IBM Research

Write Amplification Reduction in NAND Flash through Multi-Write Coding

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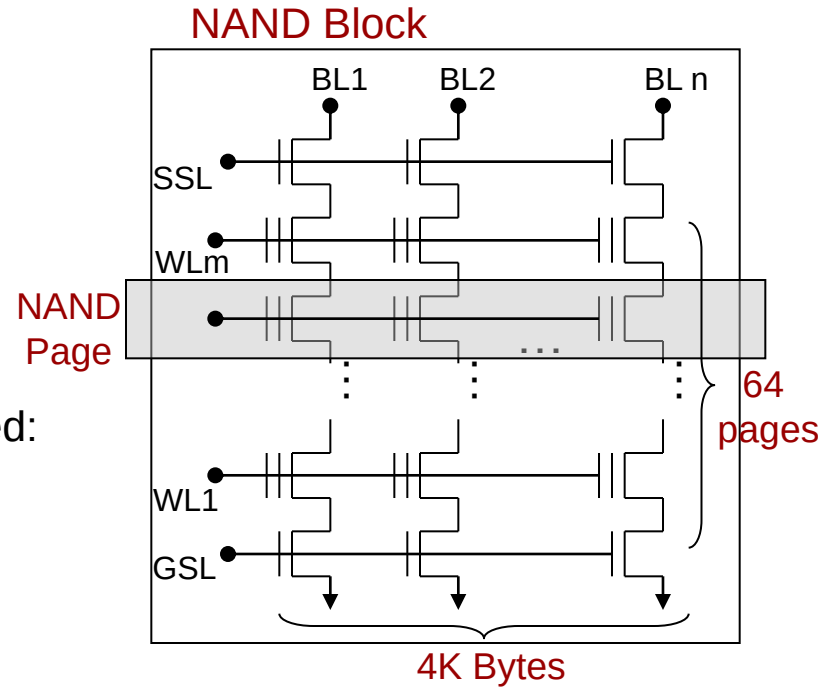
Performance Constraints in NAND Flash

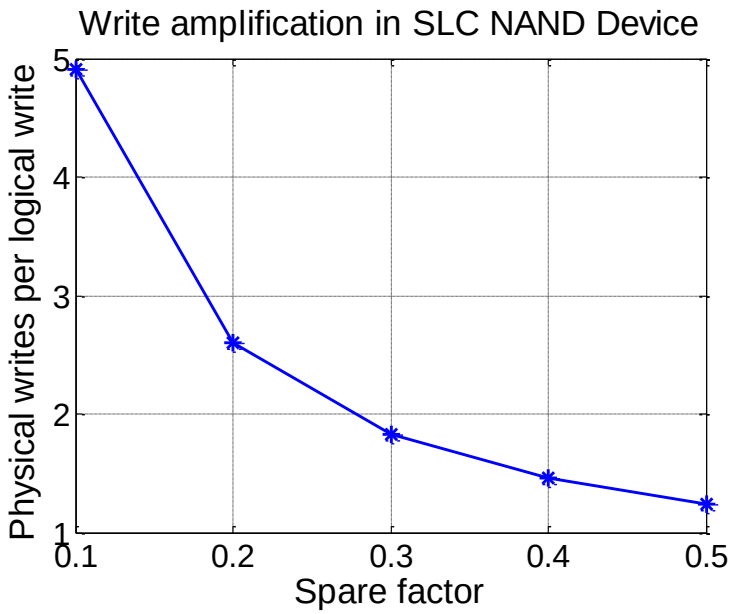
- Limited Endurance
  - Tunneling charges create charge-trapping defects in the tunnel oxide, cause shifting threshold voltages, lower retention
  - Latest MLC devices have endurance as low as 3-5k P/E cycles

- Write Restrictions
  - Pages are smallest write units, but blocks are smallest erase units
  - Erasing a programmed cell requires entire block to be erased
  - Block erase is very costly (~2ms)
  - In practice log-based file system (LBFS) used: A logical page is rewritten by mapping to different physical page, and invalidating old page (map is stored in FTL)



Garbage Collection and Write Amplification

- Periodically, the invalid pages have to be freed up through garbage collection, in which some blocks are erased
- Since valid pages in these blocks have to be copied to other blocks, this leads to write amplification (an increase in the number of writes)



- Write amplification problem is of fundamental significance in NAND Flash
  - Further reduces already limited device-life of NAND Flash device
  - Reduces performance, because page programming is costly (~200 μs for SLC, ~4x or more for MLC)
  - Write-amplification for baseline system described in Hu et al., SYSTOR '09 (WA 5 at 10% spare)

