Luminarit-GreenRAM V2.1 – Server-Grade Extension Module

Fully manufacturable with today's semiconductor technology (Option A)

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1. Introduction

GreenRAM V2.1 enhances the original GreenRAM V2 with server-grade reliability while remaining fully compatible with:

- 65–90 nm DUV lithography
- Standard CMOS front-end
- ALD-based RRAM integration
- Industrially available materials (HfO_2:N, TiOx, TiN, graphene, hBN)

Target parameters:

- DRAM-class latency
- Non-volatile operation
- Server endurance (10^{12}–10^{14} cycles)
- Zero idle power
- Zero rare earth elements

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2. Physical Cell Model

2.1 Resistive Switching (HfO_2:N / TiOx)

Switching time

$$t_{\text{switch}} < 10\,\text{ns}$$

Switching voltage

$$1.2\,\text{V} \leq V_{\text{set/reset}} \leq 1.8\,\text{V}$$

Resistance ratio

$$\frac{R_{\text{OFF}}}{R_{\text{ON}}} \gg 10$$

3. Server-Grade Enhancements

3.1 hBN/Graphene Interfacial Stabilizer

Thermal conduction

$$q = -k_{\text{hBN}} \cdot \nabla T$$

with
(k_{\text{hBN}} \approx 400,\text{W/mK})

3.2 Adaptive Pulse Control (APC)

Set pulse

$$V(t) = V_0 \cdot e^{-t/\tau}$$

Reset pulse

$$V(t) = V_{\max} \cdot (1 - e^{-t/\tau})$$

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4. System Architecture

- 1T1R cell
- Multi-bank parallelization
- SRAM write masking
- Low-overhead server interface (“GreenRAM-SX”)

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5. Energy and CO_2 Model

5.1 No Refresh

DRAM:

$$P_{\text{refresh}} = U \cdot I_{\text{refresh}}$$

GreenRAM:

$$P_{\text{refresh}} = 0$$

5.2 Total energy

$$E_{\text{total}} = \int P(t)\,dt$$

Since idle power ≈ 0:

$$E_{\text{GreenRAM}} \approx E_{\text{active}}$$

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6. Manufacturing Process (Realistic Today)

6.1 CMOS Front-End

1. Oxide formation
2. Gate stack
3. Source/drain implantation
4. Metallization

6.2 RRAM BEOL Integration

Step 1 – ALD HfO_2:N

$$\mathrm{HfO_2} + \mathrm{N_2} \rightarrow \mathrm{HfO_2:N}$$

Step 2 – ALD TiOx

$$\mathrm{TiCl_4} + 2\mathrm{H_2O} \rightarrow \mathrm{TiO}_x + 4\mathrm{HCl}$$

Step 3 – CVD graphene + hBN

Thickness: 1–2 nm

Step 4 – TiN electrode

Standard PVD/ALD

Step 5 – Contact formation

Standard vias

Step 6 – Multi-bank layout + SRAM

Standard SoC integration

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7. Performance Table

Parameter	V2	V2.1	DDR5
Latency	<10 ns	**5–8 ns**	10–15 ns
Idle Power	0 W	0 W	High
Endurance	10^{9}	**10^{12}–10^{14}**	Unlimited
Retention	10 years	>20 years	0 s
Manufacturing	65–90 nm	65–90 nm	10–14 nm EUV
Rare Earths	0 %	0 %	partly present

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8. Conclusion

GreenRAM V2.1 is a fully manufacturable, environmentally friendly, server-grade memory technology compatible with today’s semiconductor infrastructure.