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

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Shogo Hachiya, Shuhei Tanakamaru and Ken Takeuchi
Chuo University

Outline

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

[1] T. Parnell, IMW, Tutorial, 2014.
[2] T. Tokutomi et al., "Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

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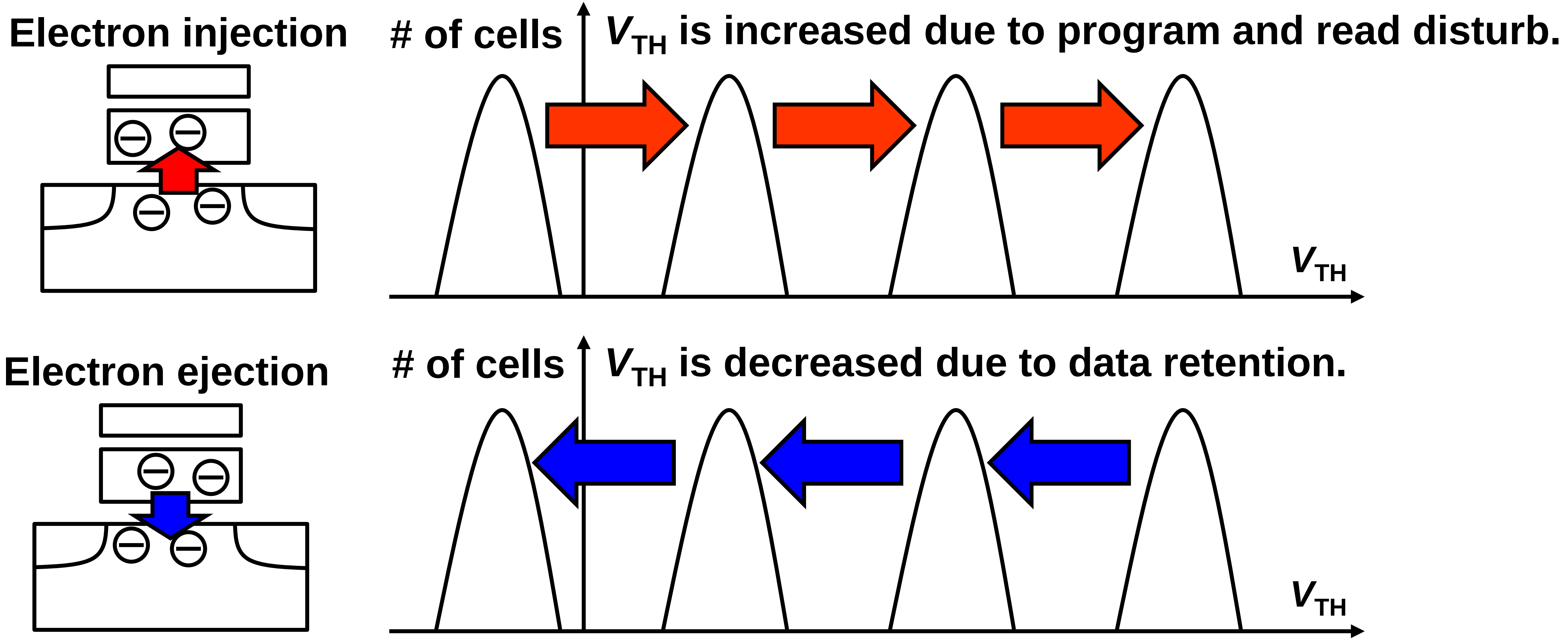
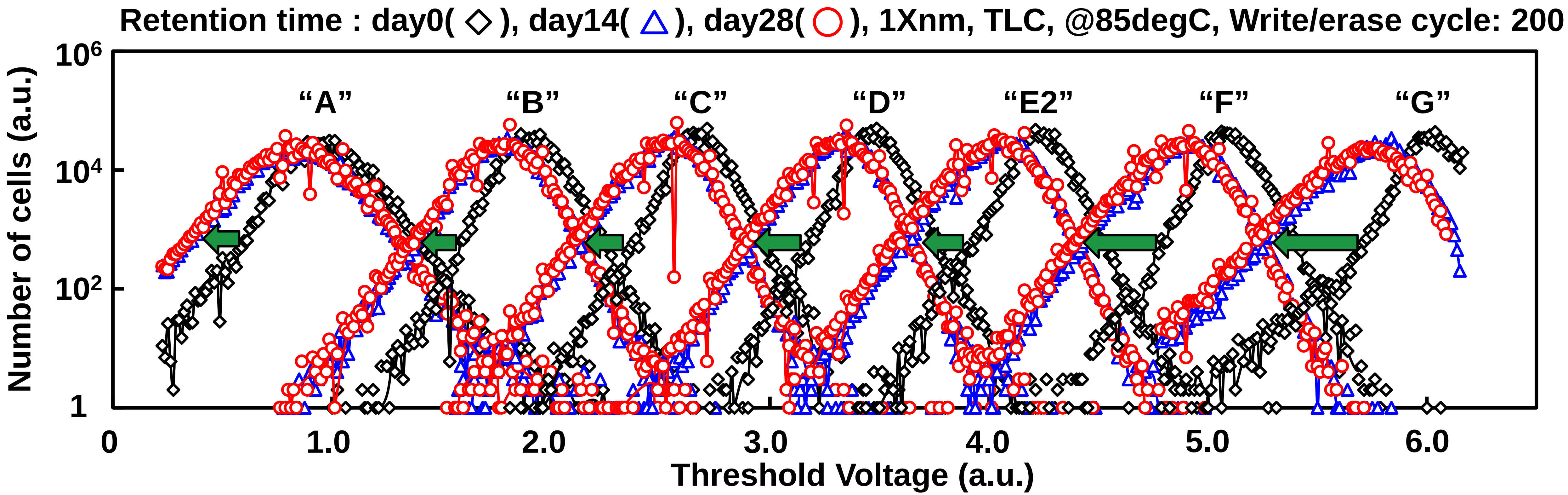
Error of NAND Flash Memory



Measured V_{TH} Distribution After Data-retention



- The amounts of V_{Ref} shift are increased as the retention time increases.
- The optimal V_{Ref}'s are different among 'A' to 'G' states. [2]

