Physical NAND Flash Security: Preventing Recovery of Deleted Data

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Topics

- A brief history of data removal
- Data sanitization methods
- NAND Flash physical requirements
- Block management
- Data overwriting
- Secure erase
- Removing residual data
- Myths

A Brief History of Data Removal

- In early storage protocols, functions existed to read and write data, but not to remove it
- Deleted data typically remains on storage media after it is no longer needed
  - The file's index record is partially overwritten
  - The file's data is not overwritten
  - Whole industry exists to recover deleted files or to protect against accidental deletion
- Volume/partition reformatting and deletion also does not remove previous data
- Focus of these operating systems is not security, but rather to protect the user from unintentionally removing wanted data
- Data sanitization focuses on removing data permanently from the storage media

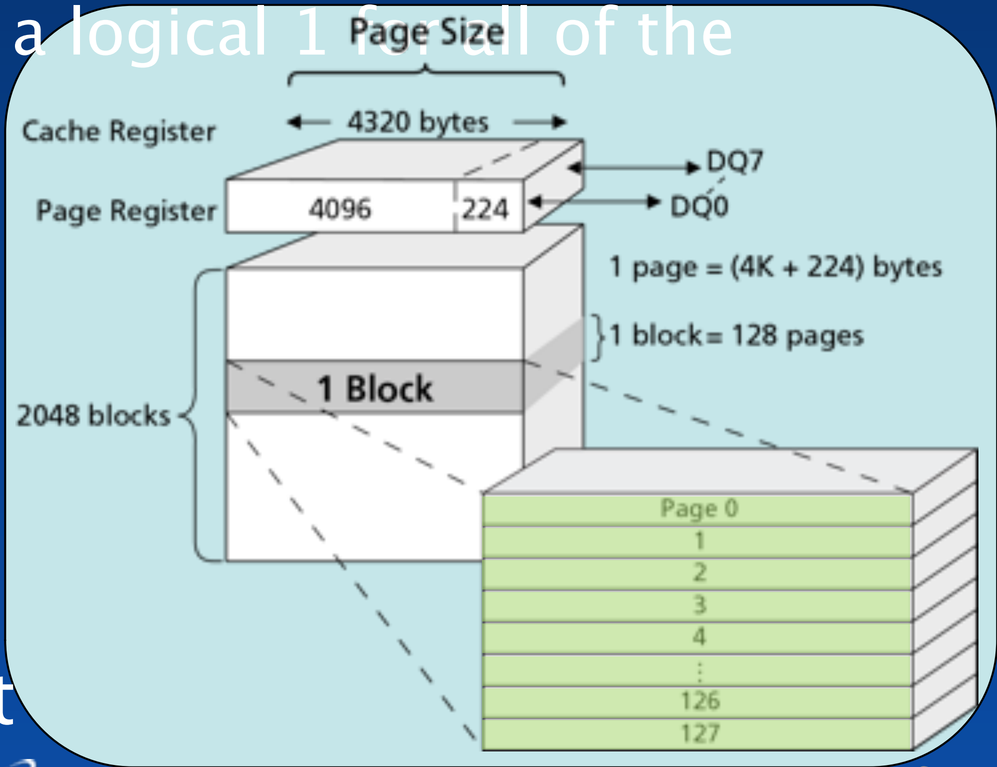
Data Sanitization Methods

- Clearing
  - Previous data may still be recoverable through laboratory attack
  - Data overwriting
  - Media is reusable
- Purging
  - Prevents laboratory attack to recover data
  - SECURE ERASE (for ATA disks)
  - Media may or may not be reusable
- Physical destruction
  - Disintegration, incineration, pulverization, melting, and shredding
  - Media is no longer reusable
- How do these methods relate to NAND Flash-based storage?

