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CONFERENCE PAPER

STUDY AND EVALUATE THE CHARACTERISTICS OF GALLIUM NITRIDE: THE NEXT GENERATION SEMICONDUCTOR

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Abstract

In contemporary society, semiconductors have emerged as an essential component in the daily lives of individuals, given their integral association with fundamental necessities such as internet connectivity,electrical power provision,and computational capabilities. The predominant semiconductor material in use at present is silicon. Its economic advantages during the initial phases of development resulted in a significant lag for alternative semiconductor materials. However, as semiconductor fabrication has advanced to nanoscale dimensions and even 3-nanometer technology, the limitations intrinsic to silicon semiconductors have become increasingly pronounced. As silicon transistor dimensions continue to diminish, quantum tunneling phenomena, including leakage current and gate leakage current, have led to a persistent escalation in power consumption. In addition, the silicon fabrication process necessitates stringent conditions, such as high vacuum, elevated temperatures, and multiple procedural steps, thereby exacerbating production costs and process complexities. Consequently, researchers have directed their aspirations towards the next-generation semiconductor material, gallium nitride (GaN), as a viable substitute for silicon.Due to its superior characteristics, including a wider bandgap, enhanced electron mobility, and improved thermal conductivity, gallium nitride (GaN) presents promising avenues for addressing the limitations associated with silicon-based semiconductors. Keywords: Semiconductor, transistor, gallium nitride.

Introduction:-

During 1st decade of 21st century the MOSFET Manufacturers face a drawback with SiO_2 that the leakage current is very high when the oxide thickness is 30nanometer.This leakage current causes production of more heat which raises temperature of the chip. Due to this rise in temperature further higher density of integration of components faced a very acute problem then a suitable alternative semiconductor is its solution.

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Gallium compounds were in lime light. Finally the Gallium Nitride (GaN) found to be its solution due to its following properties and qualities.Gallium Nitride (GaN) is a very hard and mechanically stable semiconductor. With a wide bandgap of around 3.2 eV, it offers a much higher breakdown strength, faster switching speed, higher thermal conductivity and lower resistance than silicon based equivalents with bandgaps of around 1.12eV.Gallium Nitride (GaN) is a wide-bandgap (3.4 eV) semiconductor material offering superior performance over silicon in high-power, high-frequency, and high-temperature applications. GaN chips are up to 100 times faster, smaller, and more efficient, enabling significantly reduced power loss, lighter weight power supplies, and robust performance in defense, space, and consumer electronics.

Key Characteristics and Advantages:-

The advantages of gallium nitride (GaN) in physical properties:-

- **Wide bandgap** "GaN has a wider bandgap compared to silicon, which allows it to operate at higher voltages, temperatures, and frequencies. This advantage stems from GaN's unique properties: as mentioned earlier, it is a direct wide band-gap semiconductor, typically crystallizing in the wurtzite structure.
- **Higher thermal conductivity** GaN has better thermal conductivity, which helps in efficient heat dissipation and allows for higher power density
- **High Efficiency & Power Density:** GaN enables smaller, lighter power systems with significantly higher power efficiency compared to silicon, reducing power loss by over 80% in some converters.
- **Faster Switching Frequency:** GaN components can operate at significantly higher frequencies than silicon, resulting in smaller, more efficient components.
- **Wide Bandgap (WBG):** The 3.4 eV bandgap of GaN allows it to withstand higher electric fields, higher temperatures (up to 1,000°C), and harsh environments, making it ideal for aerospace and defense.
- **Low Power Consumption:** GaN power supplies have significantly lower no-load power consumption (approx. 110 mW vs. 1.2W in Si).

Applications of GaN Technology:-

- **Consumer Electronics:** Faster, more compact phone and laptop chargers.
- **Power Supplies:** High-efficiency power converters, especially for data centers and electric vehicles.
- **Defense & Aerospace:** Used in radars, missiles, fighter jets, and satellites due to high power handling and reliability.
- **Medical & Emerging Tech:** Wireless power for implants, tiny medical imaging pills, and high-resolution MRI machines.

Industry Development:-

- **Commercialization:** Companies like Navitas Semiconductor pioneered high-voltage GaN power ICs, while EPC Co focuses on wide bandgap technology advantages.
- **Geopolitics:** India has recently developed indigenous GaN chip technology for defense applications, reducing reliance on external suppliers.

