Flash Memory SUMMIT

Rewriting Flash Memories by Message Passing

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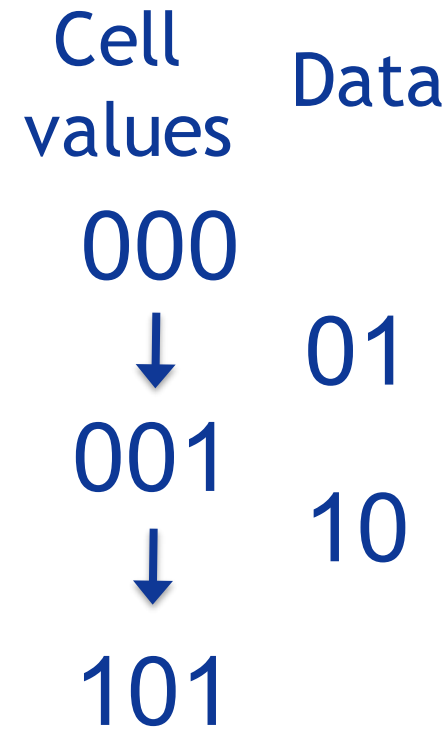
Main Limitation Of Flash: Erase Before Write

- Problem:
  - Limits endurance, speed and power efficiency
- Potential **solution**: write without erasure = rewrite
- Tool: Write-Once Memory (WOM) codes

What are WOM codes?

- Proposed by Rivest, Shamir ‘82

Data to Store	1st-write code word	2nd-write code word
00	000	111
01	001	110
10	010	101
11	100	011



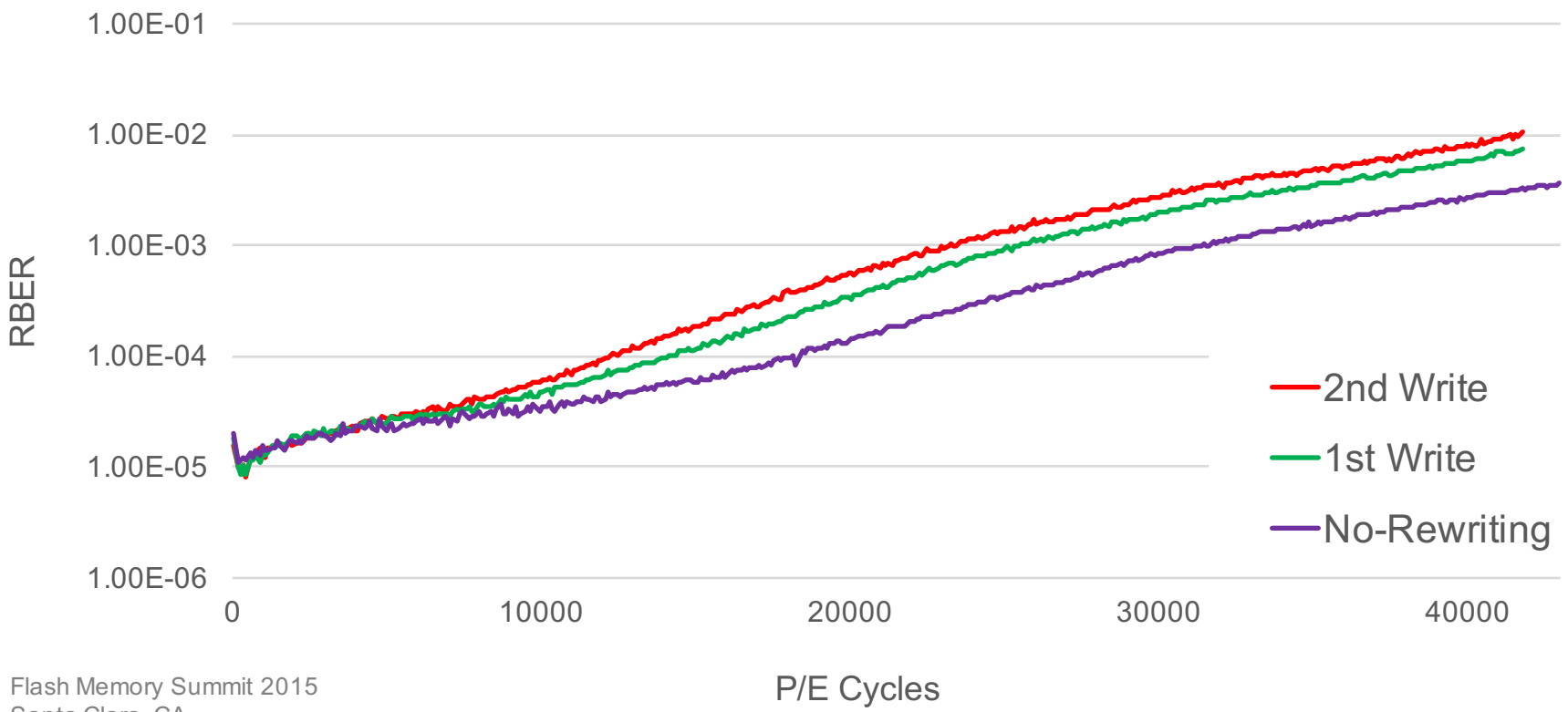
- Allow writes without erase

Challenges of WOM codes

1. Interference
2. Storage overhead
3. **Circuit complexity**

- More?

