

P&S Modern SSDs

Understanding and Designing
Modern NAND Flash-Based Solid-State Drives

Dr. Jisung Park
Prof. Onur Mutlu

ETH Zürich

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Today's Agenda

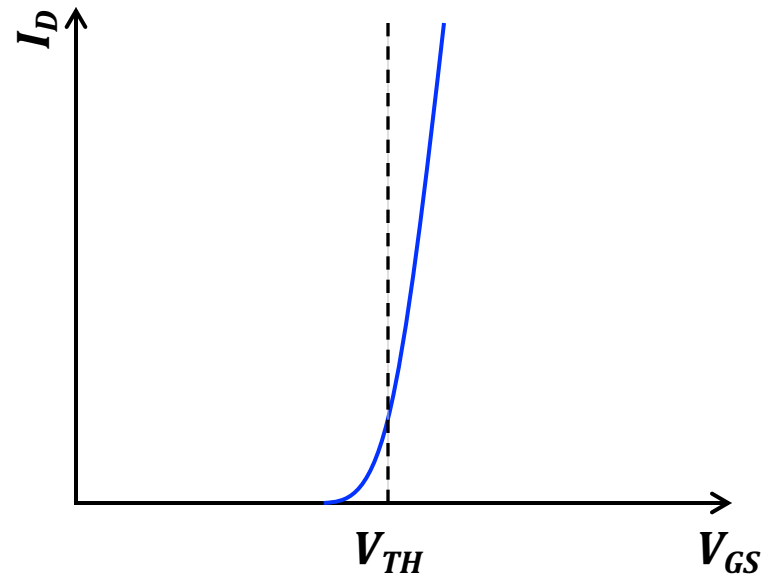
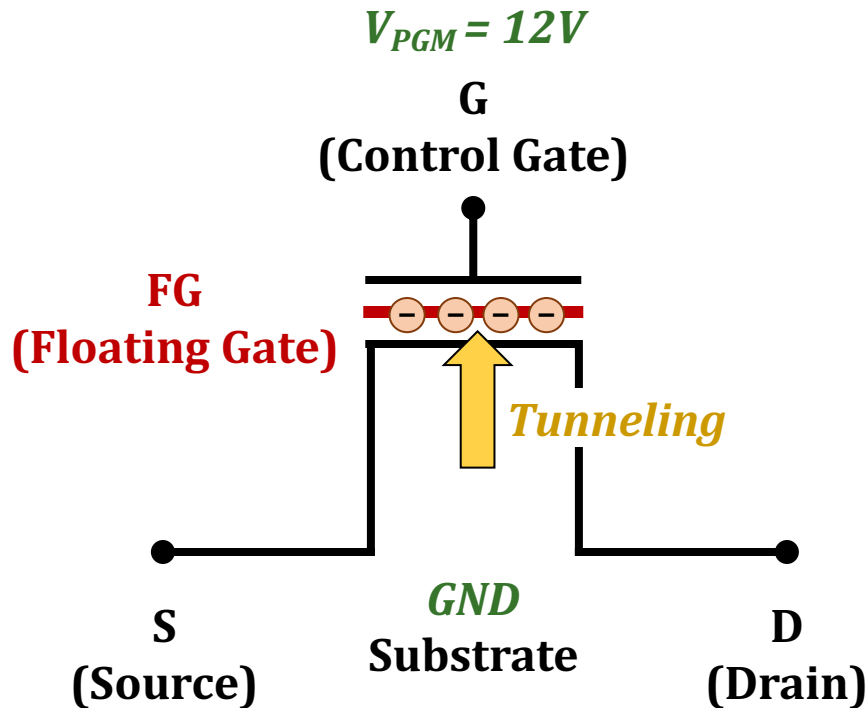
- Progress Review
- Basic NAND Flash Operation

Progress Review

- Refactoring the simulation engine
 - Push your modifications into the repository when ready
- How does the simulation engine work?
- How did you improved?
- How did you validated your modifications?
- Any Questions?

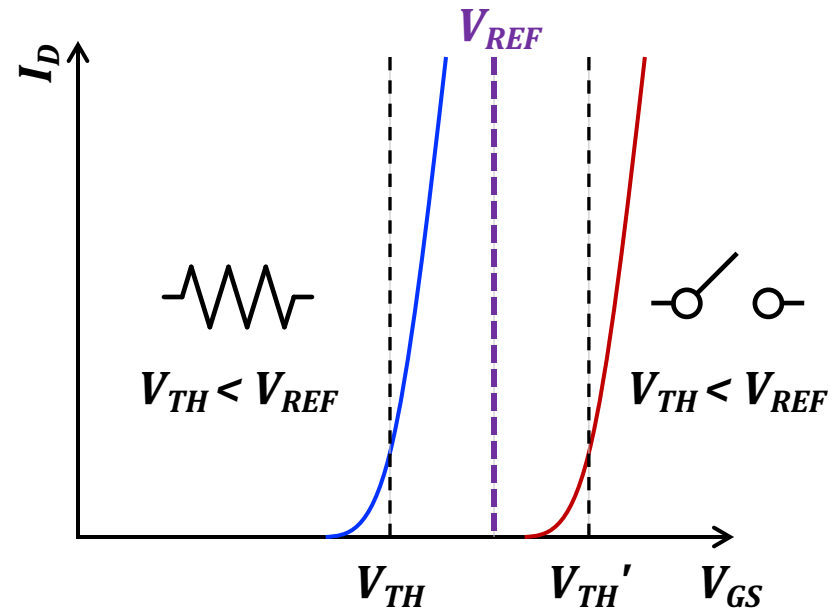
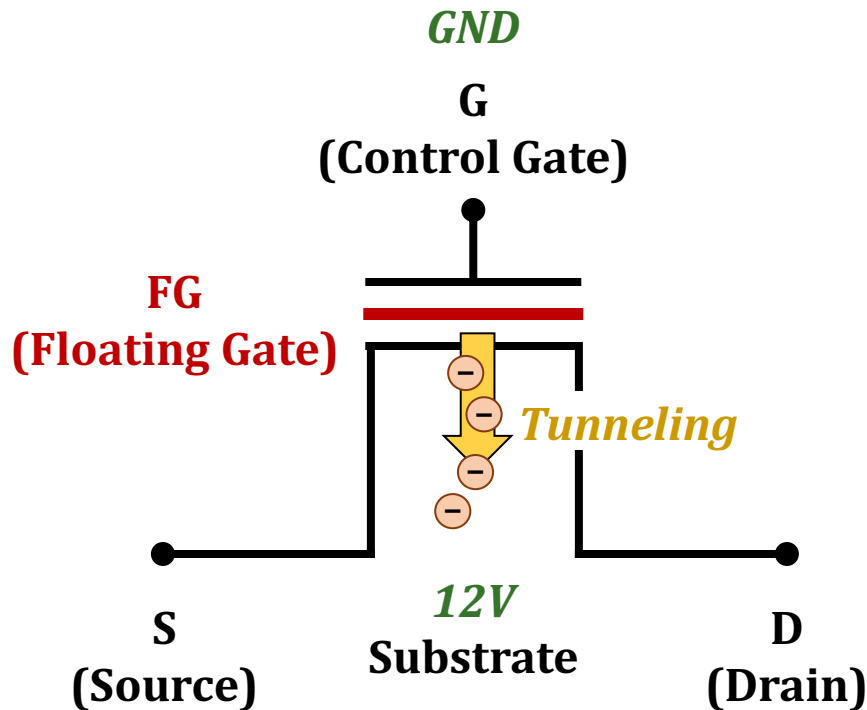
Recap: Program/Erase/Read a Flash Cell

- Basically, a flash cell is a transistor
 - w/ a special material: Floating gate (2D) or Charge trap (3D)
 - Can hold electrons in a non-volatile manner



