Highly Reliable SSDs for Enterprise Storage with Dynamic $V_{TH}$ Optimization and Auto Data Recovery

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Outline

- Introduction
- Read Level Shifting [1]
- Dynamic $V_{TH}$ Optimization (DVO) [2]
- Auto Data Recovery (ADR) [2]
- Summary

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Error of NAND Flash Memory

Electron injection

Electron ejection

# of cells

$V_{TH}$ is increased due to program and read disturb.

$V_{TH}$ is decreased due to data retention.
The amounts of $V_{\text{Ref}}$ shift are increased as the retention time increases.

The optimal $V_{\text{Ref}}$'s are different among ‘A’ to ‘G’ states. [2]
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Read Level Shifting [1]

- The $V_{\text{Ref}}$ is fixedly shifted down when the ECC fails to correct errors.

\[ V_{\text{Ref1}} - \Delta V_1 \quad V_{\text{Ref2}} - \Delta V_2 \quad V_{\text{Ref3}} - \Delta V_3 \]

Problem of Read Level Shifting

- Measured $V_{\text{Ref}}$ shift differs among states, ‘A’ to ’G’ during the data-retention.

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Dynamic $V_{TH}$ Optimization (DVO) [2]

- Dynamic $V_{TH}$ Optimization is combination of $V_{TH}$ Space Control and Adaptive $V_{Ref}$ Shift.

Adaptive $V_{\text{Ref}}$ Shift (AVS) [2]

- AVS selects the optimal $V_{\text{Ref}}$ for each state based on the retention time.

The retention time is estimated by the BER and the write/erase cycles. [3] 

Errors are decreased by using $V_{TH}$ Space Control.

$V_{TH}$ Space Control (VSC) [2]

Dominant errors are decreased.

Method of Controlling Space of $V_{TH}$ Distribution.

The population of ‘1’ or ‘0’s can be increased by $V_{TH}$ Space Control.

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Effects of $V_{TH}$ Space Control (VSC)

- Data-retention errors of ‘C’ and ‘E2’ are decreased.

### Table

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<th># of cells</th>
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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E2</th>
<th>F</th>
<th>G</th>
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</tbody>
</table>

1Xnm, TLC, Write/erase cycle: 200, $T_{Retention}$: 28 days

### Figure

- DVO (AVS + VSC)
- $V_{Ref}$ shift

### Reference

By using AVS and VSC, 80% BER reduction is achieved compared with Read Level Shifting.

- No $V_{\text{Ref}}$ shift
- Asymmetric coding [4]
- Read Level Shifting [1]
- Adaptive $V_{\text{Ref}}$ Shift
- AVS + VSC

1Xnm, TLC, @85degC
Write/erase cycle : 200
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Read Hot Data and Read Cold Data

- A high locality exists among read data.
- $V_{TH}$ is increased in read hot blocks.
- Data-retention occurs in blocks with cold data.


Auto Data Recovery [2]

- Auto Data Recovery mixes both hot and cold data in the same block to compensate both errors.

1Xnm, TLC, @85degC, Write/erase cycle: 1k

Data retention error is dominant.

V_{TH} increase and decrease are balanced.

Read disturb error is dominant.

-15%  -18%

Read cold block
Read hot block
Read warm block

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Summary
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<table>
<thead>
<tr>
<th>Technique</th>
<th>BER Reduction</th>
<th>Pros</th>
<th>Cons</th>
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</thead>
<tbody>
<tr>
<td>Read level shifting [1]</td>
<td>Baseline</td>
<td>• No Overhead</td>
<td>• Lower Reliability</td>
</tr>
<tr>
<td>Adaptive $V_{\text{Ref}}$ Shift [2]</td>
<td>-61%</td>
<td>• Higher Reliability</td>
<td>• Slower Read</td>
</tr>
<tr>
<td>Dynamic $V_{\text{TH}}$ Optimization [2]</td>
<td>-80%</td>
<td>• Faster Read</td>
<td>• Table Overhead</td>
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</table>

D.R. : Data Retention, R.D. : Read Disturb

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Thank you for your attention

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