Interference



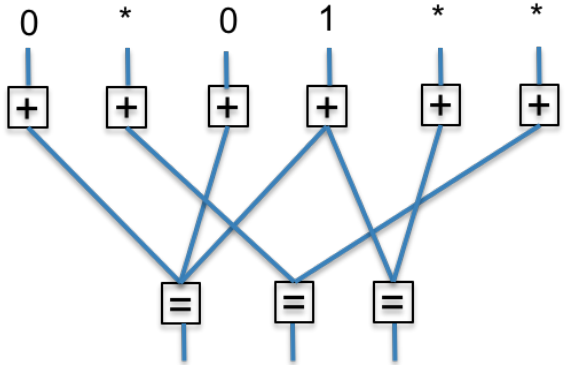
Storage Overhead

- Minimized by capacity-achieving WOM codes
  - Entropy polarization: Burshtein & Strugatski ‘13
  - Randomness extractors: Gabizon & Shaltiel ‘12, Shpilka ’13
- Reduce over-provisioning and write amplification
  - Odeh & Cassuto ‘14, Yadgar et al. ‘15

Circuit Complexity

- **Problem**:
  - good WOM codes are hard to implement
- Proposed solution: “LDPC-like” WOM codes.
- Advantages:
  1. LDPC-like complexity
  2. Can share circuit modules with ECC

Construction



G = generator matrix of LDPC code

Encoding: find x for which

1. $x \geq s$ (can write without erase)
2. $m = Gx^T$ (word represents the message)

How to find x fast:

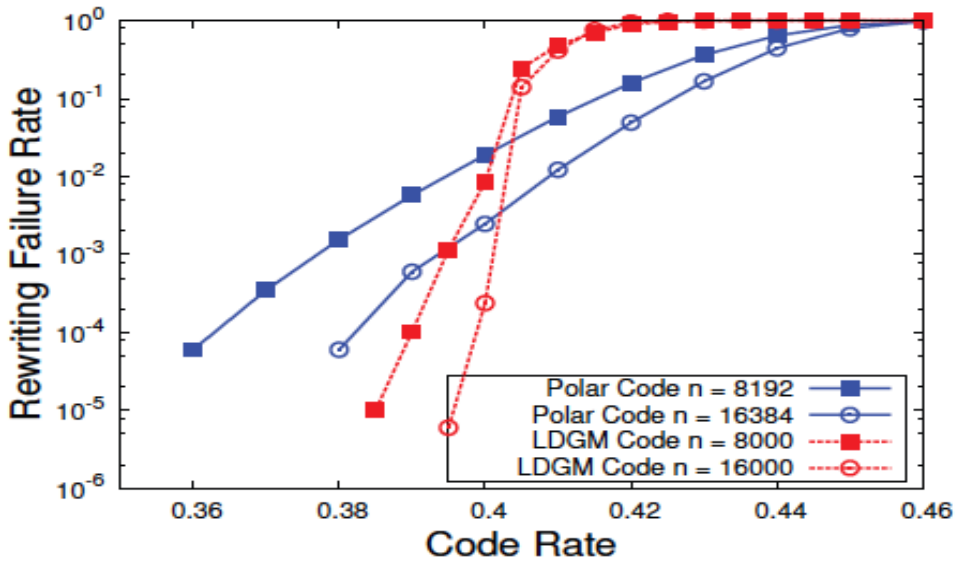
- **Message passing** on sparse Tanner graph
- Algorithm by Martinian, Yedidia '02
- Originally for data compression

Decoding: $m = Gx^T$

Rewriting Failures

- Message-passing encoder sometimes **fails**
- Failures are not as critical as in ECC => Failure rate can be higher
- Failure rate depends on code rate
- **Example**: rewriting an Invalid page
  - ½ of the cells cannot be rewritten

  ⇒ WOM code rate cannot exceed ½



Summary

- Main result: “LDPC-like” WOM codes
- Benefit: Extend endurance for low complexity penalty
- Details in ISIT’15 paper:
  - “Rewriting flash memories with message passing”
- Ongoing experiments on flash chips