Source: NIST 800-88, Table 2-1, p. 8

NAND Flash Physical Requirements

- NAND Flash requires block management
  - Erase blocks of data, consisting of multiple pages
  - Changes a logical 0 to a logical 1 for all of the cells in the block
  - Program pages within a block in sequential order
  - Changes a logical 1 to a logical 0
- When reusing a page, it must be erased first



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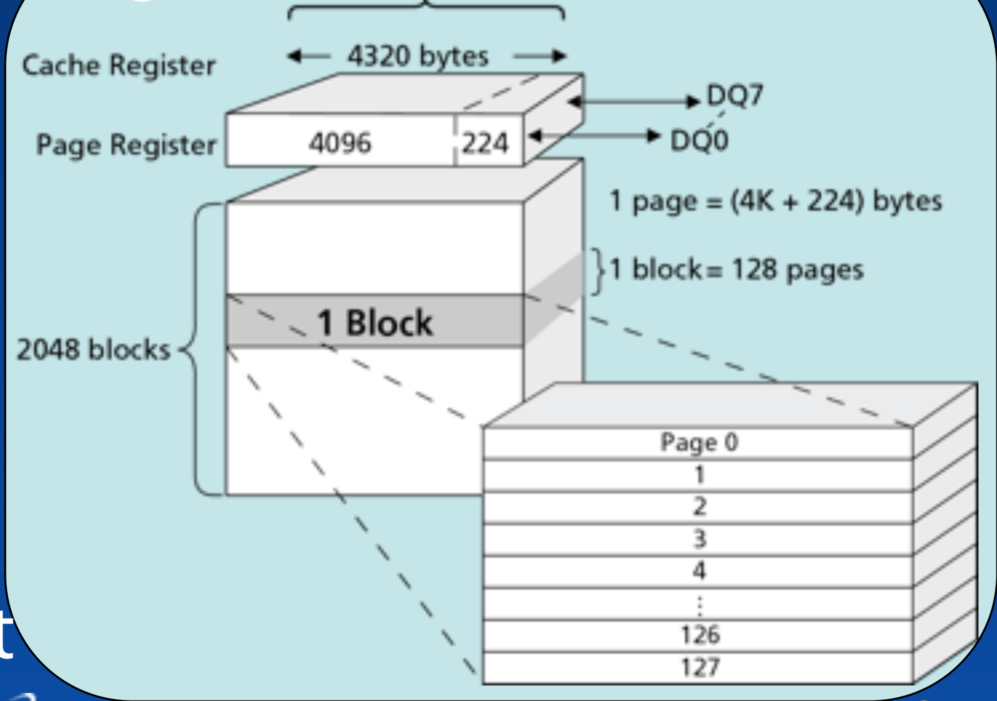

