Improving the Reliability of Next-Generation SSDs using WOM-v codes

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Motivation

Increased density – more bits per cell

Voltage can only be increased (Program)
Voltage can be reset to zero (Erase)
Motivation

Increased density – more bits per cell

Overwrite between Erase - **Write Once Memory Code**
Rethinking WOM Codes to Enhance the Lifetime in New SSD Generations

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WOM-v Codes
Cell Erase Count
(No-WOM)

4

QLC Cell
Cell Erase Count
(No-WOM)

4
Cell Erase Count (No-WOM) 4
Cell Erase Count (WOM-v) 2
WOM-v(2,4) codes reduce erase operation by 2X

Cell Erase Count (No-WOM)

4

Cell Erase Count (WOM-v)

2
Optimizations

- Code Word Sharing.
- Same Generation Transition.
- Programming beyond maximum Generations.
- Optimal GC (GC_OPT) Mode.
- No-Read (NR) Mode.
Code Word Sharing

More Overwrites possible before Erase
Challenge in introducing WOM-v codes to SSDs

- SSD Architecture
- Write Amplification
- Performance and Parallelism
- Workload Pattern
Implementation

+445 LOC in LightNVM
+240 LOC in FEMU

QLC Extension

ERASE UNIT
RING BUFFER
PARALLEL UNIT

APPLICATION
FILE SYSTEM
WOM-v Coder

KERNEL
USERSPACE

LightNVM Module
FEMU

WOM-v Coder
GC Logic

+445 LOC in LightNVM
+240 LOC in FEMU
Implementation

- APPLICATION
- FILE SYSTEM
- No-Read (NR) Mode
- WOM-v Coder
- Delay page relocation (GC_OPT Mode)
- GC Logic
- Increase Page Size
- QLC Extension
Evaluation: Real World Traces
Erase Operation Reduction

4.4 - 11.1x reduction in erase cycles

[Bar chart showing the comparison of erase operation reduction across different workloads and system configurations.]
Write Performance

< 8% write performance overhead

Bar chart showing the time (s) for different workloads and configurations.

- NO_WOM
- WOM-v(2,4)-NR-GC-OPT
- WOM-v(1,4)-NR-GC-OPT

Workloads:
- FLU-online
- FLU-websearch
- MP-auth
- Alibaba-4
- MC-stg
- MC-rsch
- MP-Backend
- Alibaba-316
- Alibaba-746
- RocksDB
Read Performance

Negligible average read latency overhead

0.6-22% read performance overhead
WOM-v(2,4) QLC v/s MLC Drive

- QLC WOM-v(2,4) can store 2 logical bits per cell.

- MLC drives also store 2 logical bits per cell.

- Without WOM-v coding, MLC drive has better endurance than QLC drive.
WOM-v(2,4) QLC v/s MLC Drive

WOM-v(2,4) QLC endurance > MLC endurance!
Summary

- **First** design and implementation of **Non-Binary WOM code** for QLC Drives.

- **4.4-11.1x reduced erase operations** with minimal performance overheads.

- TLC+QLC FEMU Extension **merged upstream** with master.

- WOM-v simulator code [https://github.com/uoftsystems/womv](https://github.com/uoftsystems/womv)
Q & A