A First Study on Self-Healing Solid-State Drives

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Overview

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- Physical Structure and Healing Process
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Motivation

NAND FLASH SSD:

- Steady-rate cost reduction has made it economically viable
- Fundamentally changing the memory and storage hierarchy in computing systems

Key Parameters:

- Retention Time: Approximately 10 years
- Endurance (i.e. P/E Cycles):
  - SLC: 100,000
  - MLC: 10,000
Motivation

- Technology scaling → Fewer number of P/E cycles
- P/E cycles → Trap Generation → Oxide Degradation

Traps → Oxide Traps → Interface Traps

Most critical obstacle for a wide adoption of SSDs, particularly for high-end computing and data storage systems.

- Trap Annihilation or Healing: Flash memory partially recovers from Interface Traps
Proposed Idea

- To leverage interface trap recovery to enable “Selfhealing SSD”s - which can survive many more P/E cycles than what is achievable in current practice.

- Selfhealing SSDs contains a self-heater die. Which can be self-heated to certain high temperature for recovering most interface traps during a reasonable amount of time.
Physical Structure and Healing Process

- Each NAND flash memory chip stacks one or multiple NAND flash memory die(s) with a self-heater die.
- The self-heater die contains arrays of Poly-silicon resistors.
Thermal Modeling

Heat generated by the heater die can be dissipate:
- Either through the encapsulation on top
- Or through the memory dies, thermal interface, interposer, PCB etc.

The latter path is the major heat dissipation path since it has a much smaller convection resistance than the encapsulation.
Cell Characteristics Modeling

If $\Delta N_{\text{trap}}$ and $N_{\text{cyc}}$ denote the trap generation and P/E cycle number, then,

$$\Delta N_{\text{trap}} \propto N_{\text{cyc}}$$

The model also captures the effects of:

• Random Telegraph Noise (RTN)
• Retention Noise
• Cell-to-cell interference.
Evaluation Result

Higher temperature allows faster recovery/healing

But

To avoid damage to the chip, temperature is bounded by properties like melting point and thermal coefficients

Example: At 210°C it takes 75 hours to remove 80% of the interface traps for a 32 chip SSD
The power consumption of the heater die linearly increases, while the time for interface trap recovery drops exponentially. So, total energy consumption exponentially reduces as the temperature increases.

Thus, from the efficiency perspective, we may want to increase the temperature as much as possible.
Summary

✓ A self-healing SSD design strategy to improve the SSD lifetime by leveraging the inherent interface trap recovery phenomenon
✓ Suggests a potential of achieving one order of magnitude improvement of SSD lifetime.

Personal Observations

➢ Stacking a separate heater die with NAND flash memory die(s) in the same chip package seems much less feasible than the authors claim

➢ Possibility of nonuniform heating of memory dies in a chip

➢ Over heating issues
Thank you
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Questions?