III- V COMPOUND HBTs and HEMTs

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***Abstract*— The new generation transistors such as HBTs and HEMTs offer some advantages over the former transistors. The transistors are made of compound semiconductors that provide features such as high frequency and high-power density. III-V compound are very common to fabricate these transistors. III-V compound HBTs and HEMTs are used at high frequency RF operations and high-power applications. Nowadays, the transistors are taking place of BJTs and MOSFETs at some applications.**

I. INTRODUCTION

From the past to present, a lot of semiconductors are used to manufacture discrete devices or integrated circuits. Thus, the electronic devices are based on the different semiconductors with different manufacturing technology. In addition, the semiconductors have different physical properties such as band gap energy, lattice constant, intrinsic carrier numbers, and they are processed to make them use at different operations.

Up to now, the silicon is very common at semiconductor manufacturing thanks to abundance and ease of manipulation. [1] However, in situation of need of high speed and high power, silicon fails to satisfy the conditions. At this point, compound semiconductors come into play. Compound semiconductors are semiconductors that are made of more than one semiconductor. Most common compound semiconductors are Group III -V combinations such as Gallium Arsenide, Gallium Nitride, Gallium Phosphide, Indium Phosphide. The compound semiconductors give better transportation characteristic and higher operation speed. Therefore, high speed transistors such as HBTs and MODFETs are made of the compound semiconductors. In addition, they offer large breakdown voltages and high operation temperatures. Thus, high power and high temperature devices such as HEMTs are made of them. [1]

Nowadays, HBTs are taking place of BJTs. HBTs offer some features such as higher frequency and speed that are not provided by homojunction BJTs. HEMTs are taking place of Mosfets. HEMTs offer some features such as higher breakdown and power at high frequencies that are not provided by the Mosfets.

II. HETEROJUNCTION BIPOLAR TRANSISTOR

A. General Definition of the HBTs

Heterojunction bipolar transistor is a kind of BJT with different type of semiconductor at base and emitter. The motivations of development HBTs are enabling to operate at higher speed and higher cut-off frequency. The advantages are related to materials that are used at base and emitter, and difference of bandgap energy is important to determine features of the devices.

B. Device Structure and Specification:

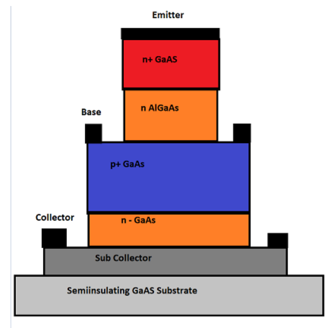

Figure 1 Physical Structure of HBTs

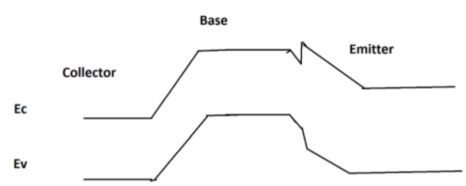

Figure 2 Energy Band Diagram of HBTs

The device structure and energy band diagram are illustrated basically at Figure1 and 2.

The device structure is similar to homojunction BJTs. However, materials of emitter and base are different, and HBTs have advantages over the BJTs in respect to wide band gap emitter. Also, doping process type affects the performance and specification.

Basically, the current gain and the cut-off frequency can be related to material and doping. For the homojunction BJTs, the current gain depends on doping level, length and diffusion coefficient of emitter and base. [1]

$$\beta = \frac{Dnb\ npb\ Lpe}{Dpe\ pne\ Wb} \qquad \text{Formula 1}$$

Large current gain requires that emitter doping is much bigger than base doping with respect to Formula 1. However, smaller base doping increases the base resistance. Thus, the bigger current gain causes the smaller cut-off frequency.

Considering HBTs, the current gain depends on difference of band gap energy between emitter and base(

Formula 2). Thus, both current gain and cut-off frequency can be bigger at the same time. [4]

$$\beta \propto e^{\frac{\delta Eg}{kT}} \qquad \text{Formula 2}$$

C. Comparison of HBTs and BJTs:

HBTs will be place on BJTs thanks to some advantages over the BJT.