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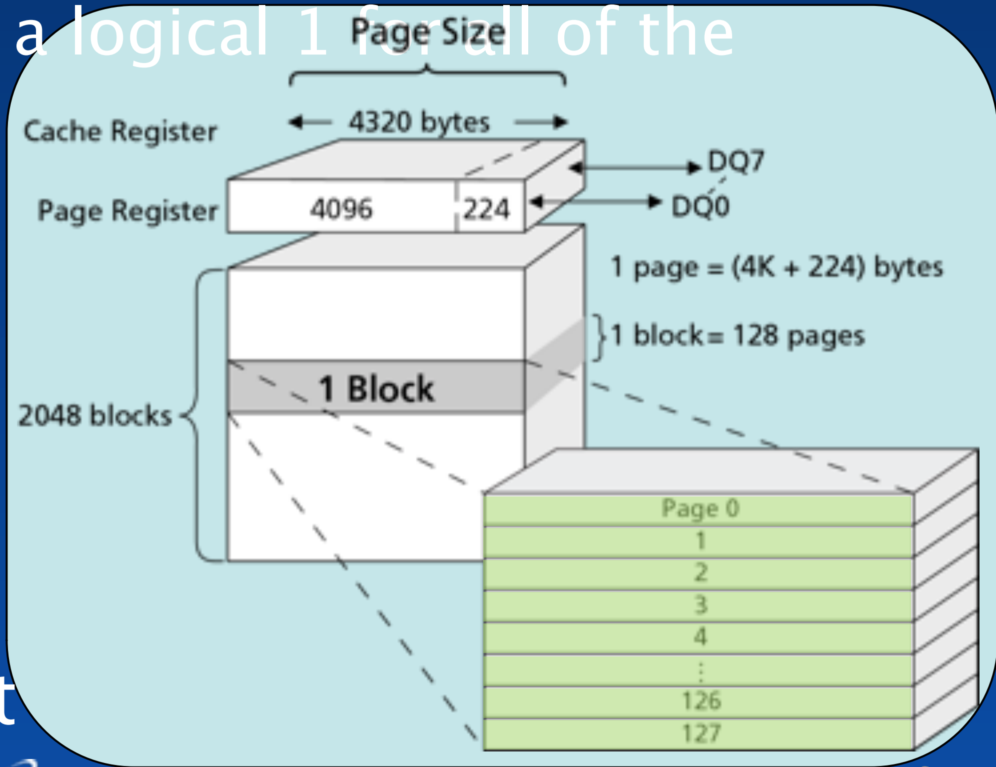
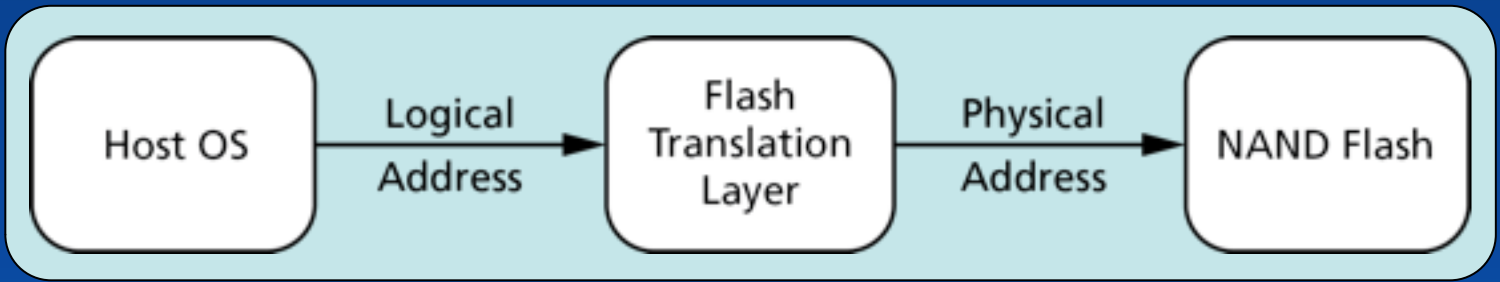