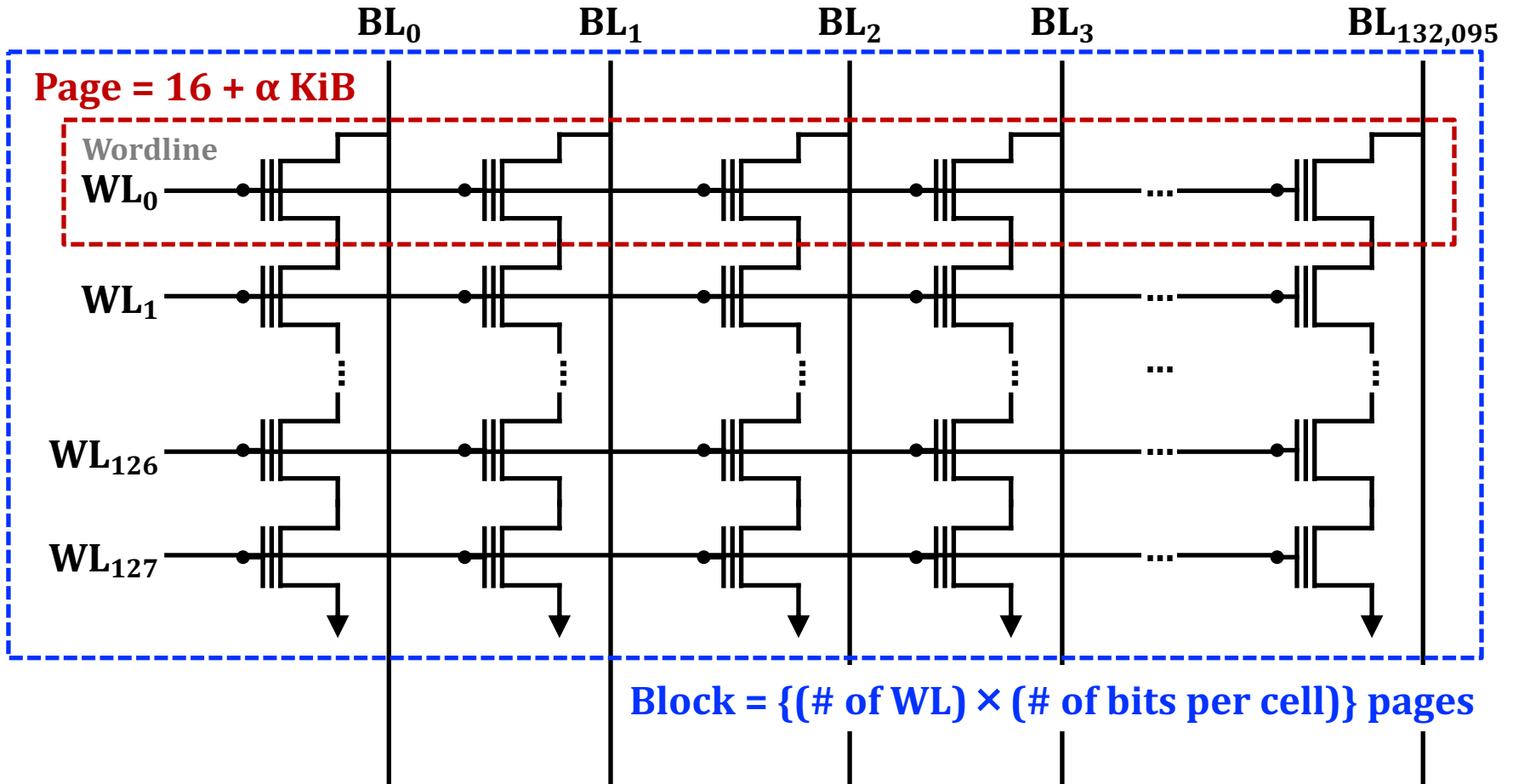
Recap: Program/Erase/Read a Flash Cell

- Basically, it is a transistor
 - w/ a special material: Floating gate (2D) or Charge trap (3D)
 - Can hold electrons in a non-volatile manner
 - Changes the cell's threshold voltage (V_{TH})



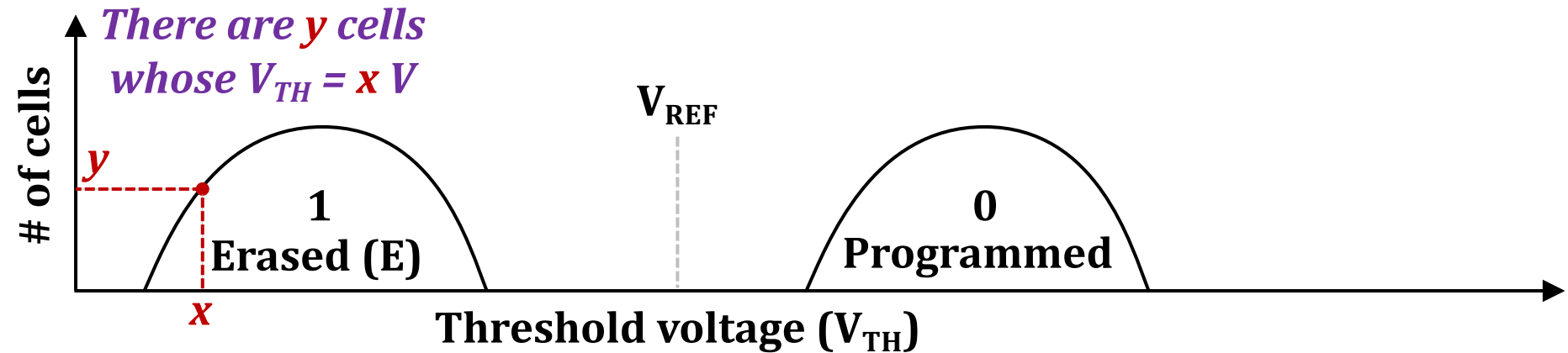
Recap: Pages and Blocks

- A large number ($> 100,000$) of cells operate concurrently



Threshold Voltage Distribution

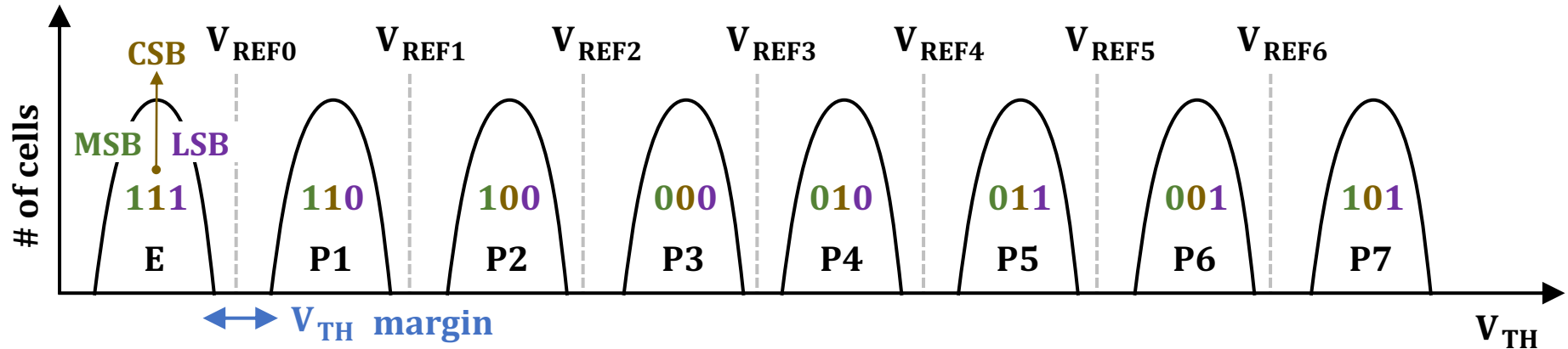
- V_{TH} distribution of **cells** in a **programmed page/block/chip**



- Why **distribution**? **Variations** across the cells
 - Some cells are more easily programmed or erased
- Why **(almost) the same shape**?
 - Every data is stored after **randomized for better reliability**
 - In reality, V_{TH} states' shapes can be different, but there **areas are almost the same**

