

# 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<sub>2</sub>:N, TiOx, TiN, graphene, hBN)

Target parameters:

- DRAM-class latency
  - Non-volatile operation
  - Server endurance (10<sup>12</sup>–10<sup>14</sup> cycles)
  - Zero idle power
  - Zero rare earth elements
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## 2. Physical Cell Model

### 2.1 Resistive Switching (HfO<sub>2</sub>: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

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

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## 3. Server-Grade Enhancements

### 3.1 hBN/Graphene Interfacial Stabilizer

#### Thermal conduction

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

with

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

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### 3.2 Adaptive Pulse Control (APC)

#### Set pulse

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

#### Reset pulse

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

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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<sub>2</sub> Model

### 5.1 No Refresh

DRAM:

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

GreenRAM:

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

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## 5.2 Total energy

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

Since idle power  $\approx 0$ :

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

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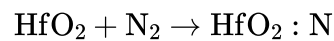
## 6. Manufacturing Process (Realistic Today)

### 6.1 CMOS Front-End

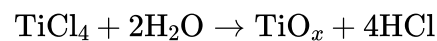
1. Oxide formation
  2. Gate stack
  3. Source/drain implantation
  4. Metallization
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### 6.2 RRAM BEOL Integration

#### Step 1 – ALD HfO<sub>2</sub>:N



#### Step 2 – ALD TiO<sub>x</sub>



#### 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	<b>5–8 ns</b>	10–15 ns
Idle Power	0 W	0 W	High
Endurance	10 <sup>9</sup>	<b>10<sup>12</sup>–10<sup>14</sup></b>	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.