A Comparative Study on Different Semiconductor Materials used for Power Devices and Its Applications

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***Abstract*: - It is interesting to note that the modern technology evolution in power electronics has generally followed the evolution of power semiconductor devices, constitute the core of recent power electronic device. They are used in power electronic converters in the form of a matrix of on-off switches, converters are widely used in applications such as heating and lighting controls, ac and dc power supplies, electrochemical processes, dc and ac motor drives, static VAR generation, active harmonic filtering, etc. Although the cost of power semiconductor devices in power electronic equipment may hardly exceed 20–30 percent, the total equipment cost and performance may be highly influenced by the characteristics of the devices. Power devices require a high blocking voltage in the off state, a low forward voltage drop in the on state and a sensibly high maximum operating frequency. An engineer designing equipment must understand the devices and their characteristics thoroughly in order to design efficient, reliable, and cost-effective systems with optimum performance.. The expansion of microelectronics has greatly contributed to the knowledge of power device materials, processing, fabrication, packaging, modelling, and simulation**

***Keywords:* Gallium arsenide (GaAs), silicon (Si), silicon germanium (SiGe), Gallium Nitride (GaN).**

I. INTRODUCTION

Gallium arsenide (GaAs) is a composite of the two elements, gallium and arsenic. It is a fundamental composite semiconductor material and forms the core substrate for semiconductor technology. The abundance of consumer communication products such as digital mobile phones, personal communication systems, GPS navigation units , satellite and fiber optic communications and wireless networks have driven demand for semiconductor devices manufactured with GaAs. Semiconductor technology devices based on GaAs circuitry are a key element of many wireless and wi-fi consumer electronic products. Some electronic properties of gallium arsenide are advanced to those of silicon. It has a higher saturated electron velocity and higher electron mobility, allowing gallium arsenide transistors to function at frequencies in excess of 250 GHz. GaAs devices are moderately insensitive to overheating owing to their wider energy band gap and they also tend to produce less noise in electronic circuits than silicon devices, especially at high frequencies. This is a effect of higher carrier mobilities and lower resistive device parasitic.

II. SEMICONDUCTOR AND APPLICATIONS.

Power devices require a high blocking voltage in the off state, a low forward voltage drop in the on state and a sensibly high maximum operating frequency. These three characteristics make conflicting demands on material properties. Conductivity modulation requires a long minority carrier lifetime which reduces the maximum operating frequency most power devices are made in silicon. The technology of silicon device manufacture is well established so improvements in performance usually result from novel device design. This usually increases process complexity and hence the device cost. An alternative approach is to use a different semiconductor with better material properties. Gallium arsenide is an obvious candidate as, compared with silicon it has:

1. A higher electron mobility, allow lower on-state resistance
2. Larger bandgap so higher operating temperatures are likely (although this increases the built in junction potential).
3. A direct bandgap, so minority carrier lifetime is shorter allowing a better dynamic response and the possibility of energy dissipation via radiative band-to-band transitions.
4. A higher critical field strength allowing a thinner structure to be used for a given breakdown voltage.
5. Easy implementation of a hetero junction technology which should improve current handling capability.

The most admired semiconductor materials used in the manufacture of RF components—particularly power amplifiers—are silicon (Si) and gallium arsenide (GaAs). Silicon devices are naturally much cheaper to manufacture than gallium arsenide compounds. Unfortunately, silicon-based RF devices typically don't work as well as GaAs for most high-frequency or for high-power applications. Two exceptions include silicon-based lateral double-diffused MOSFET (LDMOS), a version of power MOSFETs, which are used as high-powered amplifiers (100W and up) in wireless base station applications.

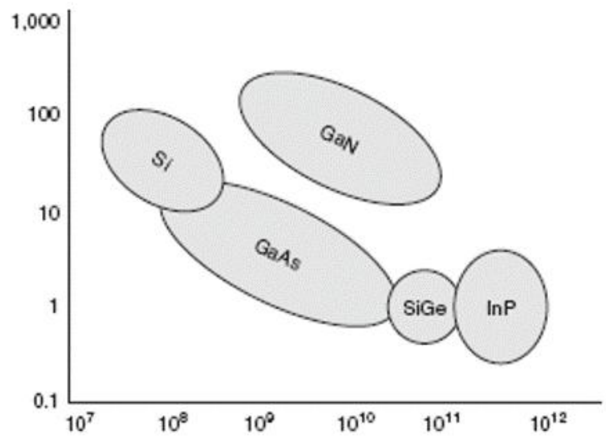

Figure1. RF Power Vs Frequency for RF power Semiconductor devices

Silicon germanium is another silicon-based device that can exceed the presentation of GaAs devices, though only in low-power, high-frequency applications, such as in the front-end design of mobile phones (see Figure 1). SiGe power amplifiers provide better linear performance and better power efficiency over GaAs. Better efficiency, combined with the lower cost of silicon manufacturing, has made SiGe more popular in recent years.