V_{TH} Distribution of MLC NAND Flash

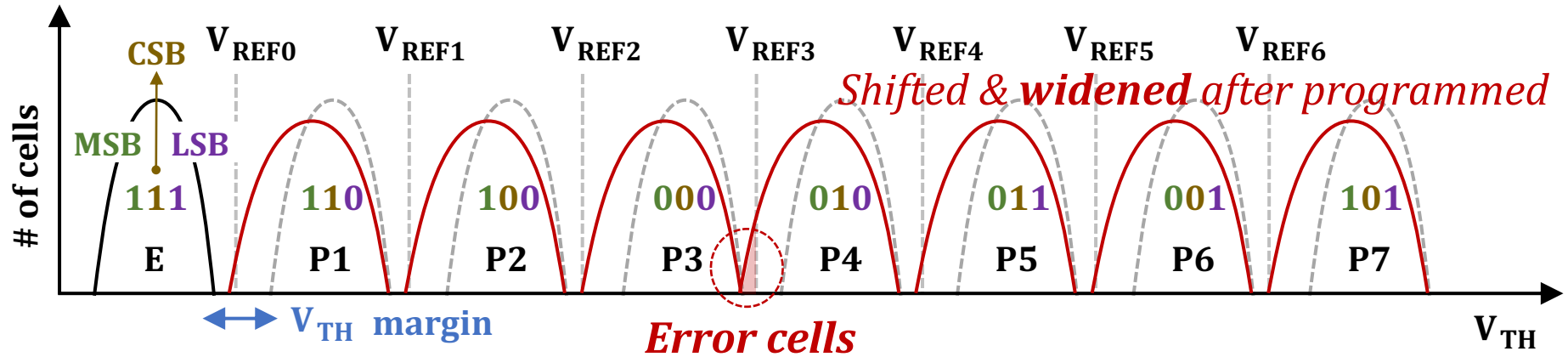
- Multi-level cell (MLC) technique
 - $2^m V_{TH}$ states required to store m bits in a single flash cell



- Limited width of the V_{TH} window: Need to
 - Make each V_{TH} state narrow
 - Guarantee sufficient margins b/w adjacent V_{TH} states

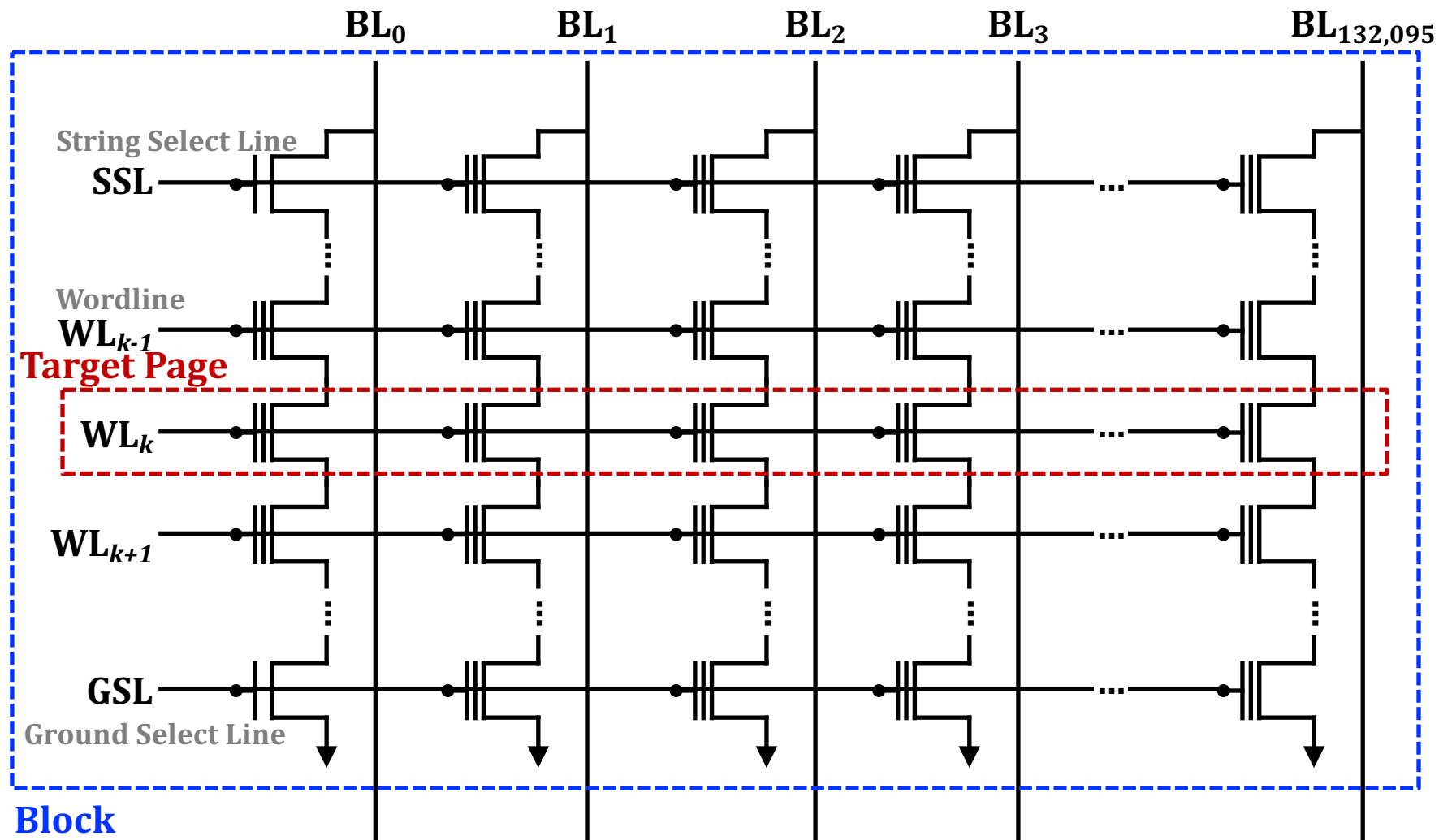
V_{TH} Distribution of MLC NAND Flash

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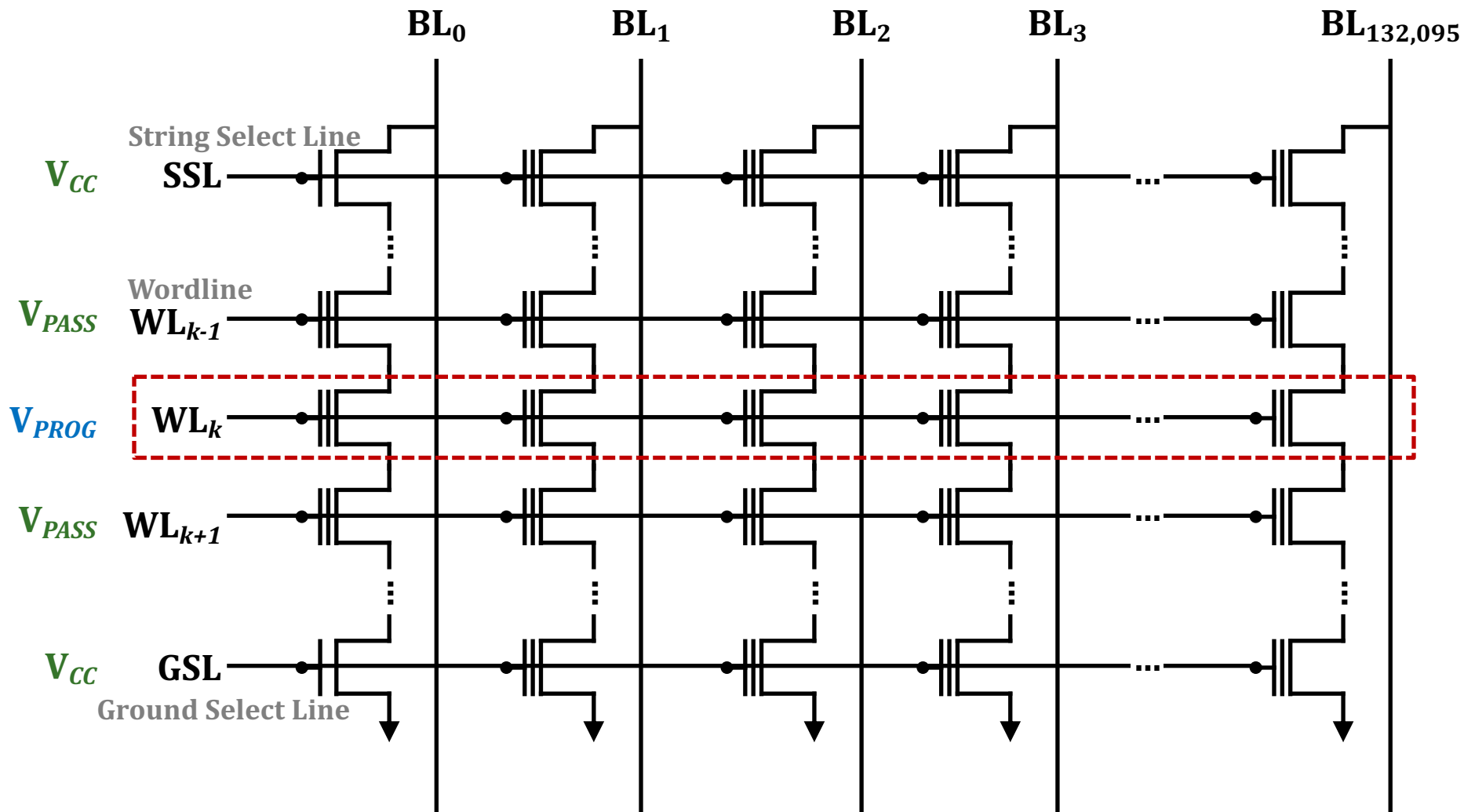
- **Limited width** of the V_{TH} window: Need to
 - Make each V_{TH} state **narrow**
 - Guarantee **sufficient margins** b/w adjacent V_{TH} states
 - V_{TH} **changes over time** after programmed
 - **Narrower** margins \rightarrow **Lower** reliability
 - More bits per cell \rightarrow **higher** density but **lower** reliability

