UNIVERSITÀ DEGLI STUDI DI FERRARA
- EX LABORE FRUCTUS -

Uniform and Concentrated Read Disturb Effects in TLC NAND Flash Memories

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Purpose

- **Characterize different read usage models** (i.e., uniform and concentrated) in scaled NAND Flash products **to expose read disturb features**
- Evaluate the peculiarities of the **read disturb under different conditions from the topology and variability standpoint**
- Provide SSD controllers designers the concept of **read disturb guard band**

Outline

- Introduction
- Experimental Setup
- Read disturb characterization
  - Page type topology dependency
  - Variability characterization per wordline
- Implications on enterprise SSD
- Conclusions

Introduction

- **Triple Level Cell** (TLC) NAND Flash memories are **largely exploited** in enterprise Solid State Drives (SSD) thanks to their **high storage density and low cost per bit**

- These storage architectures are **suitable mostly for read-intensive applications** since their endurance is quite low compared to other NAND Flash storage paradigms

- **Such a usage constraint exacerbates** a reliability issue that was almost negligible for previous NAND Flash generations, namely **the read disturb**

Read disturb – Causes and Effects

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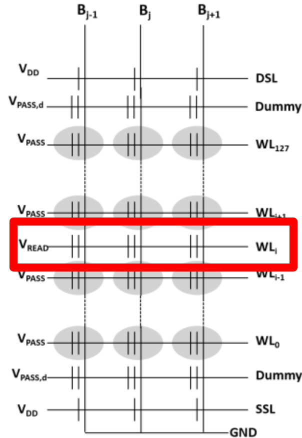

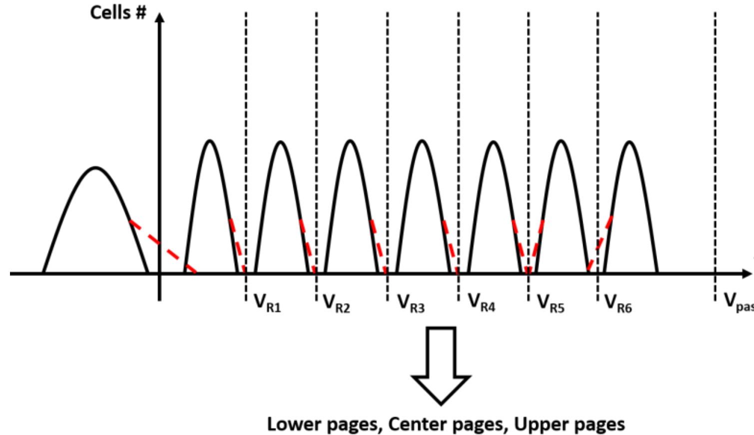

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- All the cells within a block belonging to the same string of the **cell to be read in a wordline must be driven with a** $Vread$, independently of their stored charge

- The relatively high $Vpass$ **bias** applied to the control gate of neighbor cells **may trigger several effects due to hot carrier degradation, and charge loss** that result in a **perturbation of the threshold voltage distributions** of a programmed block, yielding in turn to **read errors**

Experimental setup

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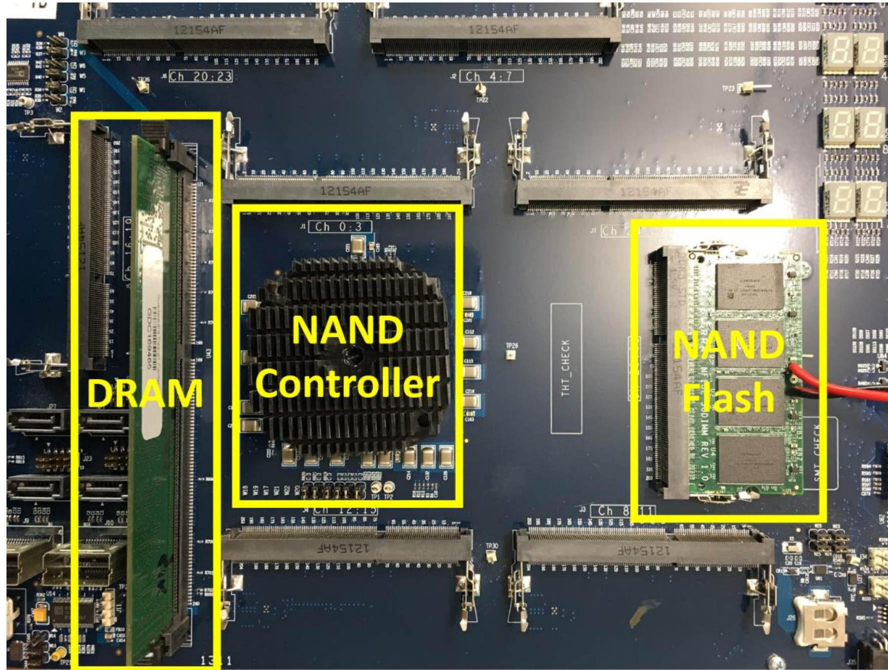

