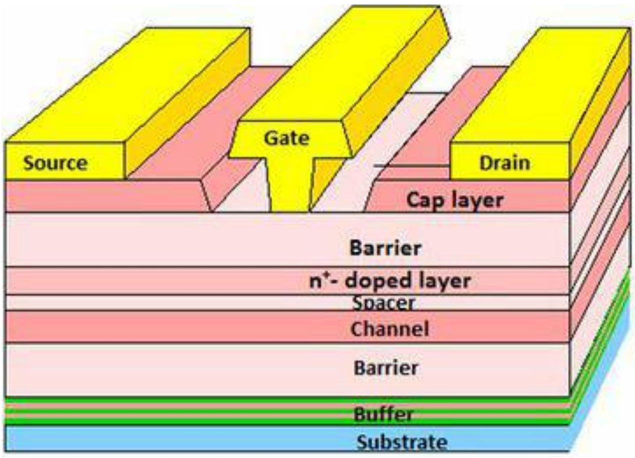

Figure 1: A general structure of HEMT

The layer of the HEMT device is as following:

Cap Layer- Top of the barrier contains the cap layer. This thin layer prevents the epitaxial layer so that oxidation of epitaxial layer cannot occurred. The cap layer is thin and highly doped. It makes possible the contacts of the source and drain of the device with low contact resistance.

Barrier Layer- Barrier layer is responsible for HEMT device performance. This layer is formed by wider band gap semiconductor material than the channel layer. Free electrons diffuse from barrier region to channel region. Thus, due to movement of electrons a change in potential occurs and an electric field will be induced. This electric field drifts electrons back to the conduction band of the wide bandgap element. The drift and diffusion processes remain continue until they create equilibrium junction like p-n junction.

Spacer Layer- The same material is used in spacer layer as the barrier layer. This layer separates the 2DEG from ionized donors at the heterointerface. The performance of HEMT device depends upon the thickness of spacer layer because it increases the mobility of electron.

Channel Layer- Channel layer is formed by the lower band gap semiconductor material than the material used in barrier layer. This layer is generally semi-insulating. It ensures proper drain-source saturations current, complete channel pinch-off and low loss at high frequencies.

Buffer Layer- Buffer layer prevents cracking due to the lattice mismatch between the substrate layer and the channel layer. Buffer layer offers a certain degree of heat spreading.

Substates- In growing process, substrate is used as a base. HEMT have various types of substrates as- GaN substrates, SiC substrates and silicon substrate.

Three metal contacts source, gate and drain are made to the top of the cap or barrier layer.

IV. THE MATERIAL SYSTEMS FOR HEMTS

1. InP Based HEMT

Many of the applications with High-Speed need devices which have higher power, higher efficiency and higher linearity at multi wave frequencies and above. In this field the iii-iv compound semiconductors and the alloy of these semiconductors have been studied and tested various band properties such as breaking of the spin-orbit or energy band gap and to examine the optical effects such as energies of critical point and optical dispersion relation. Indium phosphide (InP) is material that is attractive in nature in the optoelectronics and devices such as HEMTs, the photo-detectors, the laser diodes, and the solar cells. The merit of devices which are InP-based is high carrier densities, high saturation velocity, and high electron mobility at the room temperature. The main significant in increasing the devices that are InP-based are MOSFET and HEMT using various techniques like material, sourced/drain and gate engineering methods.

1.1 Material Properties

High operating frequency of a device is affected by material of device. Materials those have high electron mobility like InAs, GaAs and their alloys provide high transport carrier properties to channel materials. To select the barrier layer leakage current must be less and capacitance must be large. To obtain large gate capacitance there is taken high-k with suitable barrier layer thickness. A wide band gap material is suitable to decrease the leakage current.

1.2 InP HEMT Device Performance

InP based HEMT provides high transport properties. InP HEMT provides low noise and high cut-off frequency. Performance of high frequency device depends upon the length of gate. This type of device is also used in millimeter-wave technology.

2. GaN-based Semiconductor

Wide-band gap Gallium Nitride (GaN)-based semiconductor material systems are resisted in the focal point of attentiveness of this work. GaN has grab the awareness as the highly favored material system for two applications electronic and optical because GaN is evolved in the early 1990s. From every corner of the globe the experimenters have made efforts to shift the potential to commercialization of twenty-five years. Due to the large band gap, highest thermal stability, highest critical field and good properties of transport. GaN-based material system are very attracting attention for electronics applications.