Basic Operation: Page Program



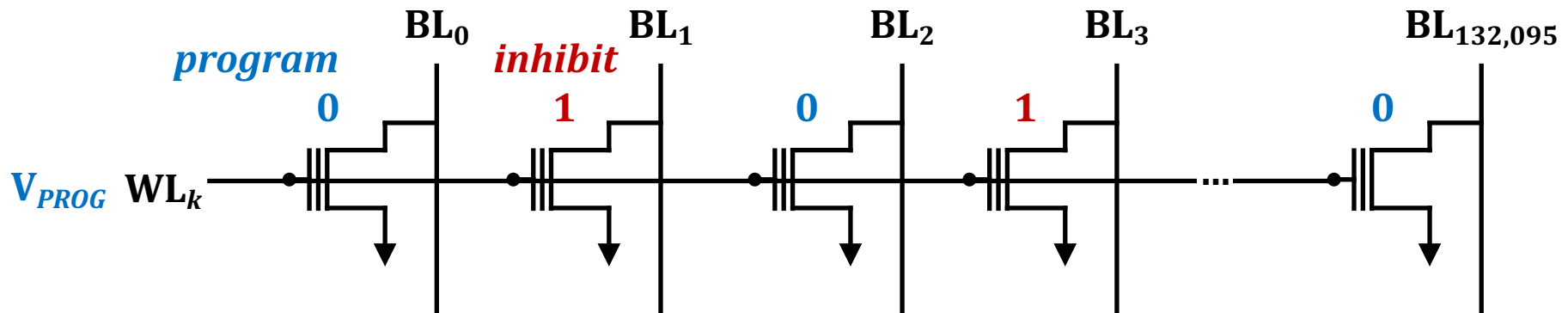
Basic Operation: Page Program

- WL control – All other cells operate as a resistance



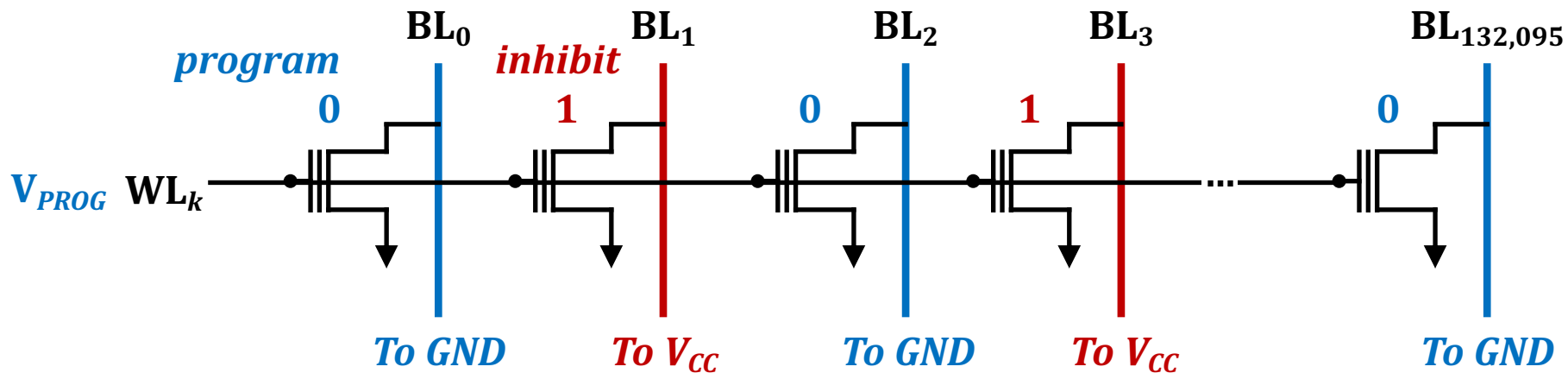
Basic Operation: Page Program

- BL control – **Inhibits cells** to not be programmed

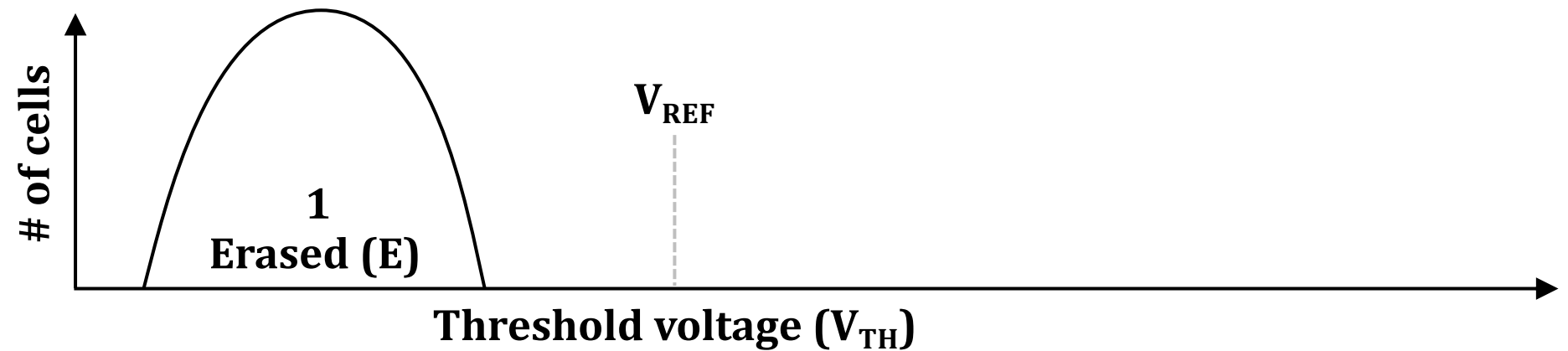
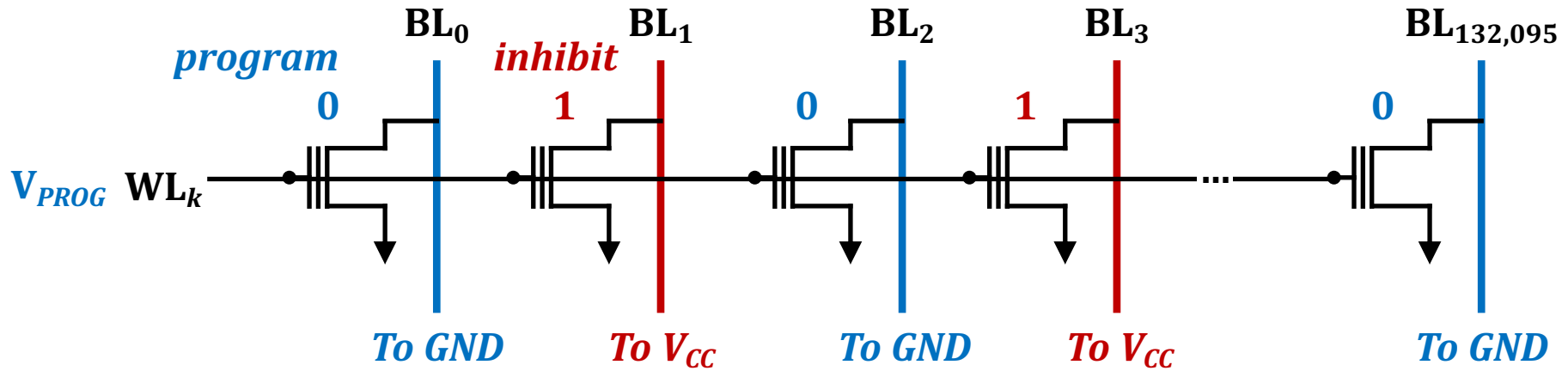