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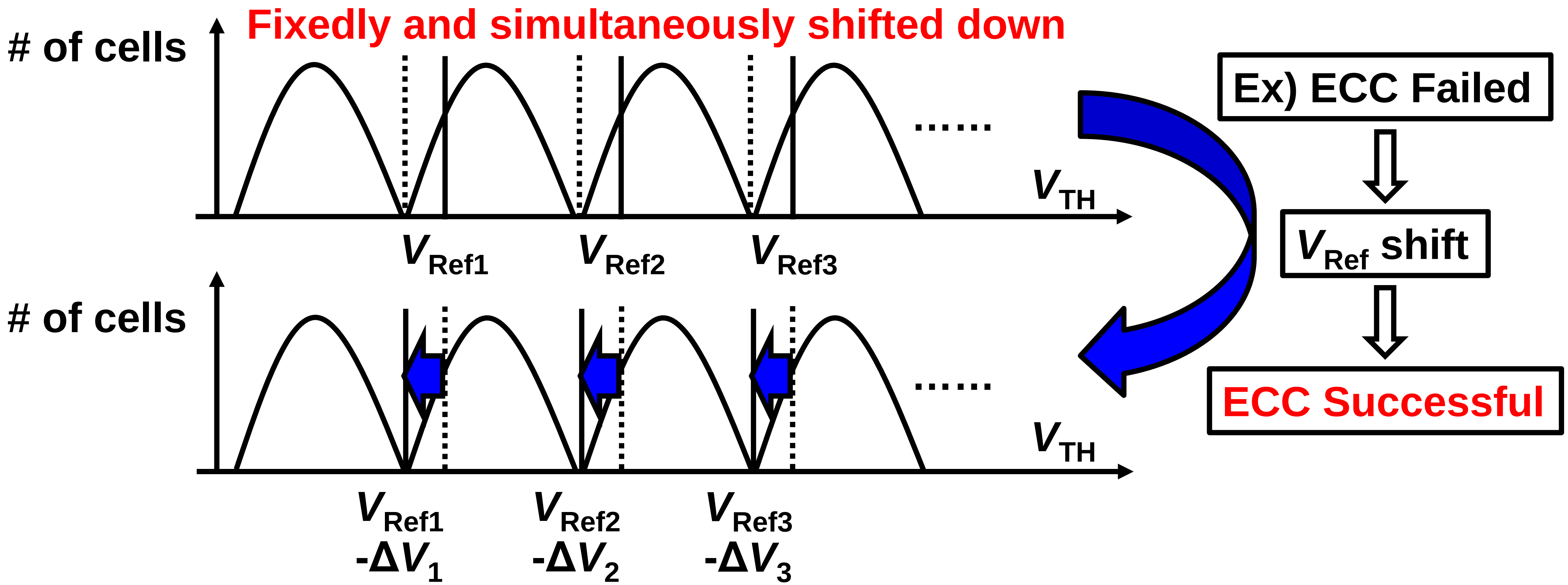
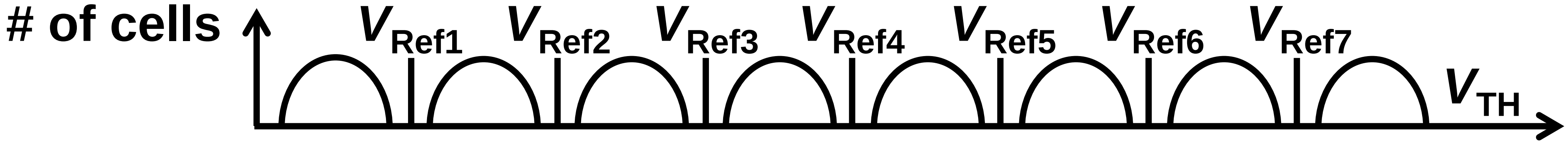
Read Level Shifting [1]

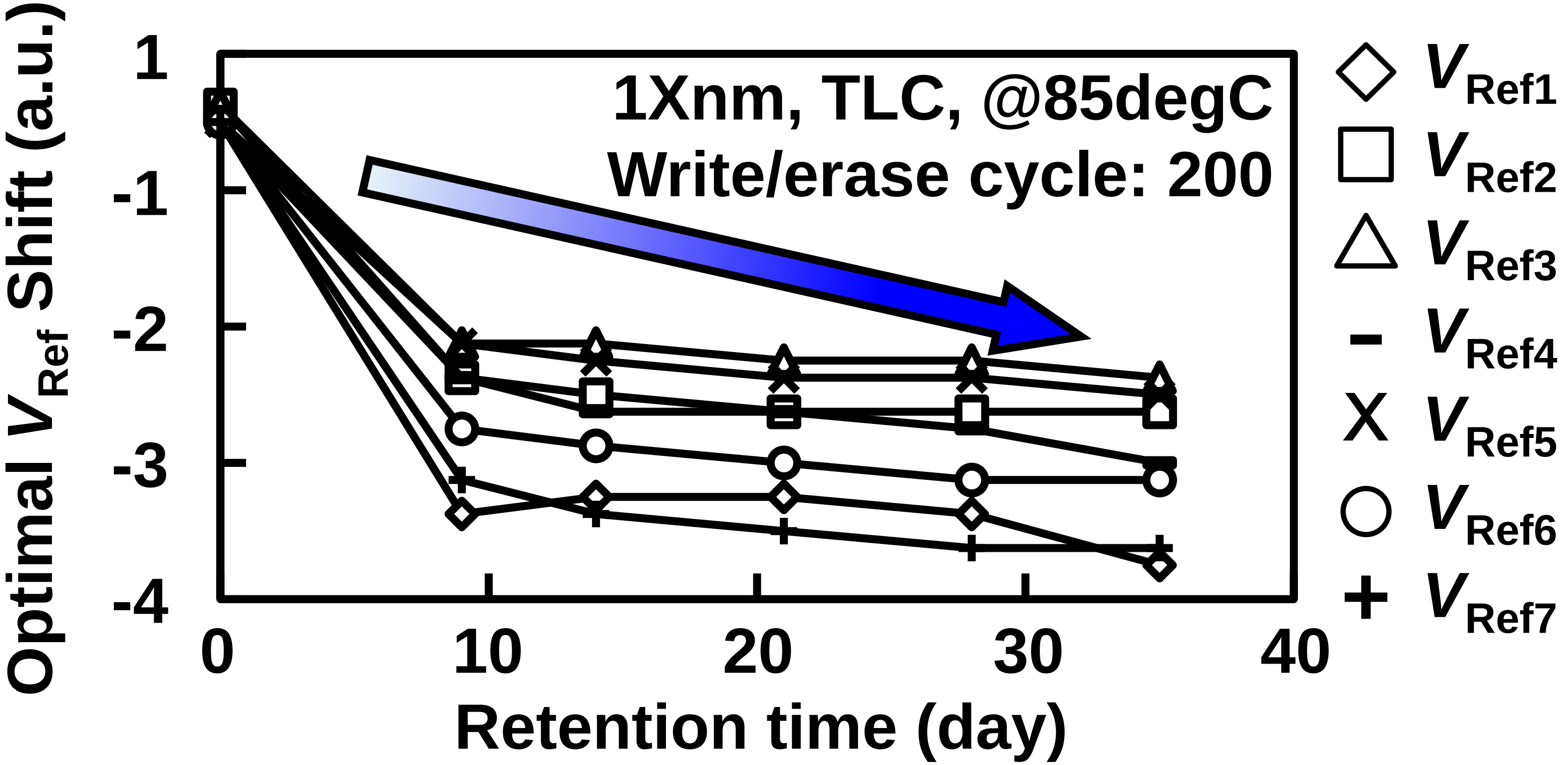


- **The V_{Ref} is fixedly shifted down when the ECC fails to correct errors.**

[1] T. Parnell, IMW, Tutorial, 2014.

Problem of Read Level Shifting





- Measured V_{Ref} shift differs among states, 'A' to 'G' during the data-retention.