The main advantages of the HBTs over BJTs[1]:

- Low base resistance
- Low forward transit time
- Low collector capacitance
- Higher efficiency
- Wide band Impedance matching [16]

The advantages provide that HBTs are used at region that is required high power and high speed.

D. APPLICATIONS:

CMOS technology is dominant at digital circuits because of static power consumption of the Homojunction BJTs. Thus, homojunction BJTs came into smaller market at digital circuits. However, HBTs are faster and less power-hungry over BJTs, so it is good for using digital applications although homojunction pairs are not used for digital circuits in general. Besides, HBTs can operate at higher frequency and higher temperature with high power. It makes it so attractive to be used at analog circuits. In short HBTs have important roles at both digital and analog circuits by offering high speed and high power. [11]

HBT provides higher frequency and lower base resistance. It is used at high power efficiency and high frequency applications for microwave circuits up to several hundred GHz. In addition, analog and digital HBTs can be manufactured on the same wafer. So, the integration of multifunction circuit made HBTs more applicable at digital signal processing at microwave frequencies. [2]

Besides, HBT provides with high power density and efficiency. Thus, it was in race with other transistors like PHEMT and HFET. However, the high power is required to high reliability and HBT did not proof its reliability at industry. Thus, HBT technologies are used at medium power systems at high efficiency. [3]

III. HIGH ELECTRON MOBILITY TRANSISTORS

A. General Definition of the HEMTs

High electron mobility transistor is a kind of field effect transistor. HEMT offers to operate at higher frequency with lower noise. Also, it has high gain and it can be used for the amplification. The main advantages of HEMTs over the Mosfets are high electron velocity and high breakdown electric field.

B. Device Structure:

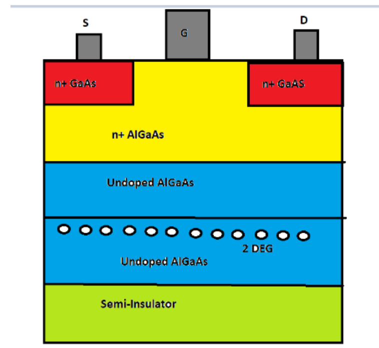

Figure 3 Physical Structure of HEMTs

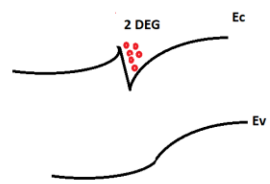

Figure 4 Energy Band Diagram of HEMTs

The device structure and energy band diagram are illustrated basically at Figure 3 and 4.

Large band gap material is contacted with lower intrinsic material. The large band gap material is heavily n-doped. The electron diffuses from large bang gap material to other. At contact, the quantum well is created. So, electrons are apart from impurity and mobility of electrons increases. [1] Thus, HEMT has higher electron mobility and large transconductance.

C. Advantage of the HEMTs

Hemts will take place of the Mosfets and Mesfets thanks to some advantages.

- High electron mobility
- Higher gain
- Lower noise
- Up to 100 Ghz frequency (GaAs/ AlGaAS)
- Higher efficiency
- Small on resistance
- High output resistance
- Higher transconductance

These provides that HEMTs are used for high power and high efficiency operations.

D. APPLICATIONS:

HEMTs application area is broad from the RF and communication to high power. HEMTs can be used where high gain is needed with high frequency such as communication, radar and imaging.

. GaAs HEMTs are used for microwave applications and radar applications because of the high gain at frequencies higher than 1Thz

GaN is wide bandgap semiconductor and HEMT based on GaN is used at high temperature, high efficieny and high power density applications. GaN Hemt will replace the SiC mosfets because of its properties. GaN Hemt has bigger electric field, electron velocity, energy bandgap, thermal conductivity. Also, GaN Hemt is found as reliable by the industry and academy. [5][6]

E. CONCLUSION

III-V Compound HBTs and HEMTs are taking place of the BJT and Mosfets because of the physical properties and enabling the broad operation condition.

HBTs are more advantageous over the BJT in respect to higher frequency and efficiency. Thus, HBT can be used for digital circuits and analog RF circuits.

HEMTs are more advantageous over the Mosfets with respect to higher breakdown voltage and higher frequency. Thus, HEMTs can be used at high power RF circuits and power applications.

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