Multi-write Coding for NAND Flash

Aim Develop controller-level coding technique to reprogram data on a NAND Flash page multiple times without block erase

Motivation Reprogramming without erase results in significant decrease in write amplification and in memory wear (just two-writes leads to significant improvements)

Underlying Principle 1. Programmed cell can be reprogrammed without erase if floating-gate charge not required to decrease

2. Programmed page can be reprogrammed without erase if no page-cell's floating-gate charge decreases (caveats!)

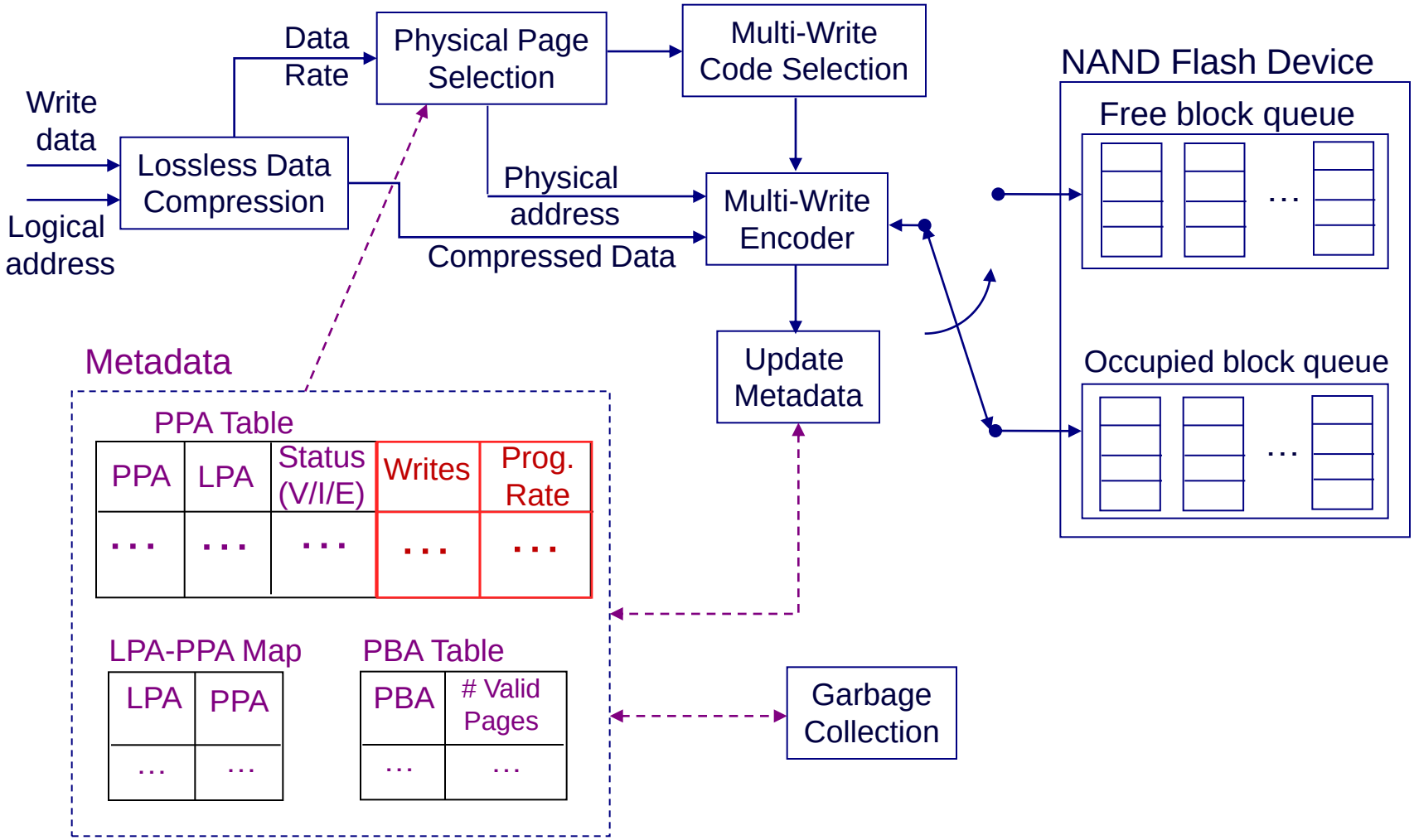
Theoretical Foundations

- Information theoretic Channel Coding with Side-information at Transmitter (CSIT) problem
- Theoretical properties and code constructions for 'permanent' or 'write-once-memories' (WOMs) in information theory