[2] T. Tokutomi et al., "Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

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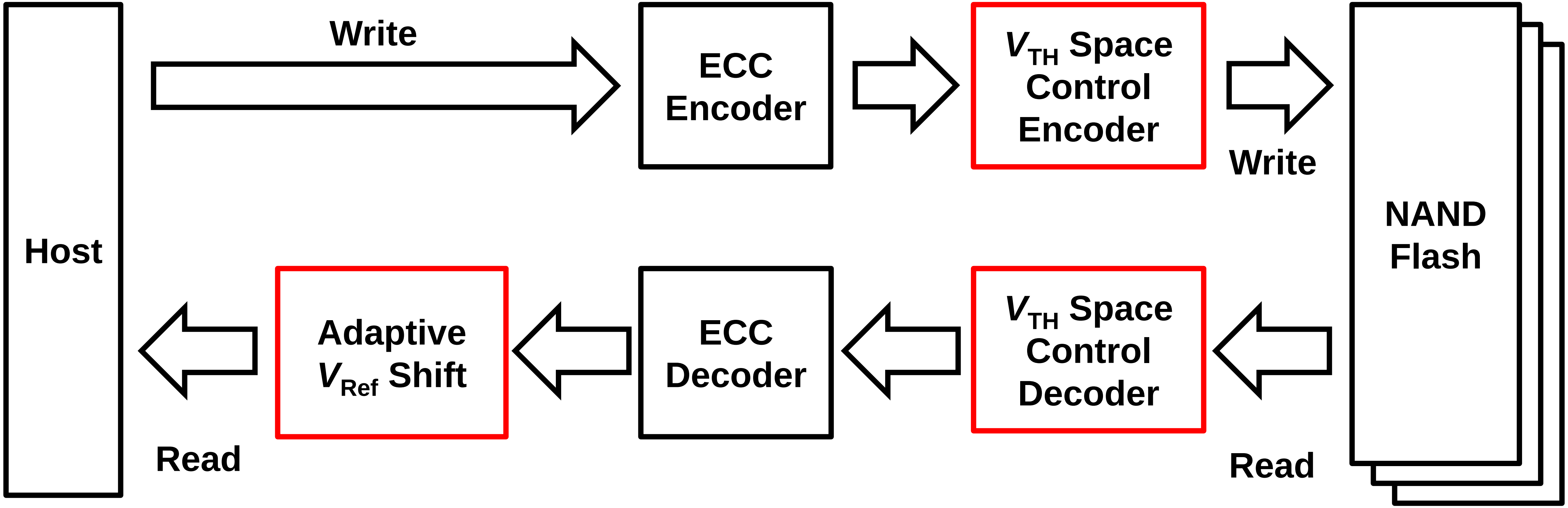
Dynamic V_{TH} Optimization (DVO) [2]

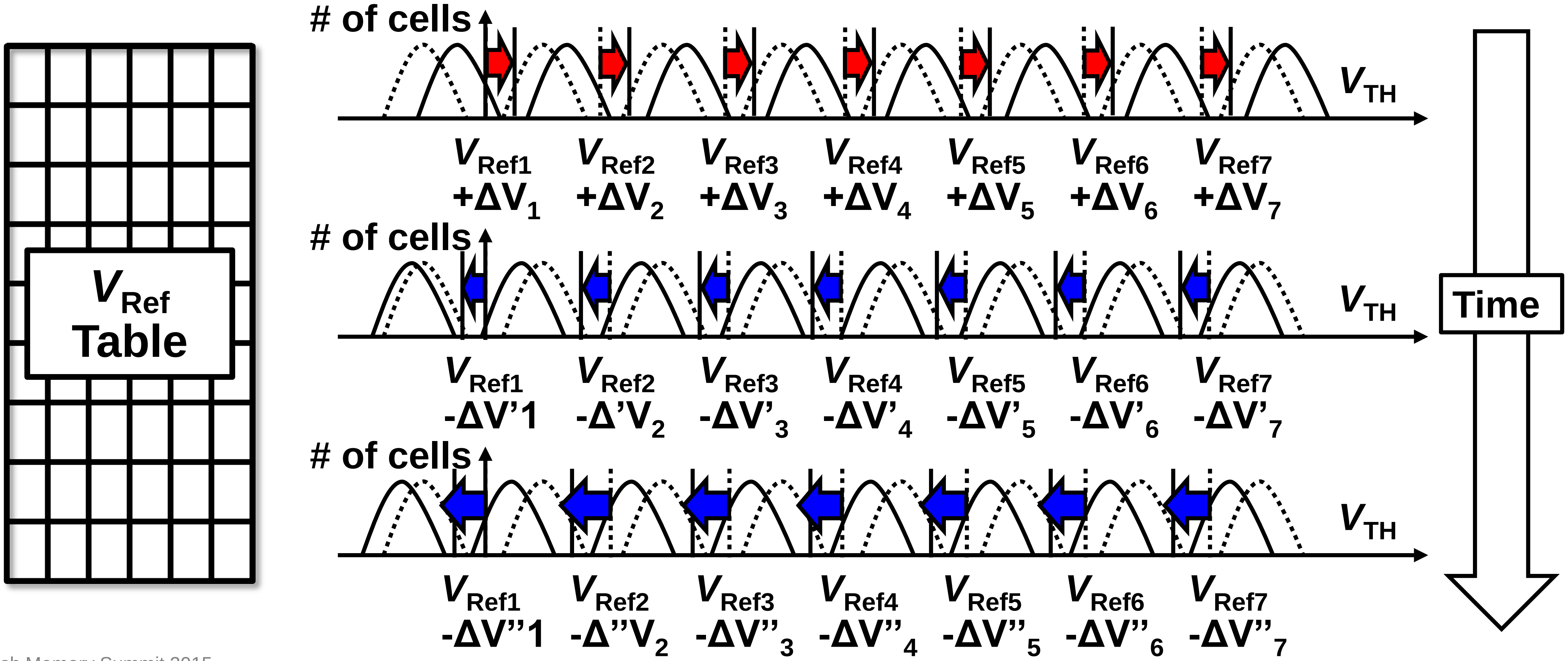


- Dynamic V_{TH} Optimization is combination of V_{TH} Space Control and Adaptive V_{Ref} Shift.