In addition to silicon germanium (SiGe), more than a few relatively newer semiconductor compounds are ahead acceptance by RF engineers (Table 1). The first is indium phosphide (InP), which provides exceptional low noise performance at very high frequencies, especially in the millimeter wave range (>40 GHz). Also, InP power amplifiers work well at higher frequencies, though are more expensive to make than SiGe.

Semiconductor	Application
Silicon (Si)	VLSI, Power Amplifiers
Gallium Arsenide (GaAs)	RF, Microwave, MM-Wave
Silicon Germanium	Mixed Signal, DSP, RF, Microwave, MM-Wave
GaN	RF and Microwave amplifier

Table1.Semiconductor compound and applications

Gallium Nitride (GaN) compounds hold great promise for high frequency, high power amplifiers (100W and up) for wireless transmitters. When combined with RF receivers in mobile phones, GaN amplifiers could enable the direct assess of communication satellites. The benefit of GaN devices is its high power density, which is many times that of GaAs or InP. The main difficulty of GaN (as with all gallium-based compounds) is one of high manufacturing expense.

III. SEMICONDUCTOR DEVICE CHARACTERISTICS OF GaAs

Why Gallium Arsenide?

Generally, to achieve high currents and high frequency operation, high charge carrier mobility (μ) and high saturation velocity (V_{sat}) are desirable. The high value for electron mobility of GaAs is the main reason that field-effect transistors (FETs) fabricated from this material have such excellent high-frequency performance.

3.1 Electron Velocity-Field Behaviour

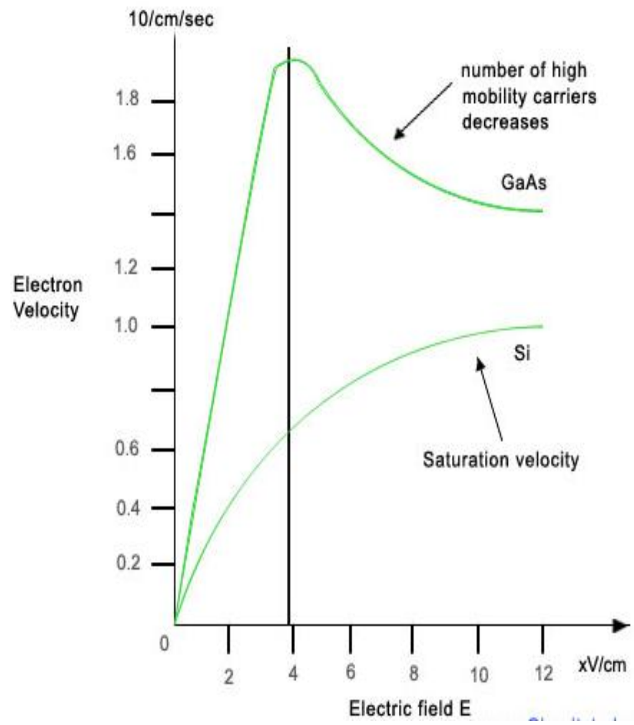

Figure 2.Electonic velocity v/s Field Behaviour

The charge carriers in the GaAs material that is the electrons will obtain energy as soon as an electric field [E] is applied. When the energy is obtained from the field, the electrons will also lose certain quantity of energy due to collisions that occur due to optical photon scattering with the lattice. Thus, due to the in advance and losing of energy, the resultant balance will either be positive or negative. If it is positive, an increase in the applied field will cause a rapid increase in the energy and drift velocity of the charge carriers. Sometimes the resulting balance will be equal, that is the energy gained from the applied field will become equal to the energy lost due to collision. This will cause the drift velocity to reach a limiting value, known as the saturation velocity, V_{sat} .The region where the hot electrons occupy an upper conduction band, the drift velocity will no longer be proportional to the electric field as shown in the figure 2.