GaN vs. Silicon:-

Features	**Gallium Nitride(GaN)**	**Silicon(Si)**
Bandgap	3.4eV	1.1eV
Breakdown Voltage	Higher	Lower
Switching Speed	Up to 100x faster	Moderate
Thermal Conductivity	High	Lower
Device Size	Smaller & Compact	Larger
Efficiency	Superior	Standard

GaN surpasses traditional silicon by providing faster switching, lower resistance, and superior thermal management. While Si is limited to lower temperatures and frequencies, GaN is efficient in high-density computing (e.g., AI), with potential to reduce carbon emissions by saving 100+ TWh in data center energy by 2030.

Inter Molecular Crystalline Structure of GaN:-

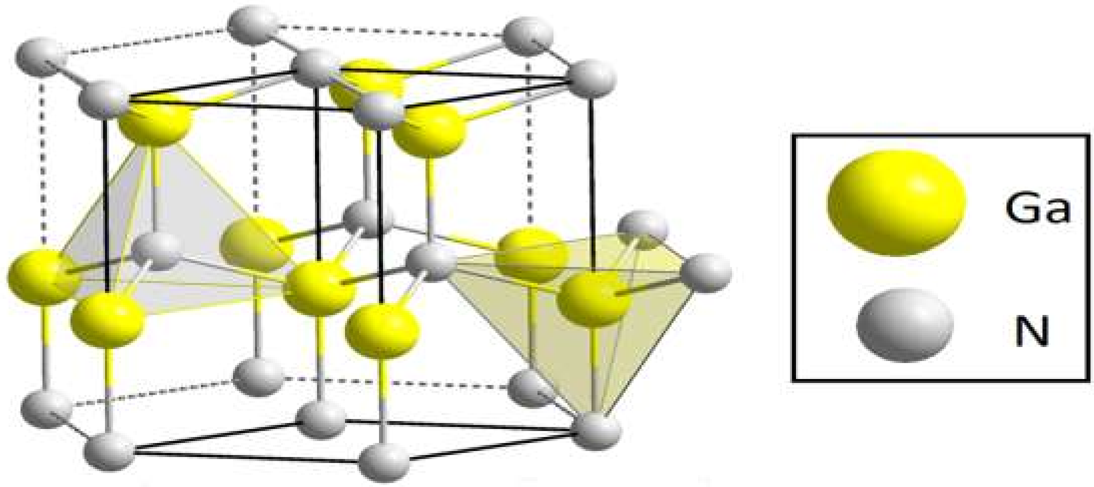

Figure 1: GaN structure courtesy Google.

Many experts even predicted that it would take a long time before these industries could recover from the scarcity of silicon. However, many companies are now using Gallium Nitride(GaN). GaN is smaller, more efficient, and eco-friendly than silicons. It is also faster and easier to make. GaN semiconductors are better suited in gadgets used in more complicated environments because they can survive higher temperatures. GaN is creating an innovative change and ripple effect in the electronic and technology world. And even though silicon chips are a vital part of gadgets that turn energy into power, it is slowly but surely being replaced by GaN. GaN is made of Gallium with an atomic number of 31 and Nitrogen with an atomic number of 7. GaN is a binary wide bandgap semiconductor. It is more compatible with transistors with very high power and temperature. GaN is also used in lasers, semiconductor power gadgets, etc. Though GaN has been used since the 1990s, it was enhanced in 2006, allowing GaN transistors and silicon to be produced in factories with the same process. The only difference is GaN is cost-effective and has better performance than silicon.

All about the GaN Technology:-
All semiconductors have a bandgap, but they are always different. Bandgap determines how well a semiconductor can conduct electricity. For example, GaN's bandgap is 3.4eV while Silicon's own is 1.2eV.This difference in bandgap means that GaN transistors can carry higher temperatures and voltages than transistors made from silicon. It also means when silicon transistors reach their limit, GaN transistors are just getting started. This makes GaN better suited for devices with high frequencies and power.Although they are smaller in shape than silicon transistors, GaN transistors can conveniently handle more expansive electric fields than silicon while having faster and better switching.GaN technology is becoming popular because they offer better output and performance. In addition, GaN technology reduces the space and human resources needed to provide output and performance. They can also be used in a variety of products.It is estimated that by 2030, A Silicon to GaN data center upgrade will reduce the loss of energy by 30% to 40%. This translates to saving over 125Mtons and 100TWhr of $CO2$ emission. This will be possible because GaN semiconductors have a 10x carbon footprint than silicon chips.In addition, as GaN technology improves, it will become more cost-effective and has better performance than silicon. As a result, there is a high possibility that GaN transistors will displace silicon transistors in the future.