[2] T. Tokutomi et al., "Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

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

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



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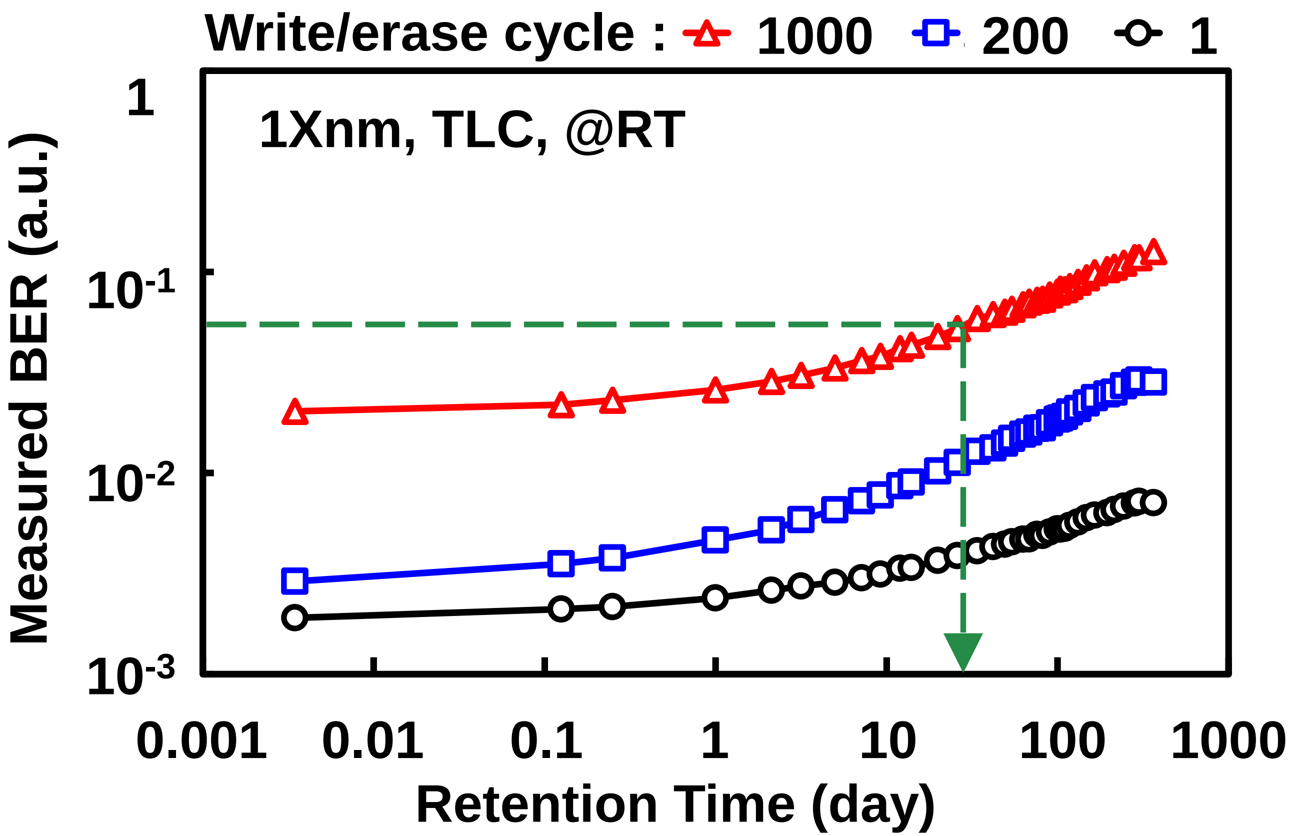
Method of Estimating Data Retention Time



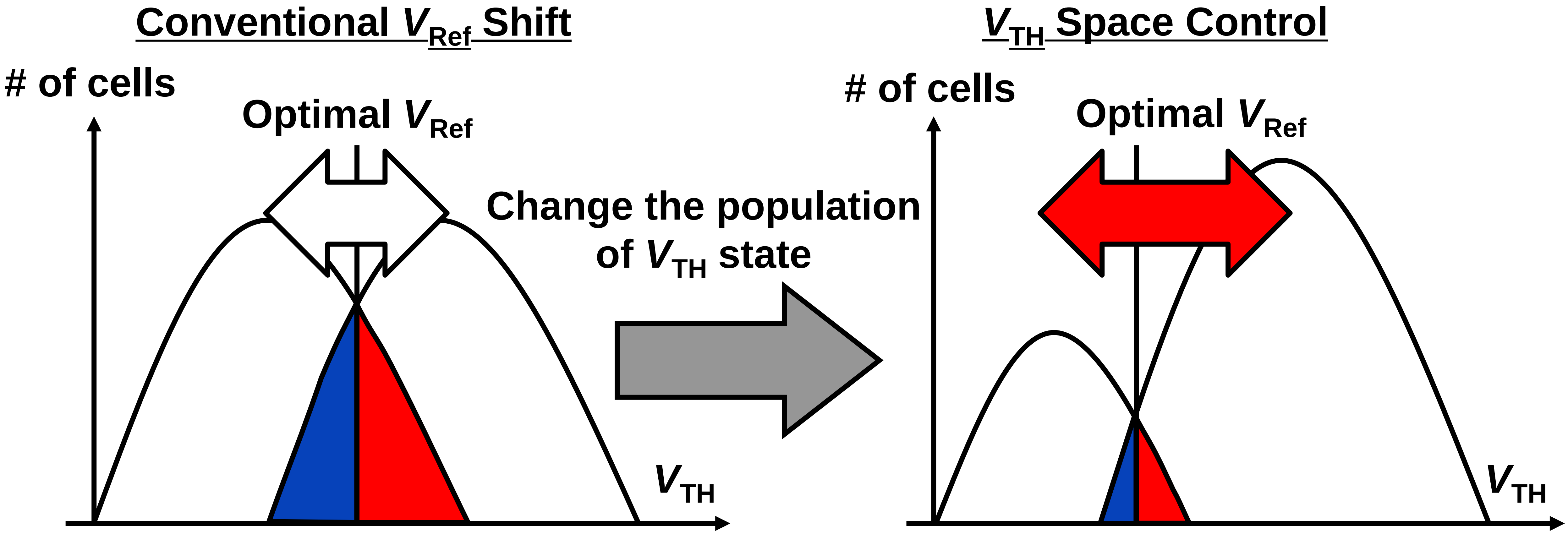
$T_{Retention}$ Table

	Day0	----	Day100
$N_{W/E}$=1	BER_{1_0}	----	BER_{1_0}
$N_{W/E}$=100	BER_{100_0}	----	BER_{100_100}
⋮	⋮		⋮
$N_{W/E}$=1000	BER_{1000_0}	----	BER_{1000_100}

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

[3] T. Tokutomi et al., "Advanced Error Prediction LDPC for High-Speed Reliable TLC NAND-based SSDs," IMW, pp. 99-102, May 2014.

