**SLIDE 1**

Good morning, everyone. My name is Sain Saburaj, and I am here to present my seminar on Ferroelectric Random Access Memory (FeRAM). This seminar is guided by Vaisakh M. Today, we will explore what FeRAM is, its working principle, advantages, limitations, applications, and future prospects.

**SLIDE 2**

- Before diving into FeRAM, let's first understand what RAM is.
- RAM (Random Access Memory) is a volatile memory that temporarily stores data while the system is running.
- It allows the processor to quickly access information needed for performing tasks.
- Key characteristics of RAM:
    - Volatile – Loses data when power is off.
    - High speed – Provides fast read/write access.
    - Multitasking – Helps run multiple applications at once.
    - Temporary storage – Holds data only while the system is on.

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- FeRAM (Ferroelectric RAM) is a non-volatile memory, meaning it retains data even when the power is off. It functions like regular RAM but is different because it does not lose stored information. FeRAM uses a ferroelectric material to store data, making it more energy-efficient and faster than traditional non-volatile memory. Key properties of FeRAM:
- Normal RAM - Volatile – Loses data when power is off.
- Non-volatile – Retains data without power.
- Saves power – Consumes very little energy.
- Fast write speed – Faster than Flash memory.
- Long-lasting – Can handle millions of read/write cycles.

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FeRAM has several unique features that make it stand out.

Features:

- Non-volatile – Data remains even after power loss.
- Speed – Faster than Flash memory.
- Low power consumption – Unlike DRAM, FeRAM does not require constant refreshing.
- High endurance – Can handle millions of read/write cycles.
- Storage density – Lower than DRAM, making it less common for large-scale storage. (A higher storage density means more data can fit in less space).
- Data retention – Stores data for years, like Flash memory.

Why Does RAM Need Refreshing?

- DRAM stores data in tiny capacitors (like small batteries).
- These capacitors lose charge quickly, so the data fades away.
- To prevent this, the computer refreshes (rewrites) the data thousands of times per second.

Uses more power because DRAM is constantly refreshed.

Slows down performance slightly, as refreshing takes time.

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Cost & Scalability – More expensive due to complex manufacturing.

Read Mechanism – Destructive read; data is erased when read and needs to be rewritten.

Radiation resistance – Can withstand radiation, making it useful for space and military applications.

Temperature stability – Performs well in extreme conditions, ideal for industrial and automotive use.

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What is Ferroelectricity?

It is a property of certain materials that allows them to have a permanent electric polarization that can be reversed by an electric field.

- When an electric field is applied, these dipoles switch, enabling data storage in FeRAM.
- In FeRAM, this polarization is used to store binary data (0s and 1s).
- FeRAM uses a special material (ferroelectric) where dipoles can switch direction when electricity is applied.
- The dipole's position represents data:
    - One direction = 1 (ON)
    - The opposite direction = 0 (OFF)

Since these dipoles stay in position even when power is off, FeRAM keeps data (unlike normal RAM, which forgets everything when turned off).

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Common Ferroelectric Materials:
A FeRAM contains ferroelectric capacitor

- Barium Titanate ($BaTiO_3$) – Used in capacitors and sensors.
- Lead Zirconate Titanate (PZT) – The most common material in FeRAM, known for its excellent stability.
- Potassium Dihydrogen Phosphate ($KH_2PO_4$) – Used in optical and piezoelectric applications.

What is Piezoelectricity?

- Some special materials can generate electricity when pressed or bent.
- This is called piezoelectricity, and it's used in many cool technologies!

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- Ferroelectric materials are used in various fields:
- FeRAM – Non-volatile, high-speed memory.
- Non-volatile memory – Used in smart cards, embedded systems, and automotive electronics.
- Piezoelectric devices – Found in ultrasound sensors and actuators.
- Energy harvesting – Converts mechanical energy into electrical energy.
- Electro-optic applications – Used in displays and optical data processing.

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- FeRAM is structured similarly to DRAM but has a ferroelectric capacitor instead of a standard capacitor.
- Each FeRAM memory cell consists of:
- A transistor – Controls data storage and access.
- A ferroelectric capacitor – Stores data using polarization instead of charge.

The ferroelectric material helps FeRAM retain data even without power, unlike conventional RAM.

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A RAM memory cell is like a tiny storage box that holds data while the computer is running. It has these important parts:

1️⃣Word Line (WL) – Tells the memory cell when to store or send data.
2️⃣Bit Line (BL) – Sends or receives the data.
3️⃣Transistor (Switch) – Controls when data flows in or out.
4️⃣Capacitor – Holds the data temporarily like a small battery (used in DRAM).
5️⃣Ground (GND) – Completes the circuit so electricity can flow properly.

Since RAM needs refreshing to keep the data, it uses more power.

An FeRAM memory cell is like a tiny switch that stores data. It has these important parts:

1️⃣Word Line (WL) – Turns the memory cell ON or OFF.
2️⃣Bit Line (BL) – Sends or receives the data.
3️⃣Transistor – Works like a gate, allowing data to move when needed.
4️⃣Ferroelectric Capacitor – Keeps the data even when power is off.
5️⃣Ground (GND) – Completes the circuit so electricity can flow properly.

FeRAM works fast, saves power, and keeps data safe even when the computer is turned off! 😊

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✅ FeRAM:

- Non-volatile, retains data without power.
- Fast read/write speeds, similar to DRAM.
- Lower power consumption, no need for refreshing.
- High endurance, can handle millions of write cycles.