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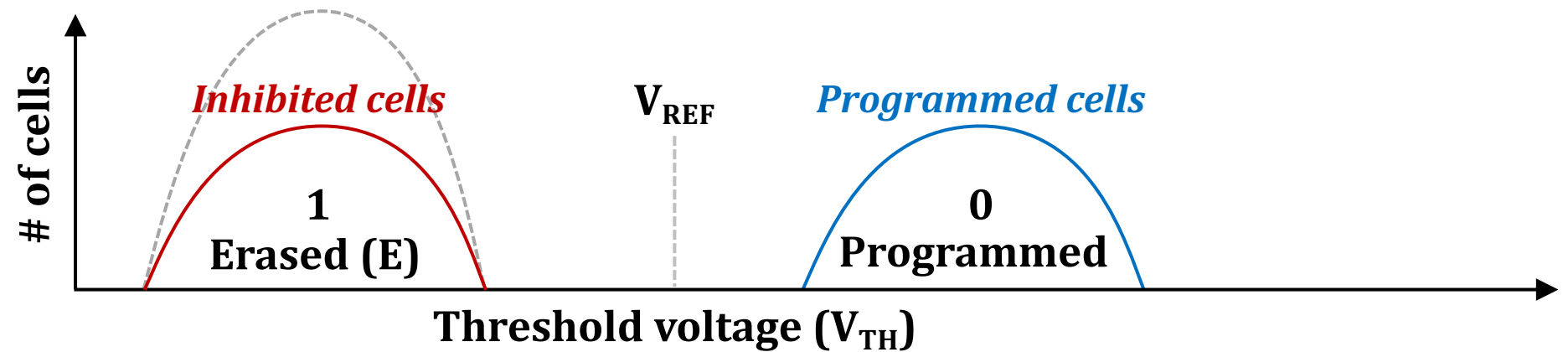
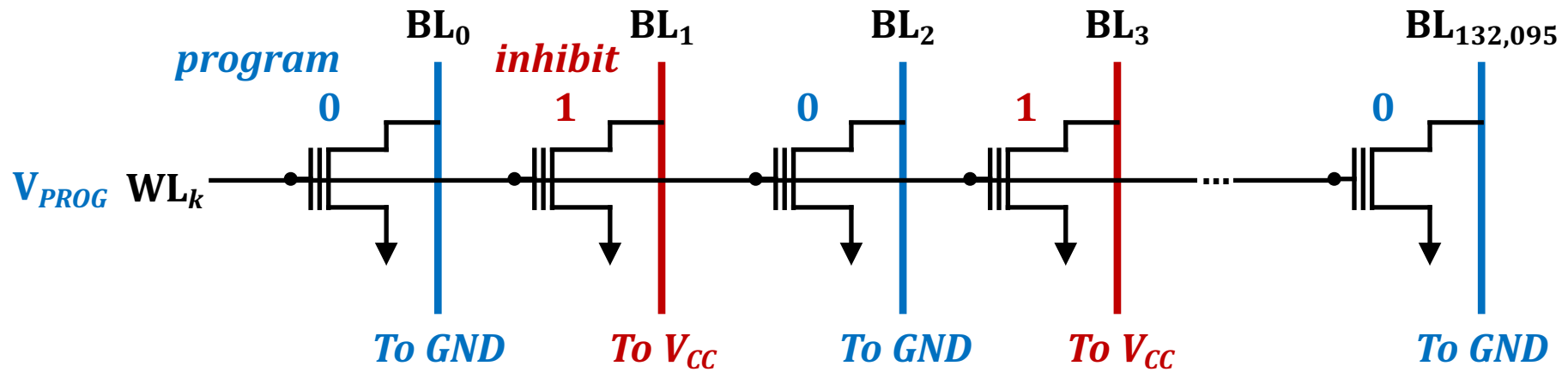
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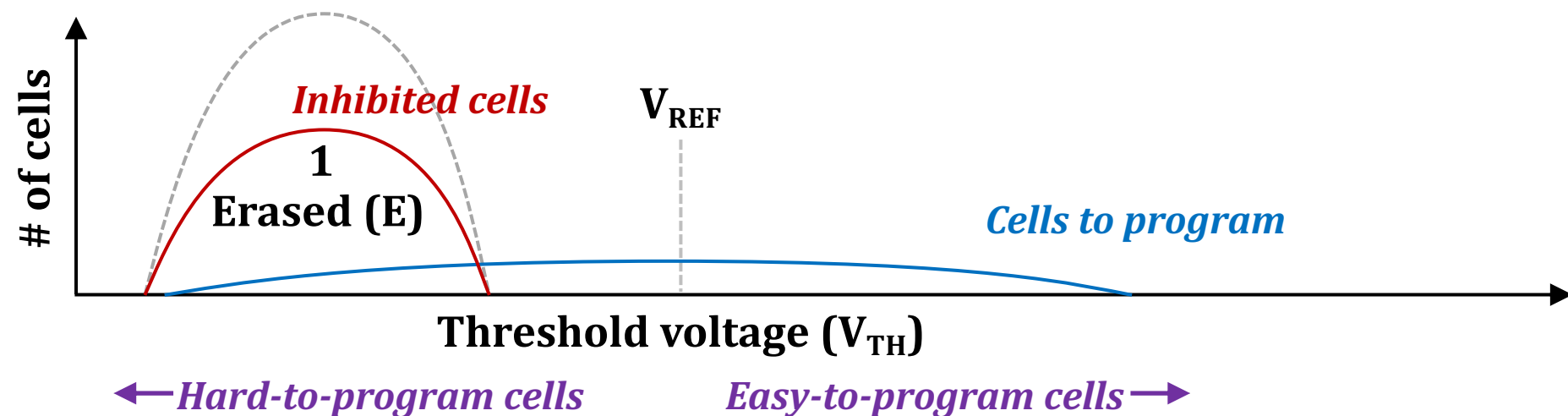
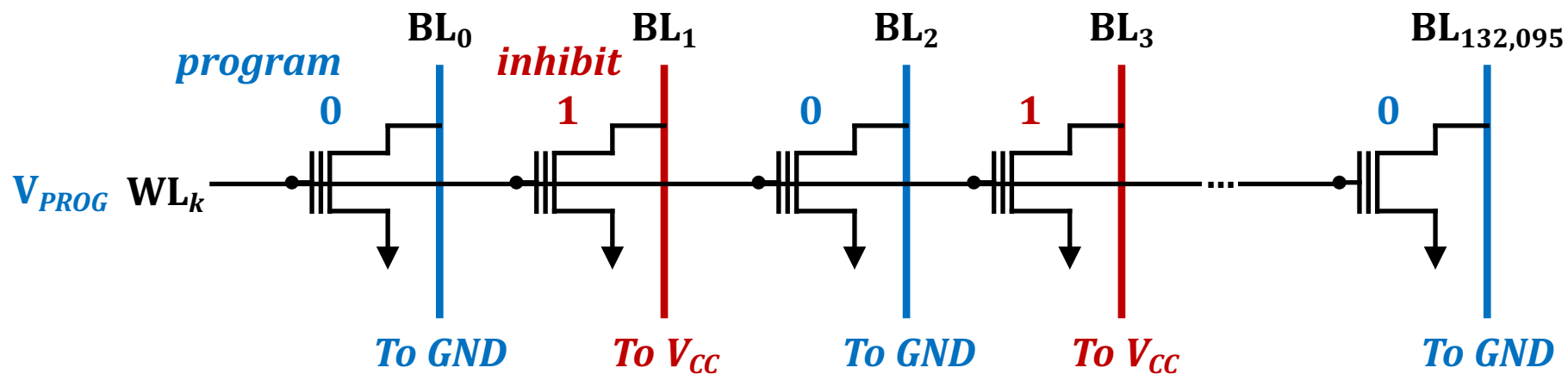
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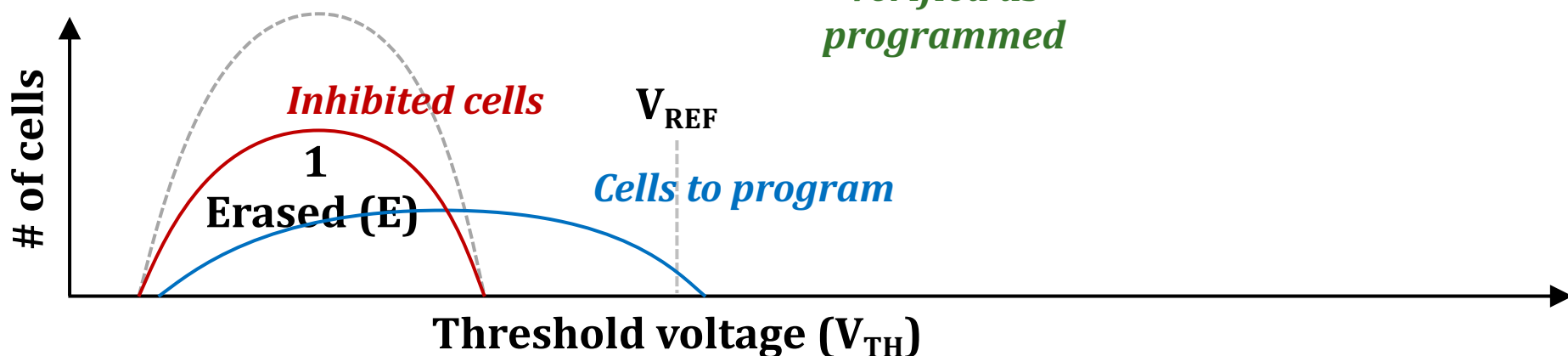
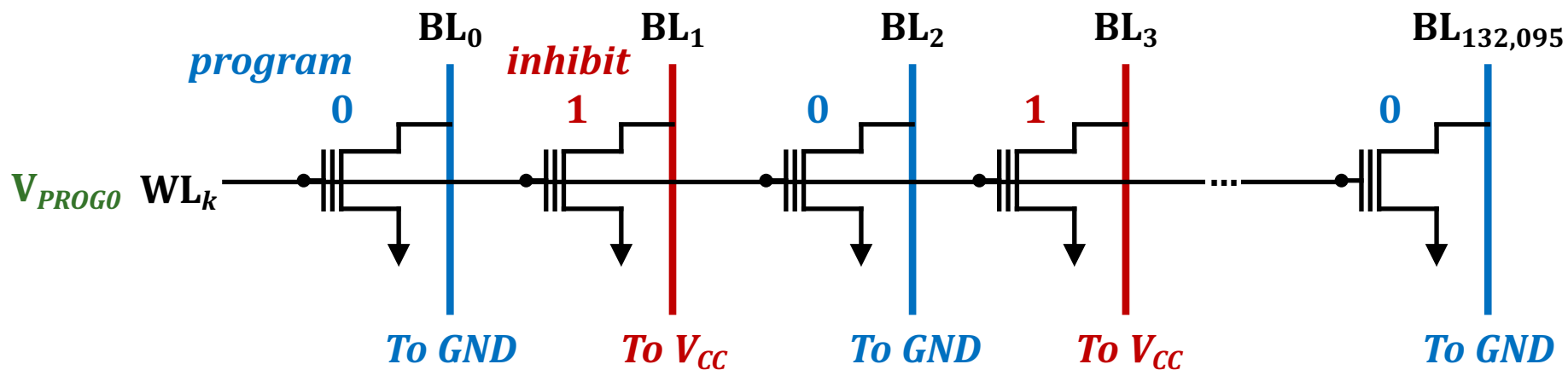