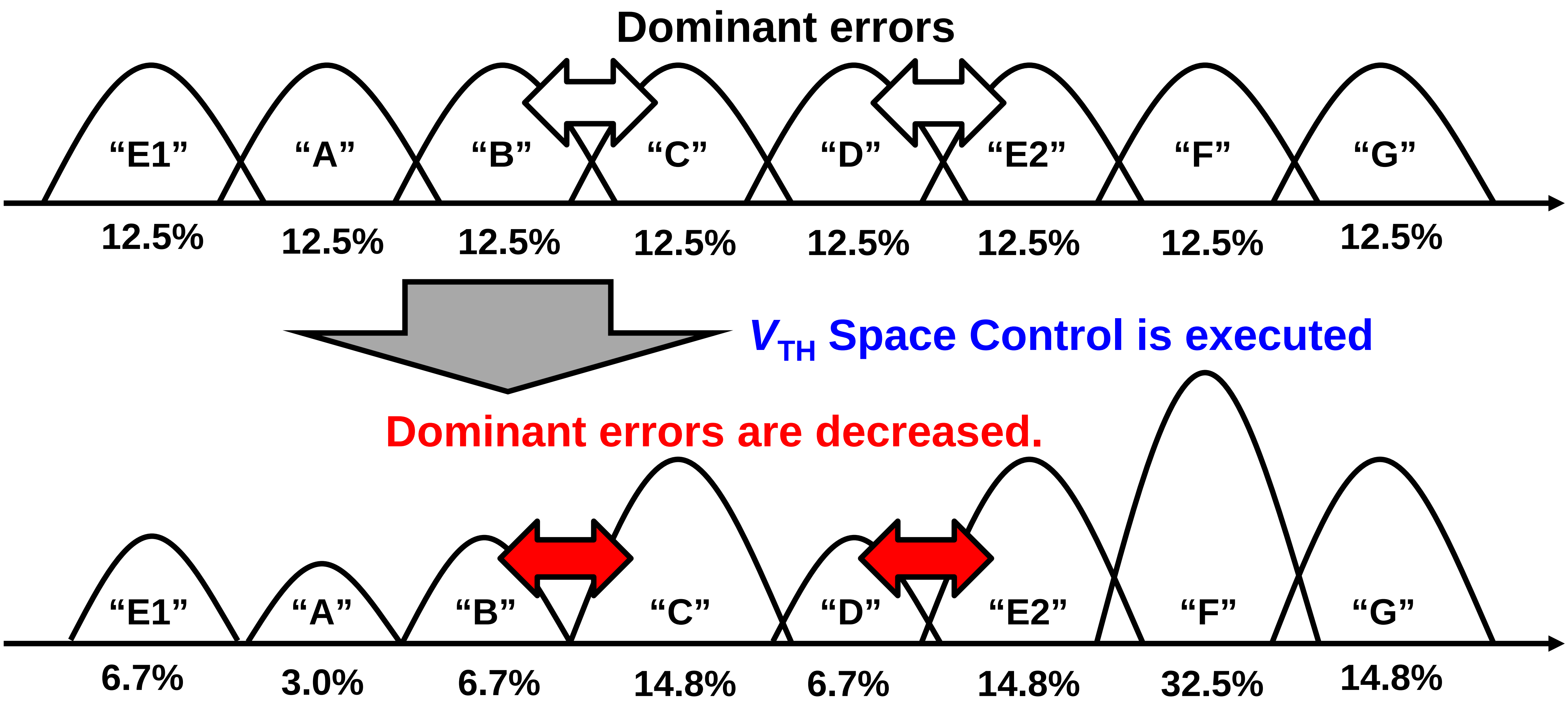
V_{TH} Space Control (VSC) [2]



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

[2] T. Tokutomi et al., "Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

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



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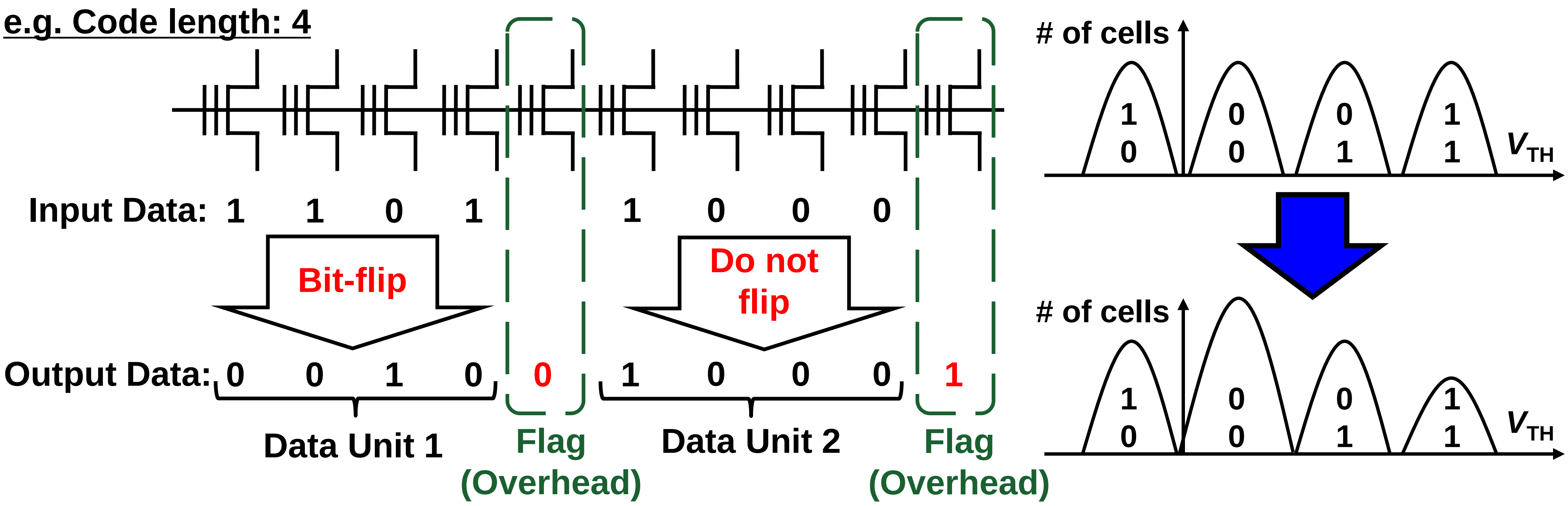
Method of Controlling Space of V_{TH} Distribution.