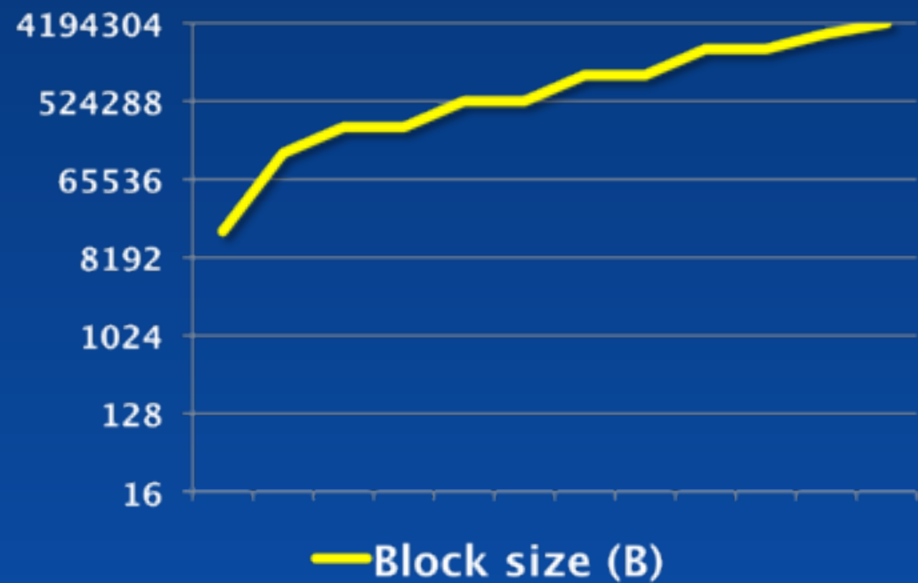
Block Management

- Block management is used to make sure NAND physical requirements are met
- The Flash translation layer translates host addresses (logical) to NAND addresses (physical)
  - Software running on a host operating system
  - Firmware running on a NAND controller



Block Management Today

- Block management algorithms have become more complex as block sizes have increased
  - Typical data sizes are still 512B or 4KB
  - Page sizes are moving to 8KB or 16KB for SSDs
  - Block management algorithms are optimized for sequential throughput and IOPS
- More data fragments remain on the media through use



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Data Overwriting

- For hard disk drives (HDDs), the primary method to clear individual files was through data overwriting
- Sensitive data is overwritten with one or more data patterns to remove it
- Residual data may still be recoverable if overwritten only once (though unlikely with today's HDDs)
- Data overwriting applications/algorithms were developed around direct addressing—an LBA points to the same physical location for every write
- Securely deleting a file is typically a tradeoff of thoroughness (number of passes) and performance (time)

Data Overwriting with NAND Flash

- Because of block management, data overwriting is not effective to clear individual LBAs of data
- NAND Flash uses indirect addressing—an LBA points to a different physical location for every write
- This results in multiple copies of the data existing
  - Current version
  - Older versions
- Older versions are eventually discarded when the blocks they reside in no longer have valid data in them and are erased
- Data overwriting is mostly effective if the entire drive is overwritten, but some previous data typically remains in hidden blocks and can be recovered through laboratory attack
  - Typically less sophisticated to recover than an HDD data overwrite
  - Slow
  - Risk is proportional to the amount of overprovisioning

Secure Erase

- Secure erase was developed to permanently purge <u>all data</u> from HDDs, including areas not directly addressable
- Secure erase implemented on many SSDs
- e·MMC has adapted secure erase to purge data from portions of the memory device

Secure Erase and Block Management

- If purging a portion of the media, a host-issued SECURE ERASE command would be responsible for the following NAND functions
  - Identify all physical copies of data (current and previous) representing a host LBA or LBA range
  - Copy/move all good, valid data around the data to be purged to new locations
  - Properly erase the blocks

- Time is required to perform the block management function of identifying all copies of a particular LBA and consolidating valid data

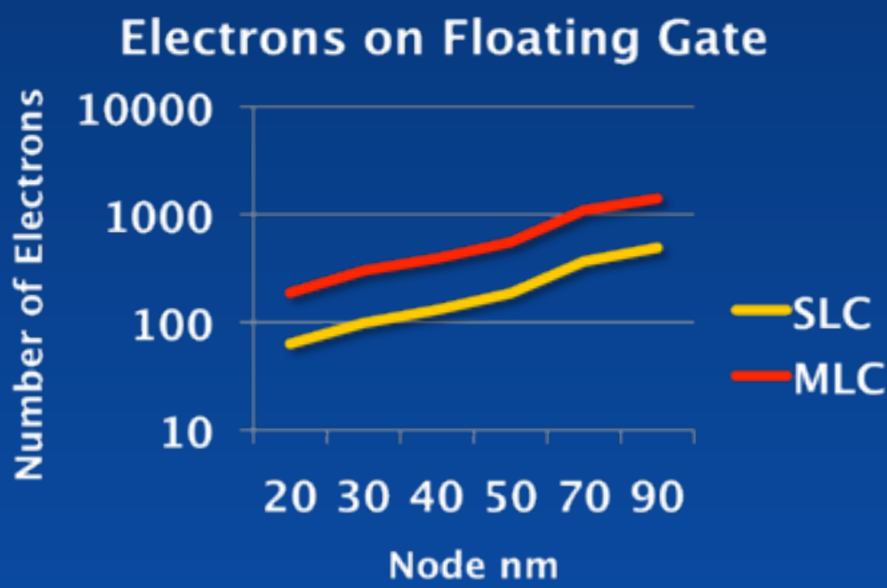
- If purging all drive data, then SECURE ERASE is fairly quick because no block consolidation needs to occur