✅ Conventional RAM (DRAM/SRAM):

- Volatile, loses data when power is off.
- DRAM needs constant refreshing, consuming more power.
- Higher storage density, making it more common in large applications.
- Cheaper & widely used in PCs and gaming consoles.

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How It Works:

1️⃣The dipoles are like tiny switches inside the ferroelectric capacitor.
2️⃣When no voltage is applied, they stay in their current position.
3️⃣When electricity (voltage) is applied, the electric field pushes them to switch direction:

- One direction = "1" (ON).
- Opposite direction = "0" (OFF).
  4️⃣When the power is turned off, the dipoles stay in place, keeping the data safe!
- The ferroelectric material inside FeRAM allows dipoles to flip when voltage is applied.
- Once flipped, they remain in that state until changed again, making FeRAM non-volatile (keeps data even without power).
- Energy Efficient – Does not require constant refreshing like DRAM.
- Non-volatile – Retains data even when power is off.

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- Different types of FeRAM architectures:
- 1T1C (One-Transistor One-Capacitor) – Simple design, fast but has scalability issues.
- 2T2C (Two-Transistor Two-Capacitor) – More reliable but uses more space.
- FeFET-Based FeRAM – Uses ferroelectric transistors, enabling non-destructive reads and better scalability.

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✅ With CPU:

- FeRAM's non-volatile nature helps retain data after shutdown, reducing boot times.
- Provides fast access speeds, improving performance.
- Low power consumption benefits battery-powered devices.
- Persistent caching prevents data loss during power failures.

✅ With GPU:

- FeRAM offers fast data access, improving rendering and AI processing.
- Low power usage reduces GPU energy consumption.
- Real-time data updates improve efficiency in parallel computing.
- Persistent buffering ensures stable data storage even during failures.

⚠ Challenges: FeRAM has lower storage density and a destructive read process, requiring further advancements.

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- Radiation Resistant – Performs well in space and medical devices.
- High Speed – Faster read/write than Flash memory.
- Low Power Consumption – No refreshing needed.
- High Endurance – Can handle billions of write cycles.
- Non-Volatile – Stores data even after power is turned off.

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Scaling Challenges – Hard to reduce cell size while maintaining reliability.

Lower Storage Density – Not suitable for high-capacity storage.

Destructive Read Process – Requires a rewrite after reading.

Higher Manufacturing Cost – Expensive due to special materials.

Limited Commercial Adoption – Not widely used in mainstream memory applications.

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✅ Embedded Systems:

- FeRAM is widely used in automotive and industrial control systems where high reliability and fast data storage are crucial.
- Unlike traditional memory, FeRAM's non-volatility ensures critical data is not lost in case of power failures.

✅ Medical Devices:

- FeRAM's low power consumption makes it perfect for implantable medical devices, such as pacemakers and hearing aids.
- In patient monitoring systems, FeRAM ensures continuous data storage without frequent battery replacements.

✅ Smart Cards & Security Systems:

- FeRAM is ideal for secure authentication and financial transactions because of its fast write speeds and high durability.
- Used in credit cards, ID cards, and encryption systems, where rapid and secure data storage is required.

✅ IoT Devices:

- In IoT applications, sensors and edge computing devices require efficient energy use and fast data access.
- FeRAM helps improve performance in smart home devices, industrial IoT, and real-time monitoring systems.

✅ Aerospace & Defense:

- FeRAM is used in satellites, avionics, and military applications because it can withstand extreme temperatures, radiation, and harsh environments.
- Unlike traditional RAM, FeRAM ensures data integrity and reliability even in space missions and defense systems.

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✅ Increased Storage Density:

- Current FeRAM faces limitations in storage capacity compared to DRAM and Flash memory.
- Ongoing research aims to increase FeRAM's density, making it a viable option for larger-scale applications like data centers and consumer electronics.

✅ Non-Destructive Read Mechanism:

- Traditional FeRAM has a destructive read process, meaning data must be rewritten after every read.
- Scientists are developing new architectures to enable non-destructive reads, improving speed, efficiency, and durability.

✅ Cost Reduction:

- One of FeRAM's biggest challenges is high production costs due to specialized materials.
- Innovations in manufacturing techniques and new material research aim to reduce costs, making FeRAM more affordable and commercially competitive.

✅ Integration in AI & Edge Computing:

- With AI and real-time processing becoming mainstream, FeRAM's fast access speeds and energy efficiency make it a strong candidate for use in AI accelerators and edge computing devices.

✅ New Ferroelectric Materials:

- Current FeRAMs mostly use PZT (Lead Zirconate Titanate) as the ferroelectric material.
- Researchers are exploring new materials like Hafnium Oxide ($HfO_2$) to improve scalability, efficiency, and compatibility with modern semiconductor technology.

✅ Expansion in IoT & Wearables:

- FeRAM's low power consumption and durability make it perfect for next-gen IoT devices and wearables.
- It can be used in smart sensors, medical wearables, and industrial automation where power efficiency is critical.

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✅ "To summarize, FeRAM is a promising memory technology that combines the speed of RAM with the non-volatility of Flash memory."

- It offers fast read/write speeds, low power consumption, and high endurance, making it ideal for applications in automotive, medical, IoT, and security systems.
- Unlike traditional RAM, FeRAM retains data even after power loss, making it highly reliable.
- Despite its lower storage density and higher cost, ongoing research in new materials, non-destructive read mechanisms, and cost-efficient manufacturing is making FeRAM more competitive.
- With its potential in AI, edge computing, and next-generation electronics, FeRAM could play a key role in future memory solutions.

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Thank You!