- ASIC PCIe Gen3 NVMe SSD memory controller
- DRAM buffer for temporary data storage
- 8 SO-DIMMs each one populated with 8 NAND Flash chip
- A single chip contains 8 mid-1X TLC NAND Flash memory dies

- The characterization system communicates through a PCIe interface with an x86-PC where the data are collected for post-processing purpose

Read disturb state-of-the-art testing Uniform Read Disturb

- In TLC NAND Flash the **state-of-the-art read disturb testing is performed by cycling all the pages within the memory blocks up to a given P/E** for lower, center, and upper pages

- Then the block **content is consecutively read following the programming sequence.** This is called Uniform Read Disturb test

- **How can I keep track of the actual read disturb level?**
  - Endurance → P/E cycle
  - Retention → Time, temperature
  - Read disturb→ ?

Calculating the Page Read Count

- As said, the **read disturb testing is performed with a sequential read access** usage model (i.e., from the first to the last word-line). Considering:
  - A block composed by 128 wordlines (i.e., 384 pages),
  - 3300 block reads,
  - **<u>The actual total page read count is 384*3300=1267200 per block</u>**

- The page read count is the number tracked by many algorithms in the SSD firmware coping with read disturb to understand its criticality for the disk reliability.

- **<u>With a uniform read access of the NAND Flash blocks every page gets the same amount of accesses</u>**

Page type topology dependency

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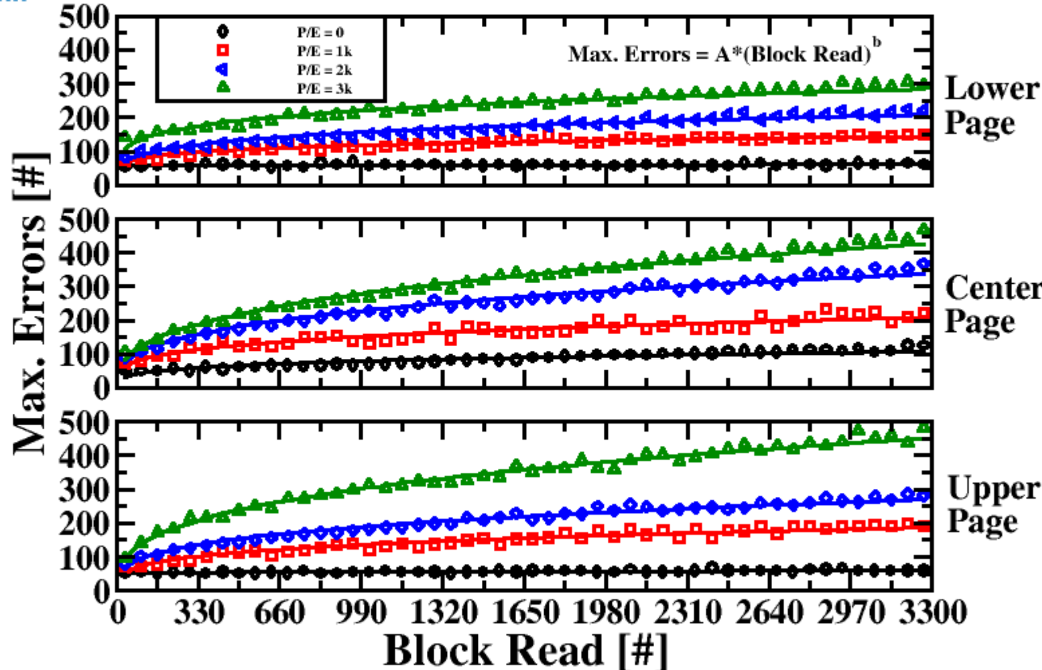