Working Principle of GaN Semiconductor Technology:-
GaN semiconductors are used in integrated circuits and power transistors to achieve high efficiency. A thin layer of Aluminium Gallium Nitride is grown on top of a Gallium Nitride(GaN) crystal. A strain that produces a 2DEG (Two-dimensional Electron Gas) is created at the interface.When an electric field is introduced, this highly conductive 2DEG is used to conduct electrons efficiently. The 2DEG is highly conductive because the electrons are confined to a small space at the interface.This leads to the electrons increasing their mobility from around 1000cm^2/Vs to between 1500 and 2000cm^2/Vs. And because of the electrons' high mobility, GaN integrated circuits and transistors have better strength, thermal conductivity, resistance, and faster switching momentum. GaN

RF devices are being used for better transmission in laptops, phones, and Wi-Fi. GaN is also used in adapters and chargers to power them. Its semiconductors are also being used in data server centers. They are being widely used in different applications. This shows how flexible and dynamic they are.

The advantages of Gallium Nitride (GaN) in manufacturing costs:-

- **Simpler manufacturing process:** Compared to the complex multi-step manufacturing process of silicon semiconductors, GaN devices can be fabricated using fewer and simpler steps. The process of producing silicon transistor contains 1) Purifying natu-ral silicon using the Siemens process or other methods. 2) Cutting silicon ingots into thin slices to form silicon wafers, and performing chemical-mechanical polishing on the surface of the silicon wafers to ensure a flat and smooth surface. 3) Growing a layer of silicon dioxide (SiO_2) film on the surface of the silicon wafer as an insu-lating layer, and doping with impurities through diffusion or ion implantation to create n-type or p-type regions. 4) Photolithography. 5) Dry etching or wet etching: Remov-ing unwanted material according to the photolithography pattern to form the desired structure. 6) Thin film depo-sition and structure formation. 7) Cutting and packaging. 8) Testing and sorting. As chip manufacturing processes become more refined, both the production costs and the number of steps for silicon semiconductors tend to in-crease.
- **Lower thermal budget:** GaN devices can be grown at lower temperatures, reduc-ing the energy consumption and costs associated with high-temperature processing. GaN devices can be grown at lower temperatures. Although GaN can be grown by epitaxial deposition at high temperatures (above 1000°C), which is much higher than the growth temperature for silicon, recent advancements have enabled lower tempera-ture growth processes for GaN devices. This enables the formation of higherquality crystal structures and reduces the density of defects. In multilayer structures, a lower thermal budget can protect the underlying materials from damage due to high temperatures, preserving their perfor-mance.
- **Compatibility with existing infrastructure:** GaN can be integrated with the existing silicon manufac-turing infrastructure, leveraging the existing investment and expertise. New GaN technologies can utilize existing equipment and processes, reducing upgrade or replace-ment costs.
- **Potential for monolithic integration:** GaN devices can be integrated monolithically, potentially reducing the overall system cost and complexity. Mono-lithic integration can reduce the connection distance be-tween components, lowering signal delay and improving overall performance.
- **Scalability:** GaN device manufacturing offers easier scalability com-pared to silicon devices. GaN's high breakdown voltage and high electron mobility make it excellent for high-pow-er and high-frequency applications, suitable for larger scale power electronic devices in the future.

Conclusion:-

The advantages of GaN semiconductors significantly out-weigh those of silicon semiconductors GaN is the next-generation semiconductor. And with the increased performance and potential ability of GaN in integrated circuits and transistors, technology companies should pay more attention to it.GaN semiconductors have faster switching, which reduces switching losses. They also don't need much power to drive the circuit. They operate at higher temperatures and frequencies compared to silicon chips. Without any doubt, GaN semiconductors are the next game-changer in the technology and electronic industries.

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