Basic Operation: Page Program



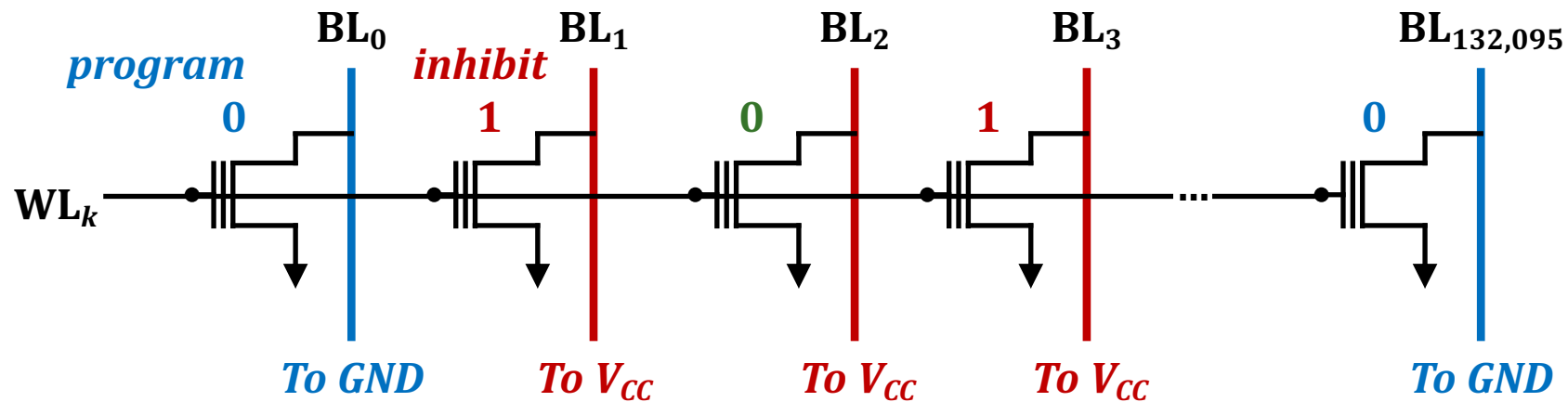
Basic Operation: Page Program

- Incremental Step-Pulse Programming (ISPP)



Basic Operation: Page Program

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Inhibit

programmed cells

Inhibited cells

1
Erased (E)

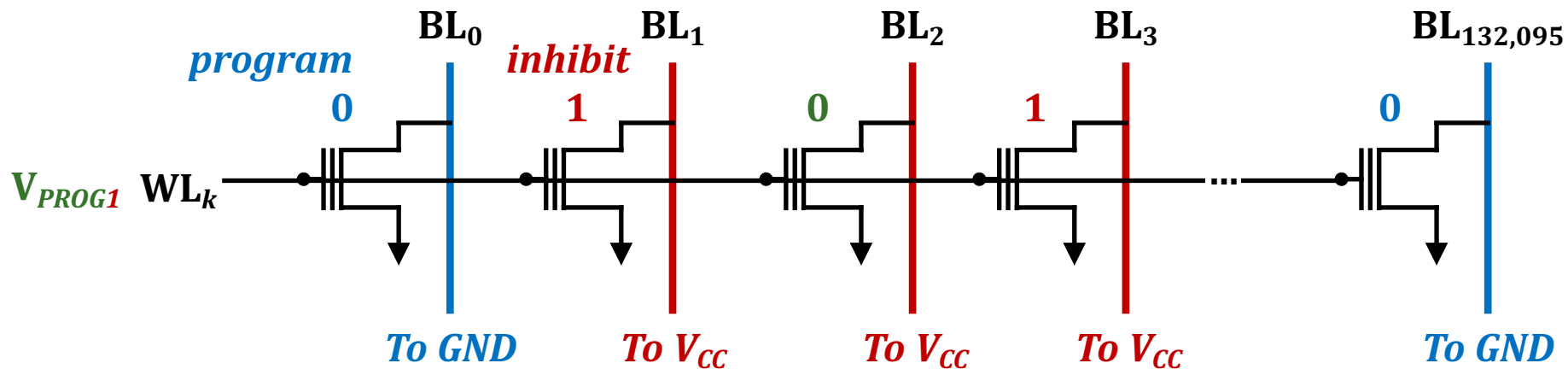
Cells to program

V_{REF}

Threshold voltage (V_{TH})

