Three-Dimensional Ferroelectric Microelectronics (3DFeM)
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Class: 2020 – 2024

***Mission Statement**: To exploit the 3rd dimension in microelectronics for functions beyond interconnects by incorporating non-volatile ferroelectric memory densely interconnected with logic to create low-power, 3D non-von Neumann computation.*

The *Center for 3D Ferroelectric Microelectronics (3DFeM)* will explore the 3rd dimension in microelectronics for *functions beyond interconnects,* enabling 3D ***non-von Neumann*** *computer architectures exploiting ferroelectrics for local memory, logic in memory, digital/analog computation, and neuromorphic functionality*. This approach circumvents the end of Moore's law in 2D scaling, while simultaneously overcoming the "von Neumann bottleneck" in moving instructions and data between separate logic and memory circuits. Empowered by new ferroelectric materials that overcome 60-year-old materials compatibility challenges, *3DFeM will tackle the non-von Neumann challenge* to propel radical advances in microelectronic devices, circuits, and systems. ***3DFeM will enable a million-fold enhancement in interconnection between memory and logic, along with substantial reductions in the energy cost to computation**.*

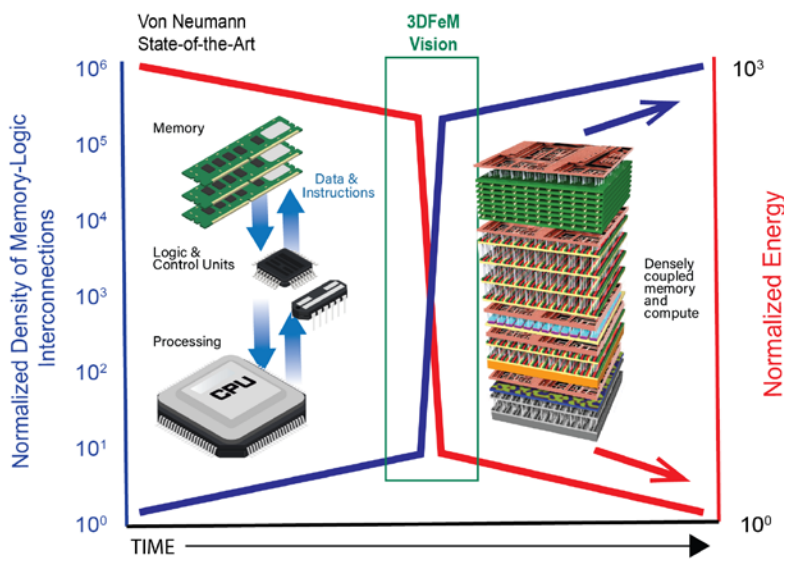

Figure 1: Existing computer architectures are predominantly based on the von Neumann architectural paradigm, where the memory and computation logic are fundamentally separable components. Thus, time and energy are lost in communicating between separate chips. The 3DFEM vision breaks the von Neumann bottleneck by integrating ferroelectric memory and computing elements in 3D, so the circuit interconnects become functional. 3DFeM would enable radical increases in memory-logic connectivity.

Computing accounts for 5 – 15% of worldwide energy consumption. While recent efficiency gains in hardware have partially mitigated the rising energy consumption of computing, major gains are achievable in a paradigm shift to 3D computing systems. The 3DFeM program will enable novel energy efficient hardware (Fig. 1). In many applications, ferroelectrics provide a 10^3-10^4 × improvement in energy efficiency relative to other technologies, while also reducing latency and area overhead. In addition, ferroelectrics enable new functionality for power management, embedded intelligence, and security for the Internet of Things (IoT), impacting a wide range of industries spanning transportation to defense to residential building. However, there are bottlenecks associated with fundamental understanding of ferroelectric physics and processing.

3DFeM Guiding Questions

- How can ferroelectricity be obtained in 3D-integration-enabling materials?
- How can materials be made far from equilibrium (an essential component of BEOL integration) using synthesis routes consistent with 3D integration and aggressive scaling?
- How can new devices leverage the cooperative nature of ferroelectricity, and can the cooperative nature of ferroelectricity be tuned for specific device requirements?
- Can new properties, such as ferroelectric quantum critical points; superconductivity; and spin, charge, or orbital ordering, enable novel devices?
- How can intrinsic or engineered properties of ferroelectric materials and devices enable novel compute-in-memory processors?

By closely coupling experiments, modeling, and theory, 3DFeM is pursuing foundational advances in materials, and devices by composing novel ferroelectric-based morphable compute elements, by answering the challenging scientific questions shown above (See 3DFeM Guiding Questions box). 3DFeM leverages world-leading expertise in integrated ferroelectrics, advanced characterization, and novel devices. Advanced Micro Devices, Applied Materials, IBM, Intel, GlobalFoundries, and Kurt J. Lesker Company are engaged 3DFeM partners.

3DFeM will achieve these goals through two strongly interconnected research thrusts. Thrust 1 will explore the basic mechanisms underpinning ferroelectricity and switching pathways. The thrust will focus on understanding ferroelectricity in HfO_2 and AlN-based systems; quantifying their properties and performance expectations; finding new BEOL-compatible ferroelectric phases; and developing the scientific underpinnings for ferroelectricity in new materials to guide their discovery and future use.
Thrust 2 will develop the fabrication processes needed for fabrication of ferroelectric devices and associated science and technology to validate Thrust 1 materials developments Thrusts 1 and 2 are linked by synchronized and continuous intersection to ensure: (1) nascent ferroelectric formulations are evaluated for compatibility with BEOL integration, (2) device design leverages realistic properties, and (3) emergent synthesis tools expand capability as it relates to both device performance and integration.

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