The cycling has been performed up to 3k P/E with minimal dwell time. Both cycling and read disturb were performed at room temperature

The maximum number of errors retrieved for all the wordlines in a block and for different page types **increases with the number of block reads by following a power law**

Take away: for the SSD controller predict the read disturb phenomenon per block is easy!!

Disturb variability
Wordline topology dependency

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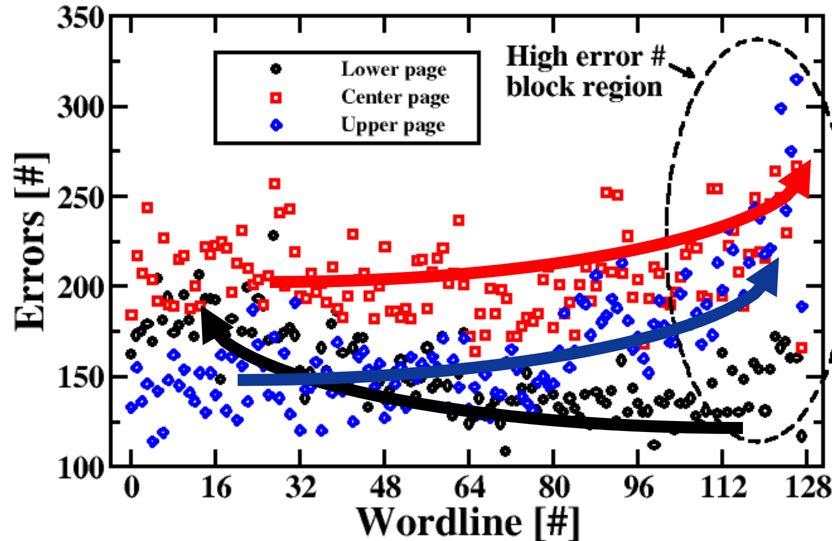

Takeaway: the wordlines close to the drain selector are those heavily affected by the disturb in center and upper pages, whereas in lower pages the trend is inverted toward the source selector

This is related both to the different electric fields near the dummy wordlines and to the effective number of experienced $Vpass$ bias

Workload Trace Example

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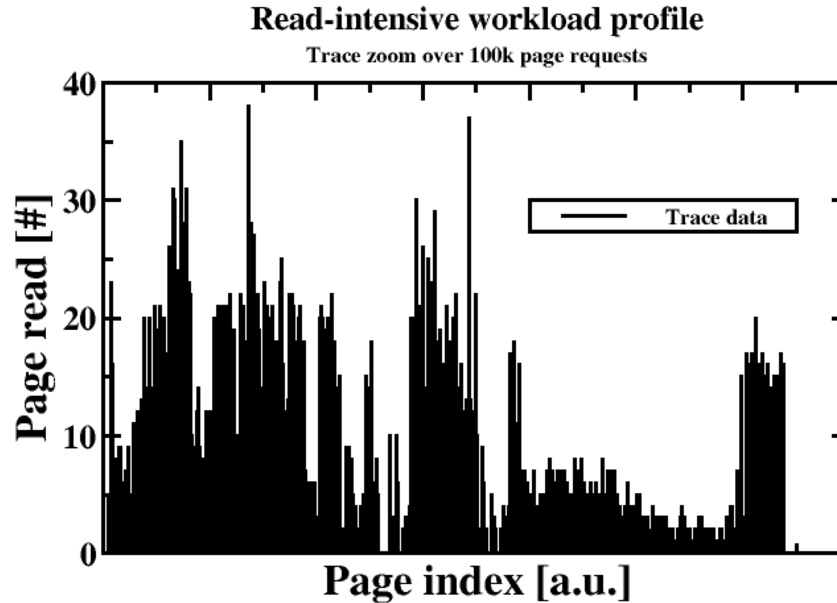