2.1 GaN Physical Properties

GaN belongs to III-V group. Ga belongs to III group while N belongs to V group. Zinc blend has cubic crystal structure and Wurtzite has hexagonal crystal structure. These crystal structure may be differed by GaN crystal structure as shown in Figure 2 and Figure 3. The cubic and hexagonal phase have small energy difference. The stacking sequence of close-packed III-N planes differ the cubic and hexagonal phases. GaN HEMT are grown on the Wurtzite phase. The Wurtzite has hexagonal structure. The structure has three lattice constants: a, c and 2 sub lattice u. Here a is the length of the side hexagonal base and c is the cell's height. These parameters have ratio c/a = 1.633 and u/c = 0.375. Here atoms are considered these are touching hard spheres.

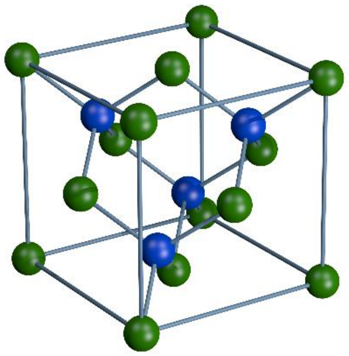

Figure 2: Zinc blend's cubic crystal structure

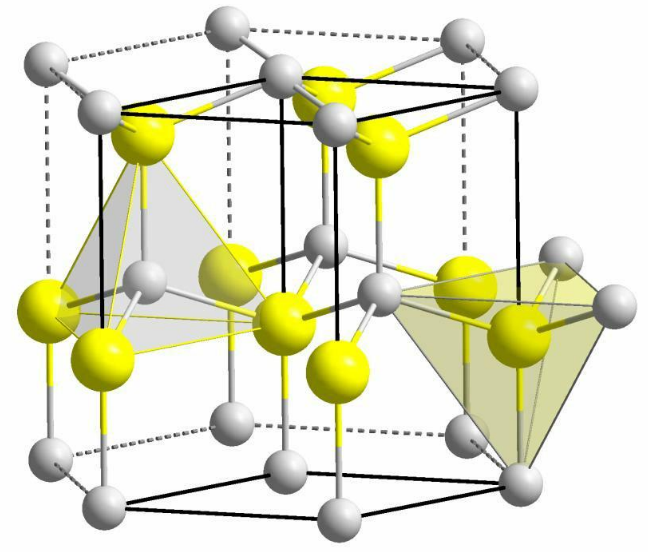

Figure 3: Wurtzite's hexagonal crystal structure

The Wurtzite structure is stable at room temperature. It contains spontaneous polarization field. Gallium Nitride has high ionicity of the metal-nitrogen covalent bond due to difference in electronegativity between the Gallium atom having 1.81 electronegativity and the nitrogen atom having 3.04 electronegativity. GaN semiconductor exhibit strong polarization because of this electronic charge. This polarization is said to spontaneous polarization. GaN and its alloys exhibit piezoelectric properties due to spontaneous polarization. The polarization strength is changed due to change of ideal lattice parameter of the crystal structure when stress is applied to GaN and its alloys. This type of polarization is called piezoelectric polarization.

2.2 Carrier Velocity in GaN-based Material Systems

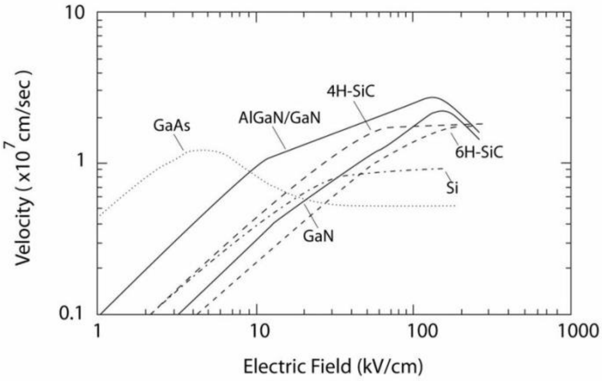

Figure 4: v-E characteristics

The movement of charge defines the current. Current is represented as the product of transport velocity and charge density. Thus, DC and RF current depends on charge carrier velocity. They are also depends on electric field in semiconductor. DC and RF current flow in semiconductor directly. To obtain high frequency and high current density there are required high saturation current and high carrier mobility. For high saturation velocity band gap of material must be wide. The electron velocity and electric field characteristics is shown in Figure 4.

V. SUMMARY

In this review paper fundamentals of HEMT device have been discussed based. HEMT device offers high electron mobility electron mobility concentration. It works on much lower noise. The principle of HEMT device is the heterostructure with modulation doping. HEMT device forms a heterojunction. The heterojunction is formed by material having different gaps.

The structure of HEMT device has different type of layers. The top of the barrier contains the cap layer. It is very thin. The performance of HEMT device depends upon barrier layer. Spacer layer is formed by same material that is used in barrier layer. HEMT structure has also channel layer, Buffer layer and substrates. Buffer layer prevents from cracking.

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