Removing Residual Data

- Can data be purged from the NAND Flash to prevent recovery through a laboratory attack?
- This requires a better understanding of the NAND PAGE PROGRAM and BLOCK ERASE commands

NAND Flash Cell Fundamentals

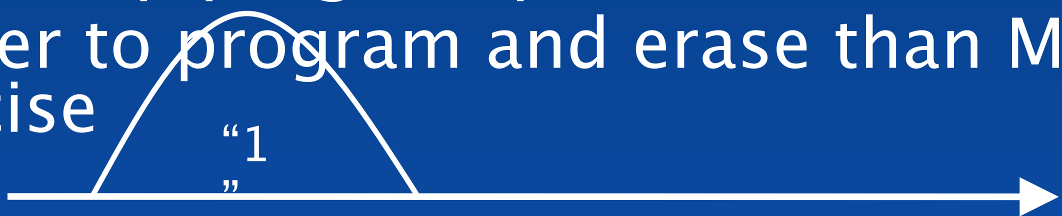
- 1s and 0s are represented by the number of electrons stored on the NAND floating gate
- Working number of electrons on each floating gate is decreasing as NAND process shrinks
- Becomes harder to discern bit states



Source: Micron Technology, Inc.

Single-Level Cell (SLC) NAND Flash

- Each NAND cell is mapped to one NAND page
- Needs fewer working electrons than MLC to distinguish bit states
- Programming increases effective voltage on cells
- Only two states represented: 1, 0
- Bits states use wider cell distributions than MLC
- One-step program process
- Faster to program and erase than MLC—less precise



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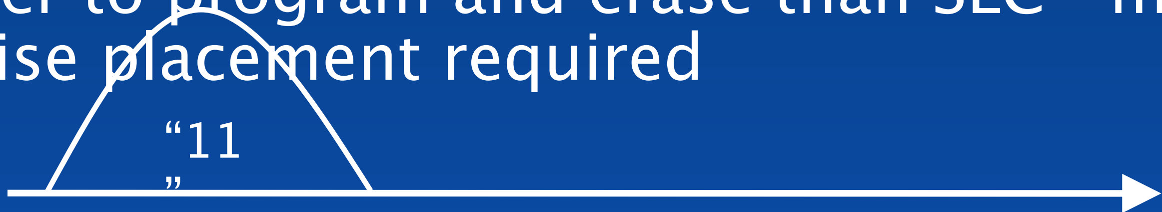
2-Bit Multiple-level Cell (MLC) NAND Flash

- Each NAND cell is mapped to two NAND pages
- Needs more working electrons than SLC to distinguish bit states
- Programming increases effective voltage on cells
- Four states represented: 11, 10, 00, 01
- Bits states use narrower cell distributions than SLC
- Two-step program process: fast page then slow page
- Slower to program and erase than SLC—more precise placement required