However, there are some read-intensive applications where the number of reads applied to the pages is concentrated in some regions of the block

Concentrated Read Disturb

- Taking the **analysis to extreme conditions** we show the impact of **concentrating all the page reads on a single page of a block**, therefore we applied 1267200 page reads after 3k P/E either **on a page in the center or in the last wordline** of the block

- When the reads are concentrated on a single page **the errors profile on the wordlines is the same as for the uniformly distributed read disturb except for the two neighbor wordlines to the continuously read one**

Concentrated Read Disturb

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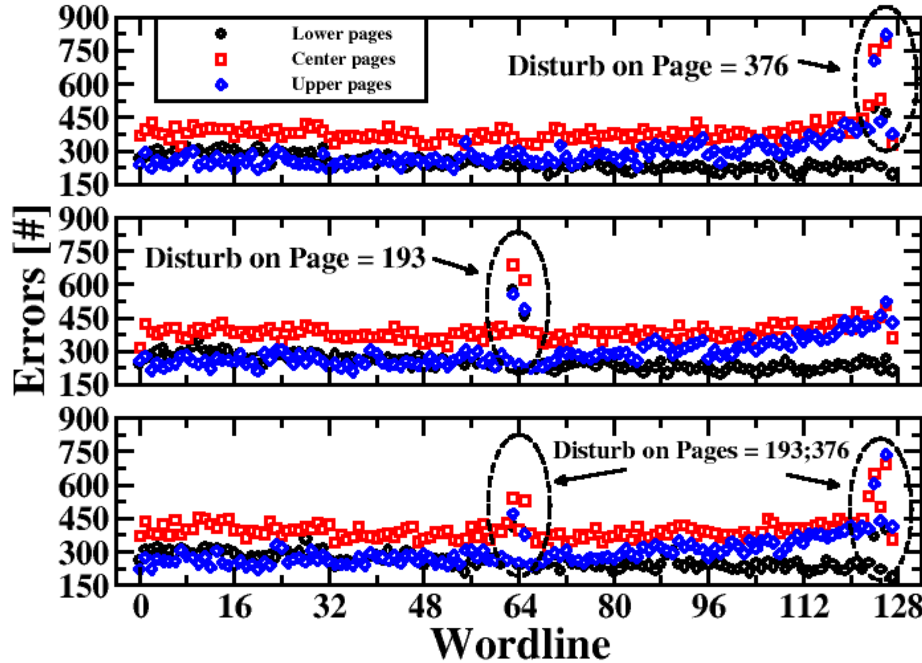

The worst case for concentrated read disturb is found to be in the penultimate wordline. Spreading the reads on two pages reduces the number of errors, but in this case four wordlines (i.e., 12 pages) become corrupted

Take away: for the SSD controller predict the read disturb phenomenon per page is HARD!!

Implications on SSDs

- **Read disturb info are usually collected "per block" and not "per page" → metadata are too big**

- To understand the read disturb level of a block it is usual to **leverage the ECC**…

- **When the number of errors** in a page due to read disturb **reaches a threshold that is defined by the SSD firmware, the entire block** where the page belongs **is relocated** on another available in the SSD, and then erased to reset the disturb effect

- **Due to a concentrated read disturb, the block relocation trigger rate could heavily increase→ higher P/E cycle count → reliability issues**

- **Therefore the actual read disturb level has to be reduced (usually by 20%)**

Conclusions

- In this work we have investigated the differences between uniform and concentrated read disturb effects in mid-1X TLC NAND Flash memories
- By characterizing the concentrated read access mode, it is appreciable that the errors profile on the wordlines is similar to the uniform case except for the two neighbors closer to the one where the read accesses are concentrated
- The implications on the enterprise SSD are evident: concentrated read disturb increases the number of P/E cycles because block relocation is much more frequent.
- …

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Thank you

Q&A