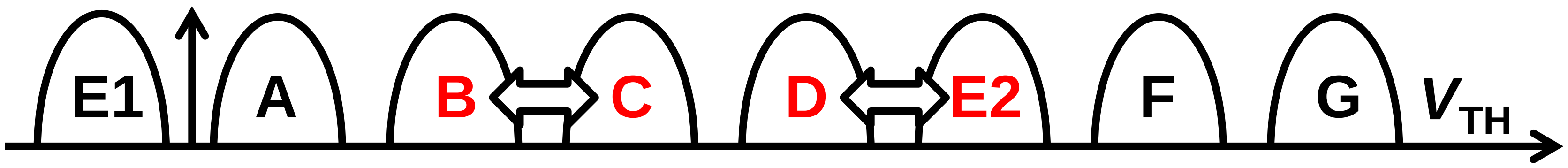


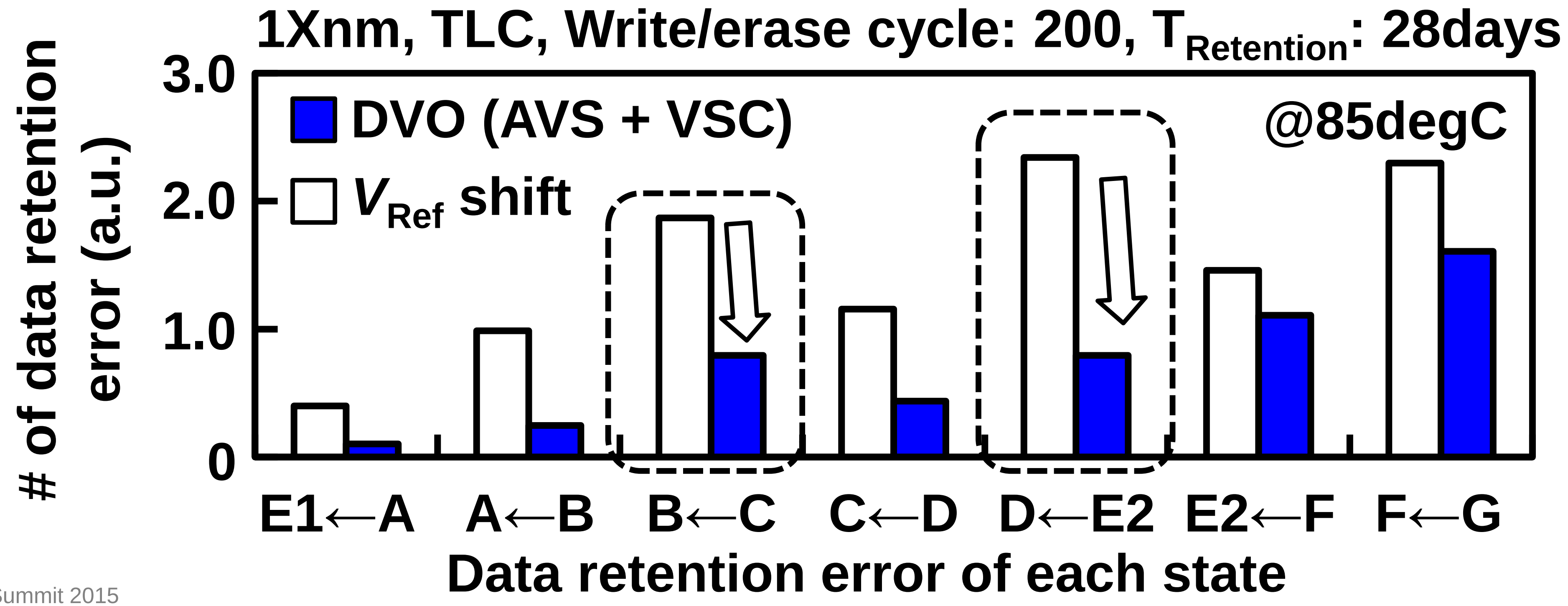
- The population of ‘1’ or ‘0’s can be increased by V_{TH} Space Control.

[4] S. Tanakamaru at al., “95%-lower-BER 43%-lower-power intelligent solid-state drive (SSD) with asymmetric coding and stripe pattern elimination algorithm,” in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2011, pp. 204-205.

Effects of V_{TH} Space Control (VSC)

- Data-retention errors of 'C' and 'E2' are decreased.





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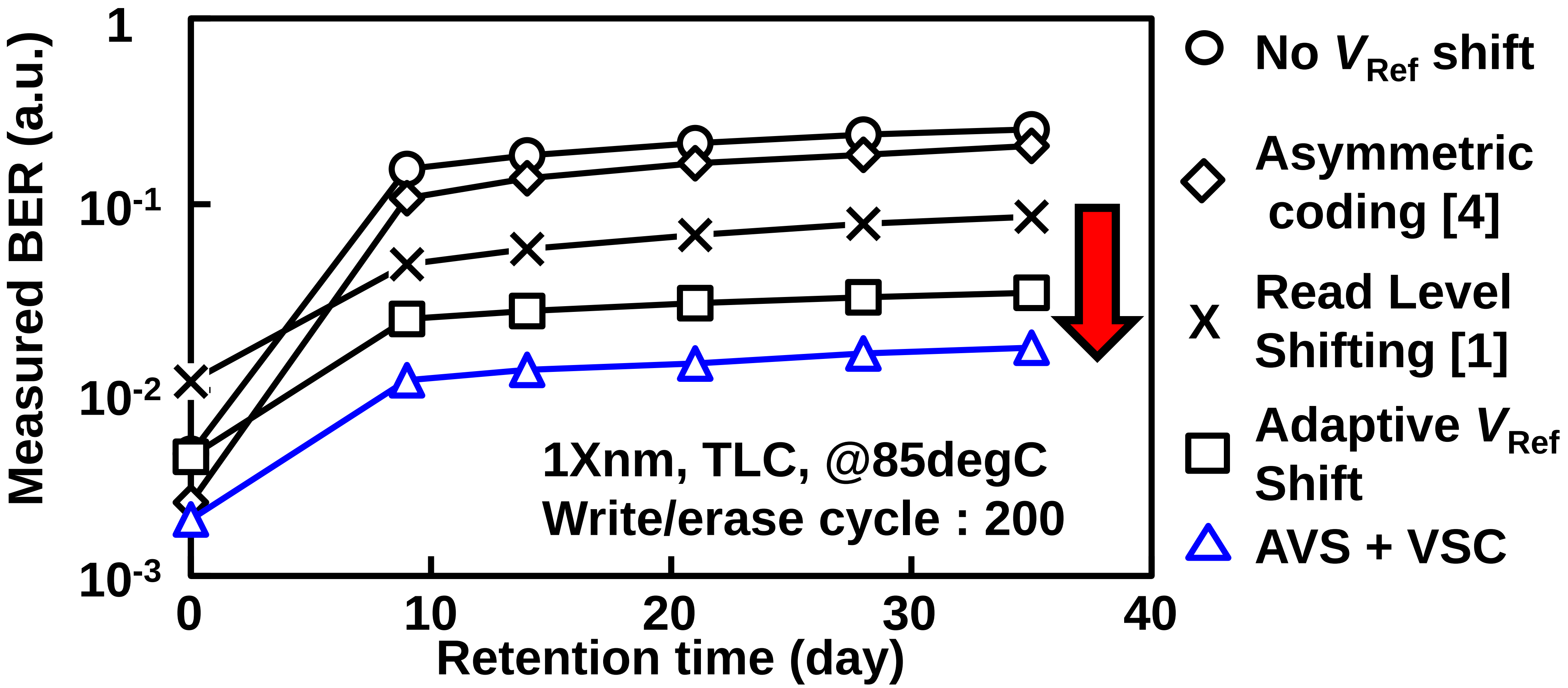
Result of Each Technique