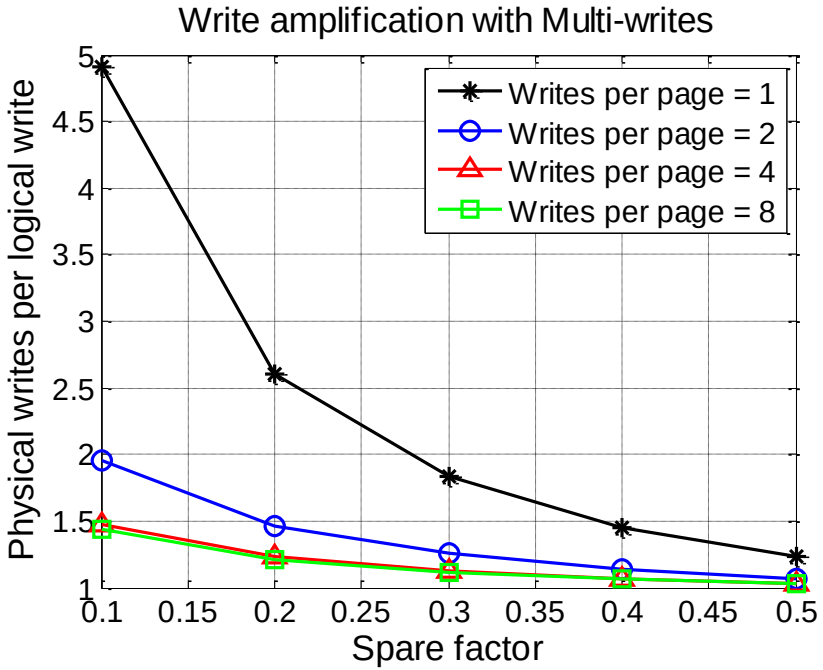
Proposed Multi-write Coding

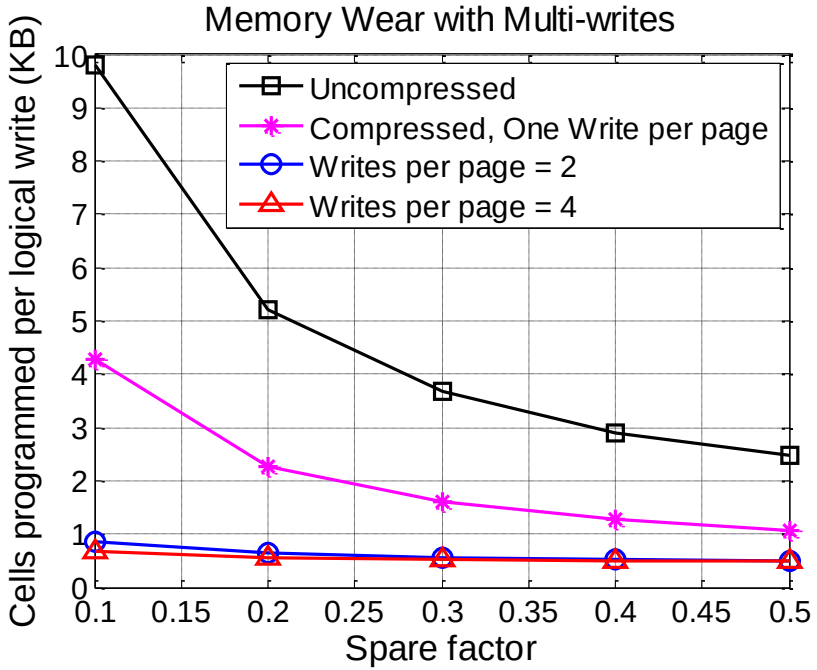
- Two-write coding technique allows each NAND Flash page to be programmed up to twice w/o erase
  - Most of performance gain can be achieved with two writes
  - Increase in BER decreases marginal utility of more writes
- Large block-length, linear-rate coding which additionally seeks to minimize memory wear
  - Quantified by # cell program ops
- Uses enumerative source coding for efficient computation of multi-write codeword
  - Efficient methods for enumerative coding known
  - Leads, in general, to data length expansion
- Used in conjunction with lossless compression
  - Ensures page alignment, reduces management overhead

System Description



Results





- Simulation results on data which is ~2:1 compressible on average
- Write Amplification Two-writes with 20% spare as good as conventional system with 40%
- Memory Wear Two-write coding almost order of magnitude better than uncompressed system