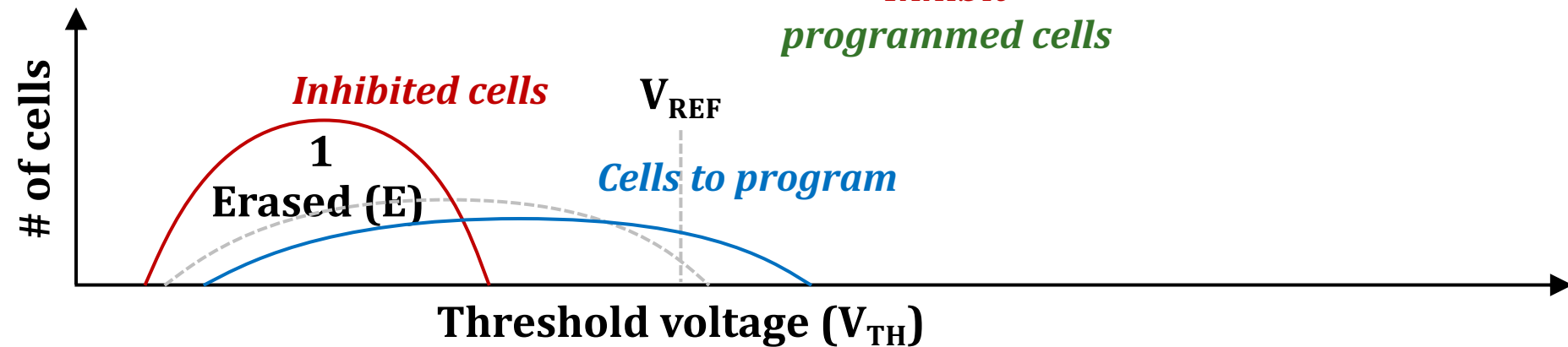
Basic Operation: Page Program

■ Incremental Step-Pulse Programming (ISPP)



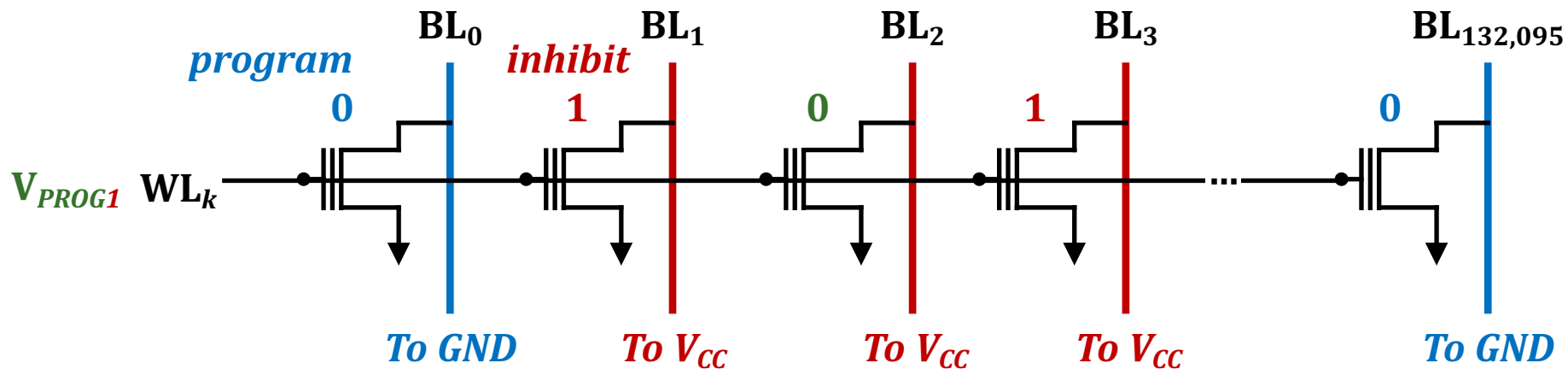
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programmed cells



Basic Operation: Page Program

- Incremental Step-Pulse Programming (ISPP)



Inhibit

programmed cells

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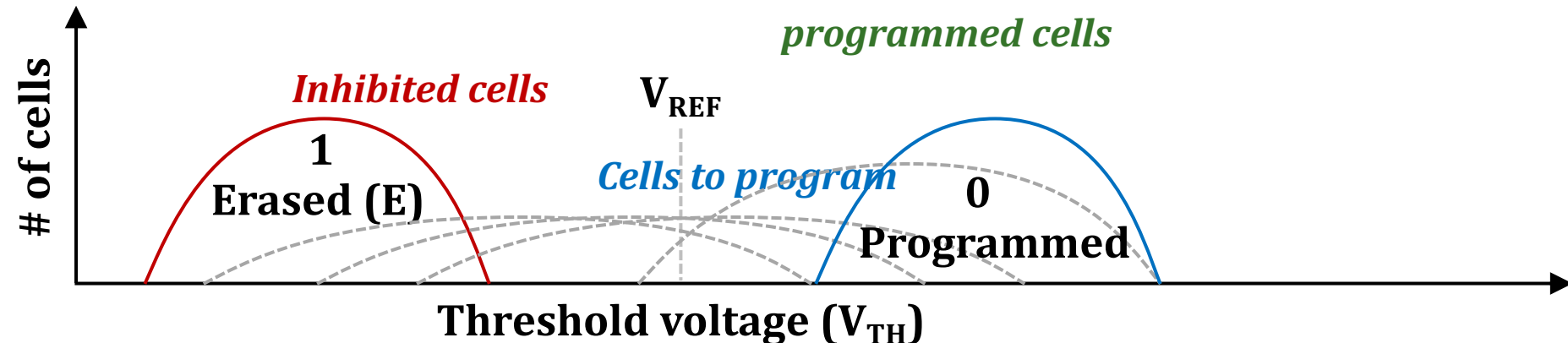
V_{REF}

Cells to program

1
Erased (E)

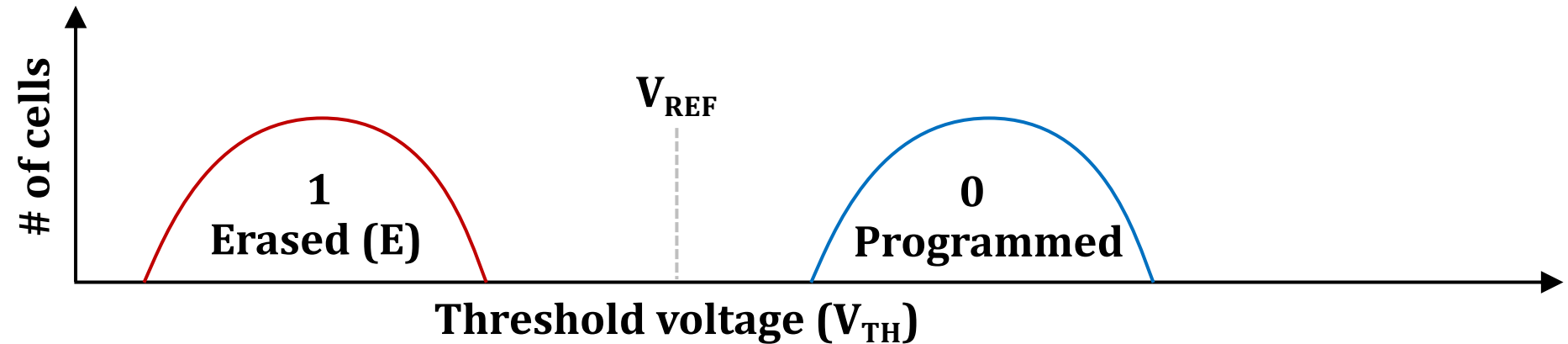
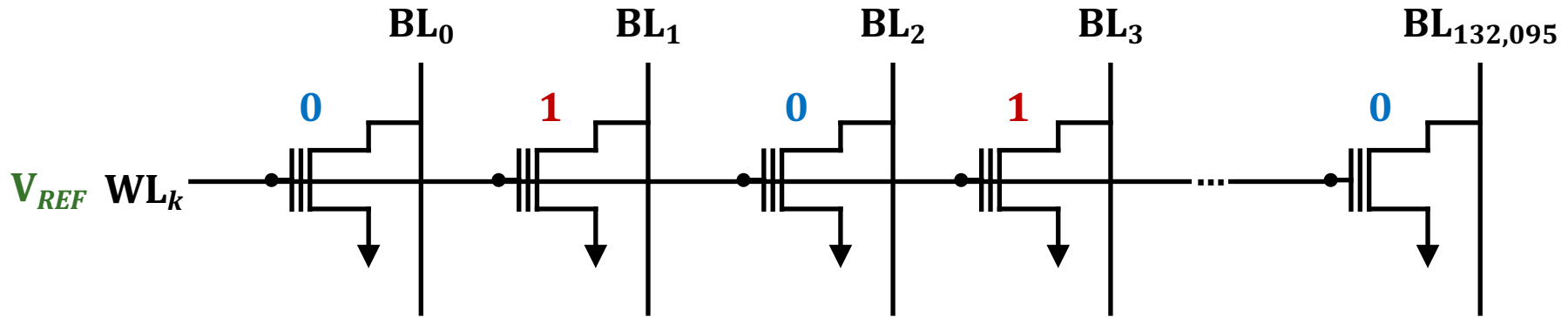
0
Programmed