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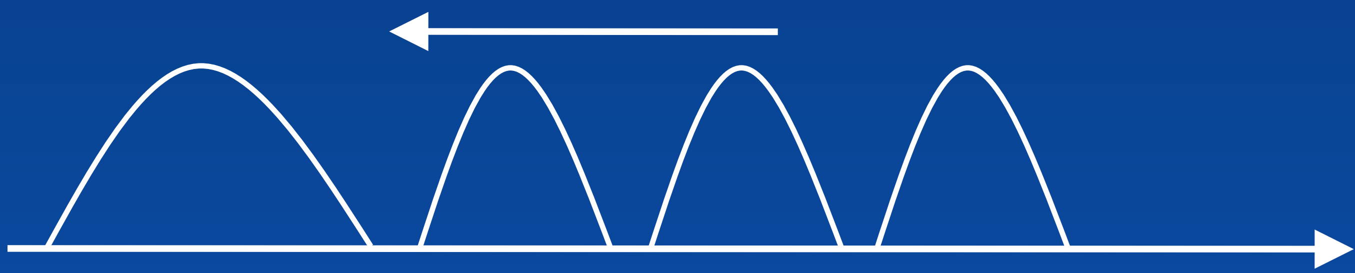
Goals of a BLOCK ERASE Operation

- Decrease effective voltage on all cells by removing electrons from the floating gate
- Increase effective voltages on deeply erased cells
  - Tightens erase distribution
  - Significantly reduces possibility of data recovery through laboratory attack



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MLC NAND Flash Block Erase Algorithm

- MLC NAND Flash block erase algorithms already prevent laboratory attack, especially on the latest process nodes
  - Pre-erase data compaction brings all cells in the block to a close level
  - Post-erase data compaction adds electrons to deeply erased cells

- Does not require host involvement and occurs during the typical ^{t}BERS

- Note: Not all NAND vendors erase MLC NAND Flash with the same algorithms

SLC NAND Flash Block Erase Algorithm

- The SLC block erase algorithm is typically shorter than the MLC block erase, though moving toward MLC algorithms
- The typical SLC block erase for 20-30nm process nodes should adequately purge the cells within a NAND block
- For older NAND technology, the host may need to assist the NAND in purging residual data
  - Erase the block (optional)
  - Program all of the pages in the block to solid zeros
  - Erase the block
  - Can add an additional ~40ms to erase time

Myths: TRIM or "Super Voltage"

- TRIM is a command tells a drive which LBAs are no longer needed on a drive
  - Drives can discard unneeded data during block management
    - Improves performance
    - Reduces write amplification
  - Method of implementation on the NAND physical level is controller/firmware specific
  - TRIM does not guarantee old data removal because of its indeterminate nature
- Occasionally I get questions on destroying NAND Flash using a "Super Voltage"
  - Not guaranteed to destroy NAND Flash or to eliminate data in the array

Sanitization Summary for NAND Flash

- For sanitization of all data
  - Data overwriting clears data, but some data may remain in NAND blocks used for overprovisioning
  - Secure erase (if implemented at host interface) purges data from all NAND blocks with user data

- For sanitization of individual files
  - Data overwriting is ineffective—very likely to keep previous copies of data to be removed, especially if the drive is not already full
  - Secure erase or secure delete only works if block management consolidates good data from data to be removed and uses block erase to purge the old data

- Effectiveness of data purging is also dependent on the effectiveness of the BLOCK ERASE command
  - Latest 20-30nm SLC and MLC process nodes sufficiently purge data
  - Laboratory attack may be possible on older NAND process nodes

Questions?

Revisit the Micron FMS presentations at www.micron.com/fms

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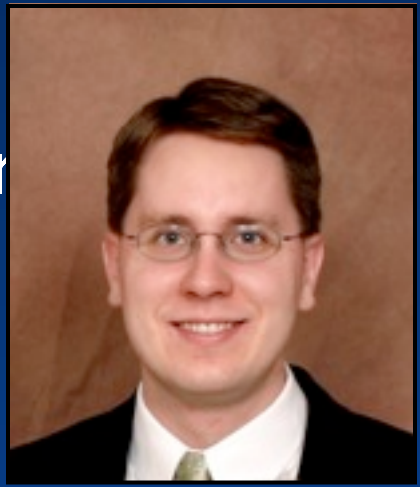
About Michael Abraham



- Architect in the NAND Solutions Group at Micron
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