Measuring 3D NAND Voltage Distributions and Optimized Read Threshold Calibration

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Think Bucket

- 3D array of buckets
- fill with water to store information
- we can overfill, spill, leak, etc
Measuring the Water Level

- insert stick

- stick is dry – read as 1

- stick is wet – read as 0
How Wet is Wet?

• accurate measurement of water level?
• insert multiple sticks of different lengths
Getting the Distribution
Making the Connection

- bucket – floating gate
- water – electrons
- stick – read threshold
Well… Almost

- NAND limitations
  - can we change the read thresholds?
  - can we read using a single threshold?
  - is the range of thresholds available large enough to capture the extremes of the voltage distribution?
  - can me make these measurements quickly?
The Technical Part (1)
The Technical Part (2)

- set all read levels to minimum threshold
The Technical Part (3)

- for each read level, record number of cells below threshold
• for each read level, increase the threshold by the same amount
The Technical Part (5)

- for each read level, record number of cells below new threshold
The Technical Part (6)

- for each read level, subtract the previous threshold number from the current
The Technical Part (7)

• for each real level, increase the threshold by the same amount and repeat etc…
• for each real level, increase the threshold by the same amount and repeat etc…
The Technical Part (9)

• stitch together voltage distribution for each read level to get overall distribution

• NOTE: the overlap tells us how far apart each default read level is!!!
3D TLC NAND Voltage Distribution (Vendor B) - 1500 PE Cycles, 1 Minute @ 30°C
3D TLC NAND Voltage Distribution (Vendor B) - 1500 PE Cycles, 8 Months @ 30°C
Wordline RBER (Vendor C) - <100 PE Cycles, 1 Minute at 30°C
notice the grouping of RBER for each layer
grouping typically demarked by different RBER behaviour in the 1st wordline of the layer
What are They Good For?

- optimized read threshold calibration
  - reduce raw bit error rate
    - improves hard ECC correction performance
  - improve quality of soft data (LLR generation)
    - improves soft ECC correction performance
- NAND quality estimation
  - theoretic channel capacity
Read Voltage Calibration

• minimize cell error rate over all read level configurations
  • for TLC there are 7 read levels, scales badly
• approximate by minimizing error rate at each read level individually
  • low complexity, reasonably accurate in most situations
3D TLC NAND Voltage Distribution (Vendor B) - 1500 PE Cycles, 8 Months @ 30°C
3D TLC NAND Voltage Distribution (Vendor B) - 1500 PE Cycles, 8 Months @ 30°C
- average raw bit error rate drops from $10^{-1.7}$ to $10^{-2.5}$
- from 1 in 50 to 1 in 320
- BCH code is still enough!
Want to Learn More?

• visit our booth – 800
• NAND tester live demonstrations (with 3D NAND)!
• discussion!
• and more…!