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

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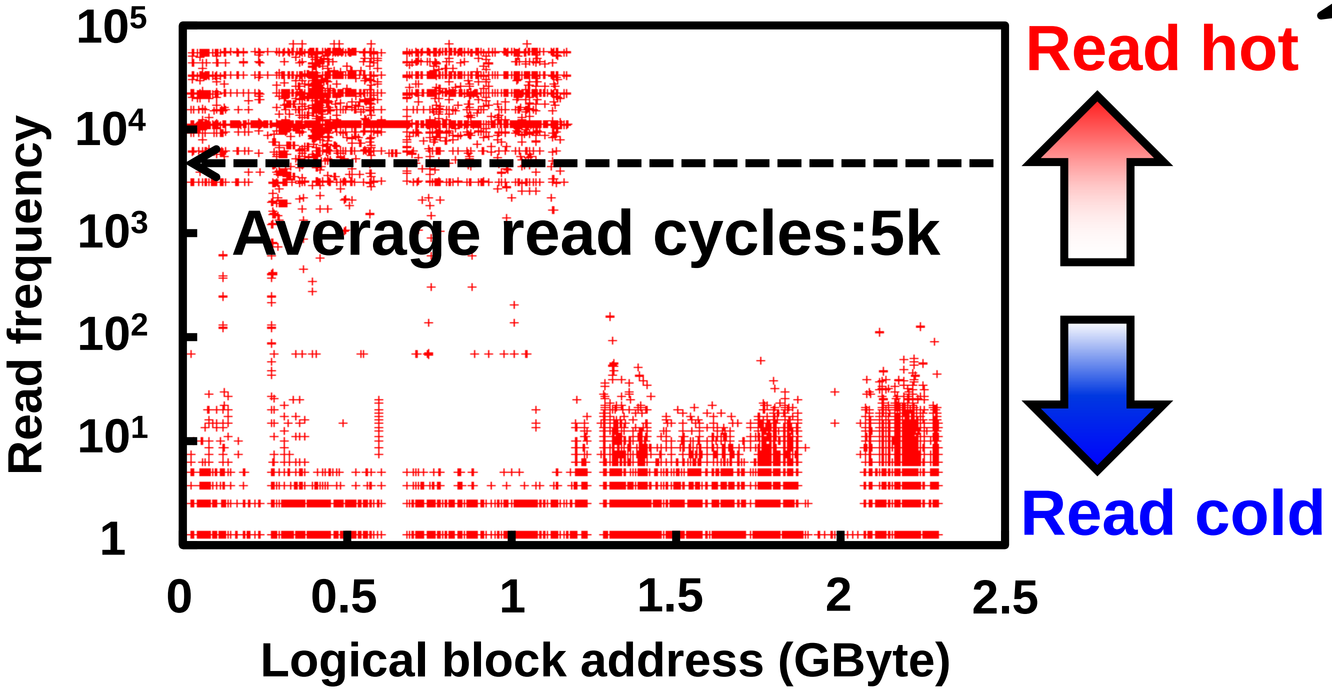
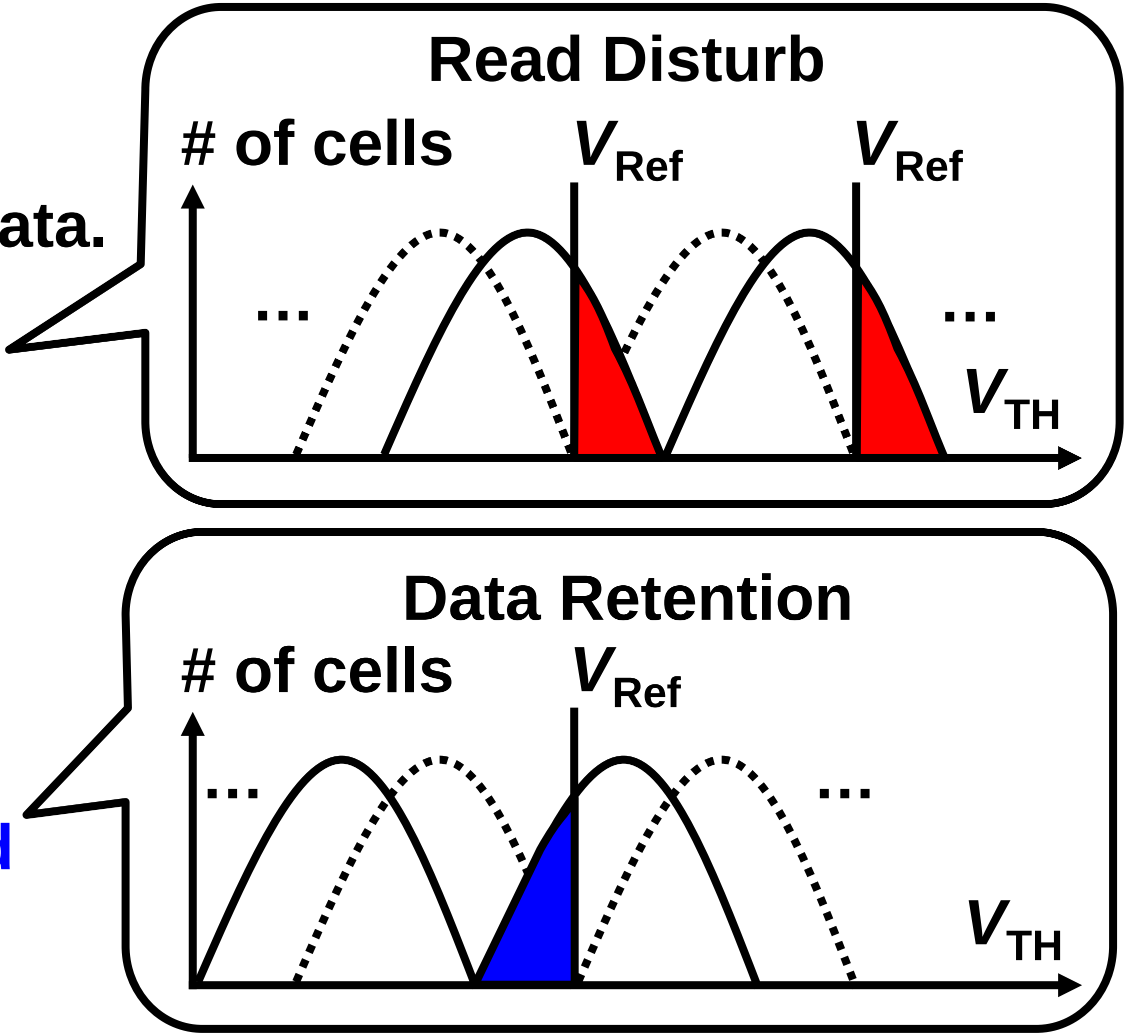
Read Hot Data and Read Cold Data