3.2 Energy Band Structure

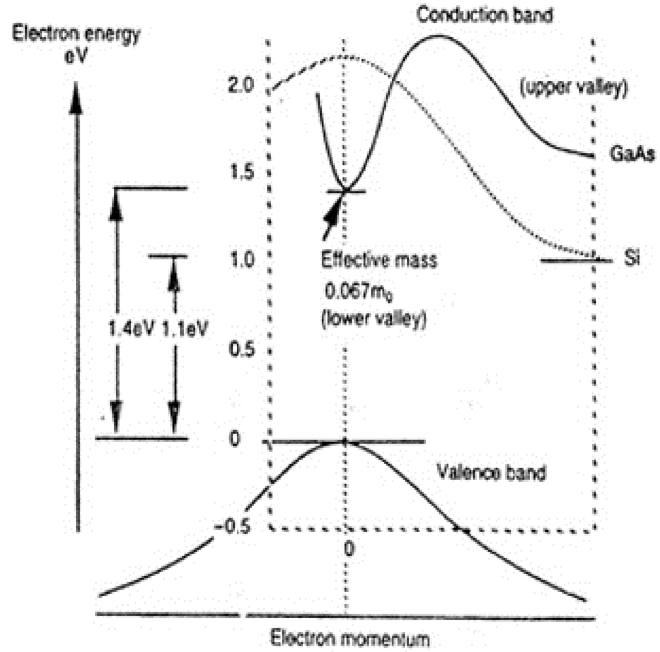

Figure 3.Electronic Energy V/s momentum

One of the significant characteristics i.e. attributed to GaAs is its finer electron mobility bring about as the result of its energy band structure as shown in the figure. GaAs is a direct gap material with a maximum valence band and a minimum conduction band and is supposed to coincide in k-space at the Brillouin zone centres. In the graph shown figure3, we can see that the some valleys in the band structure are narrow and some are sharply curved. These curves and narrows differ corresponding to the electrons with low effective mass state, while valleys that are wide with gentle curvature are characterized by larger effective masses. The curvature that is seen in the graph of the energy versus electron momentum profile clearly shows the effective mass of electrons travelling through the crystal. The minimum point of gallium arsenide's conduction band is near the zero point of crystal-lattice momentum, as opposed to silicon, where conduction band minimum occurs at high momentum. Now, mobility, μ, depends upon

- Concentration of impurity, N
- Temperature, T
- And is also inversely related to the electron effective mass, m.

IV. METAL SEMI-CONDUCTOR FET (MESFET)

The gallium arsenide (GaAs) field-effect transistor (FET) is a bulk current-conduction majority-carrier device. This device is fabricated from bulk gallium arsenide with the help of high-resolution photolithography as well as ion implantation method into a semi-insulating GaAs substrate. The processing of this device is very simple as it does not need more than 6 to 8 masking stages. The figure 4 is used to compare the complexity in processing the device with the number of masks in the Y-axis and the function of time for both silicon and gallium arsenide technologies in the X-axis.

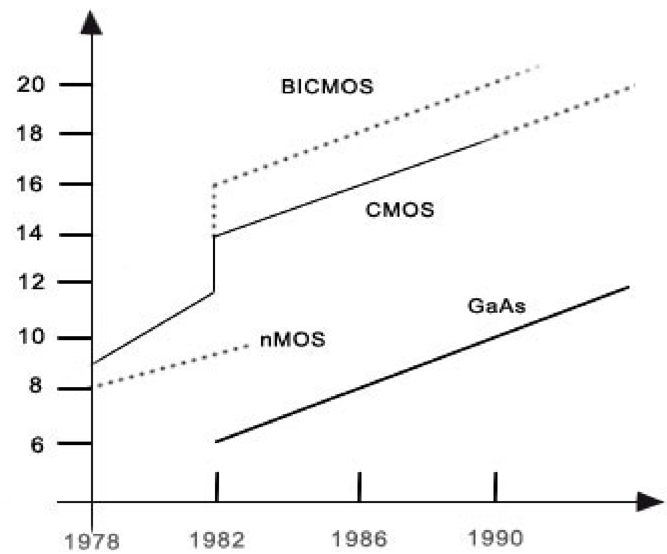

Figure 4. Mask Rate v/s Year

The structure of the basic MESFET as shown in the figure 5 below is very simple. The MESFET has a thin n-type active region which is used to join the two ohmic contacts. A thin metal Schottky barrier gate is used to separate the highly doped drain and source terminals.

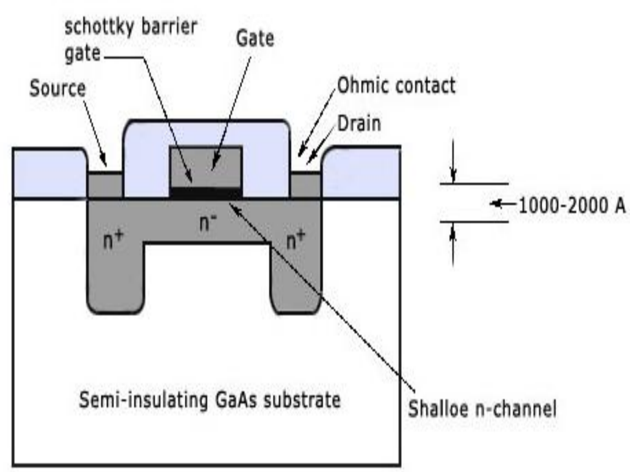

Figure 5. MESFET Structure

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