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

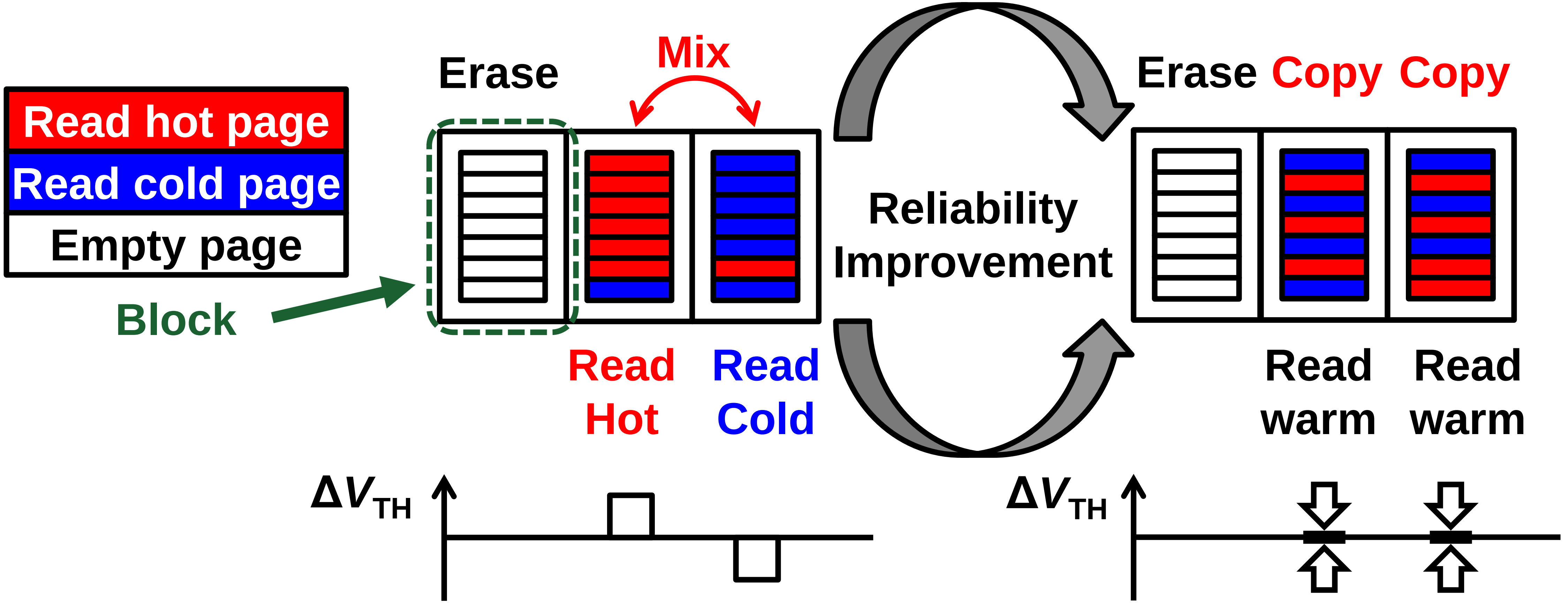




Read frequency distribution of proxy server (MSR Cambridge traces, http://iotta.snia.org/traces/388)

[2] T. Tokutomi et al., "Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

Auto Data Recovery [2]



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

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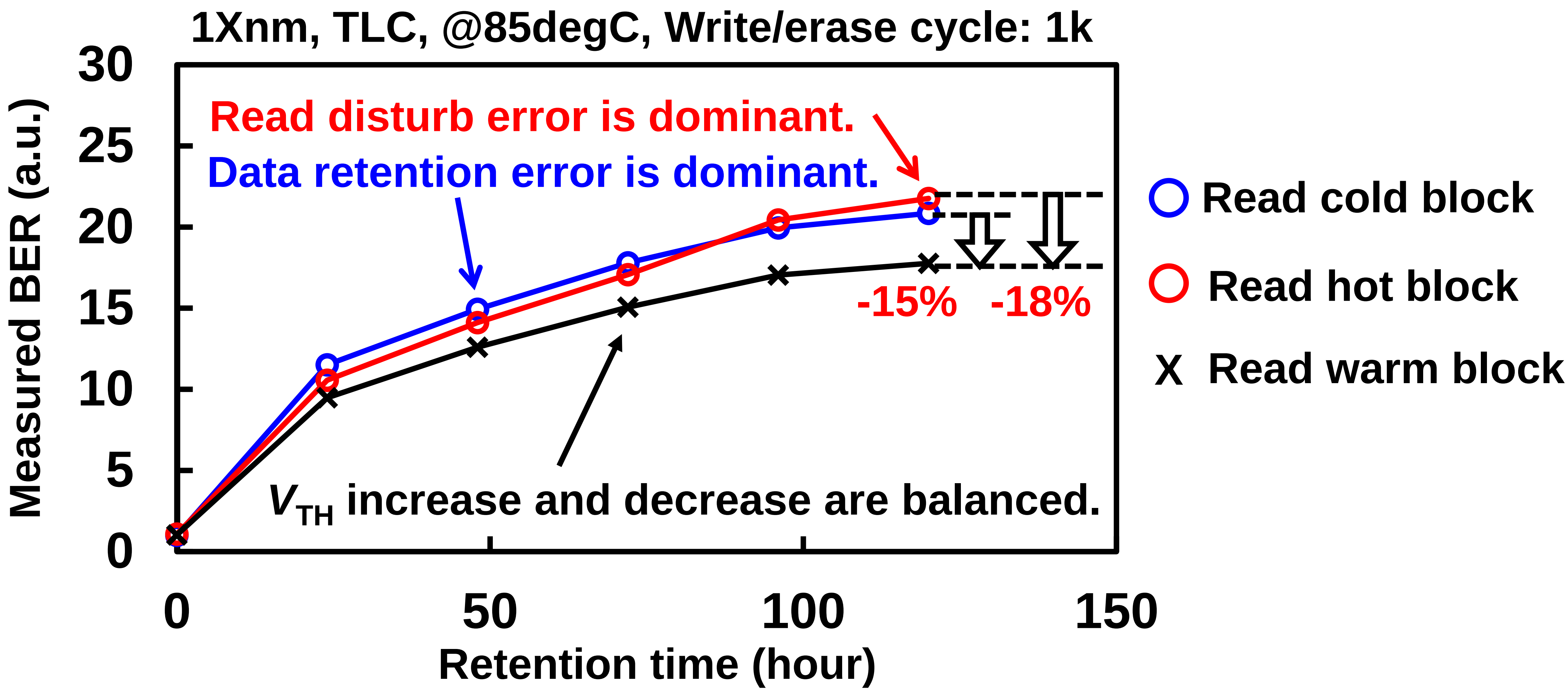
Result of Auto Data Recovery



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

<table>
<tr><th>Technique</th><th colspan="2">BER Reduction</th><th>Pros</th><th>Cons</th></tr>
<tr><td>Read level shifting [1]</td><td colspan="2">Baseline</td><td>• No Overhead</td><td>• Lower Reliability
• Slower Read</td></tr>
<tr><td>Adaptive V_{Ref} Shift [2]</td><td colspan="2">-61%</td><td rowspan="2">• Higher Reliability
• Faster Read</td><td rowspan="2">• Table Overhead</td></tr>
<tr><td>Dynamic V_{TH} Optimization [2]</td><td colspan="2">-80%</td></tr>
<tr><td rowspan="2">Auto Data Recovery [2]</td><td>D.R. BER</td><td>R.D. BER</td><td rowspan="2">• Higher Reliability</td><td rowspan="2"></td></tr>
<tr><td>-15%</td><td>-18%</td></tr>
</table>

[1] T. Parnell, IMW, Tutorial, 2014.
[2] T. Tokutomi et al., “Enterprise-Grade 6x Fast Read and 5x Highly Reliable SSD with TLC NAND Flash Memory for Big-Data Storage,” in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, Feb. 2015, pp. 140-141.

Thank you for your attention

This work is partially supported by CREST/JST