Threshold voltage (V_{TH})



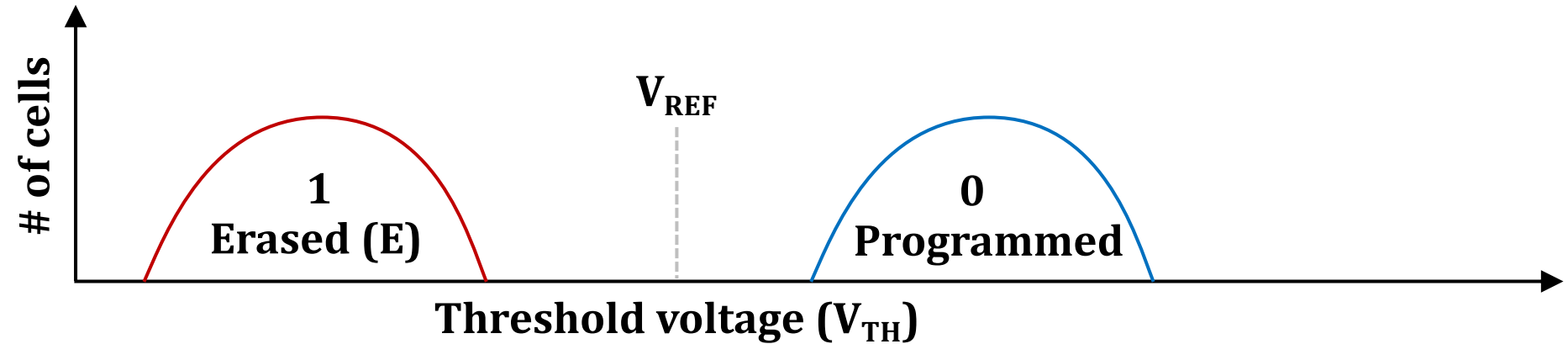
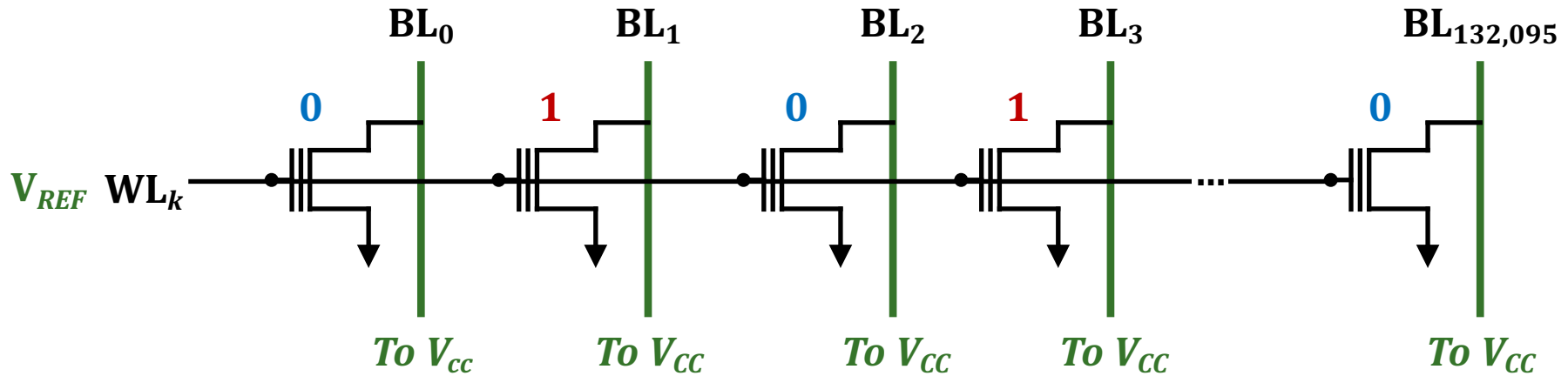
Basic Operation: Page Read

- WL control – All other cells operate as a resistance



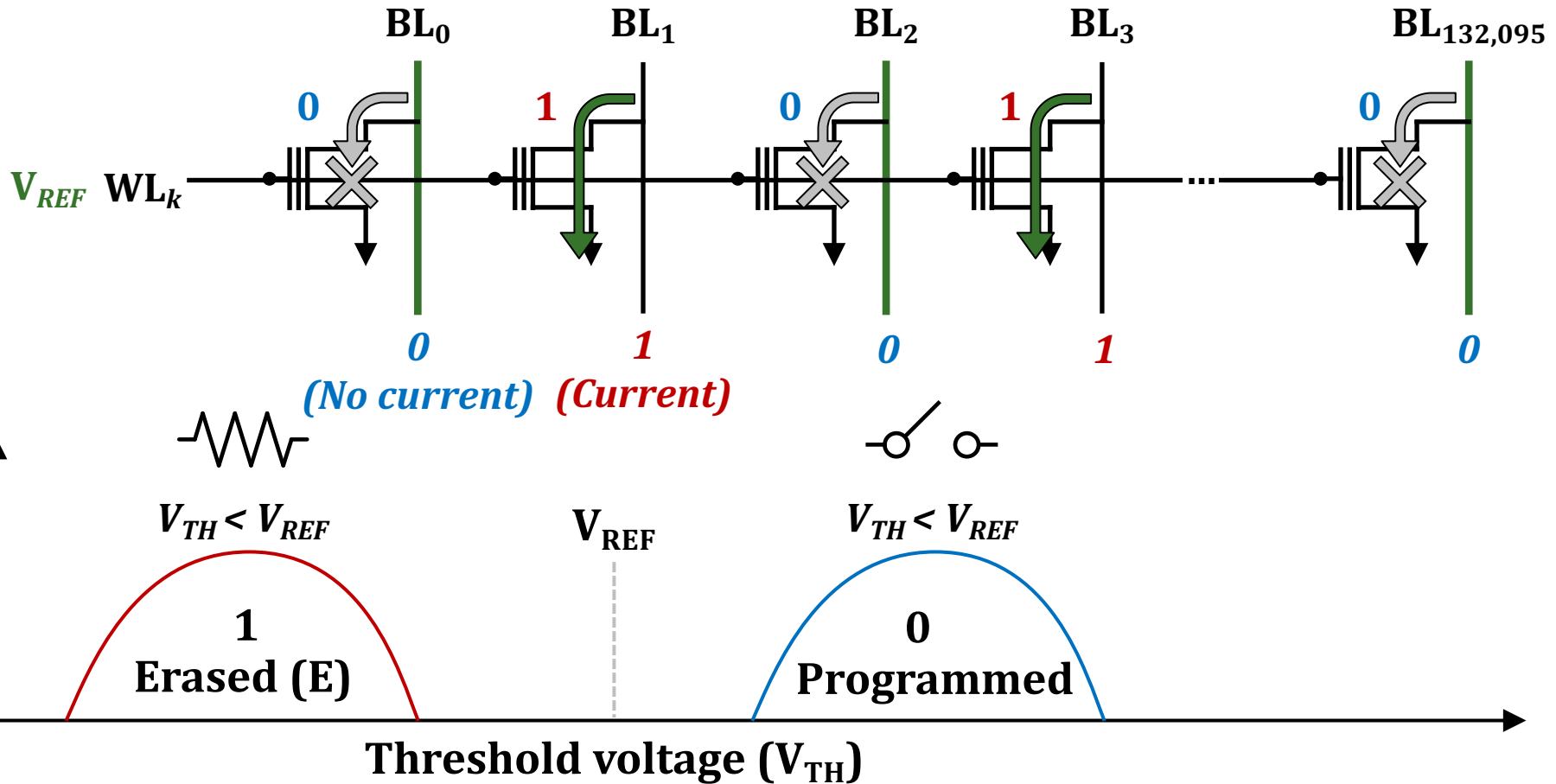
Basic Operation: Page Read

- BL control – Charge all BLs



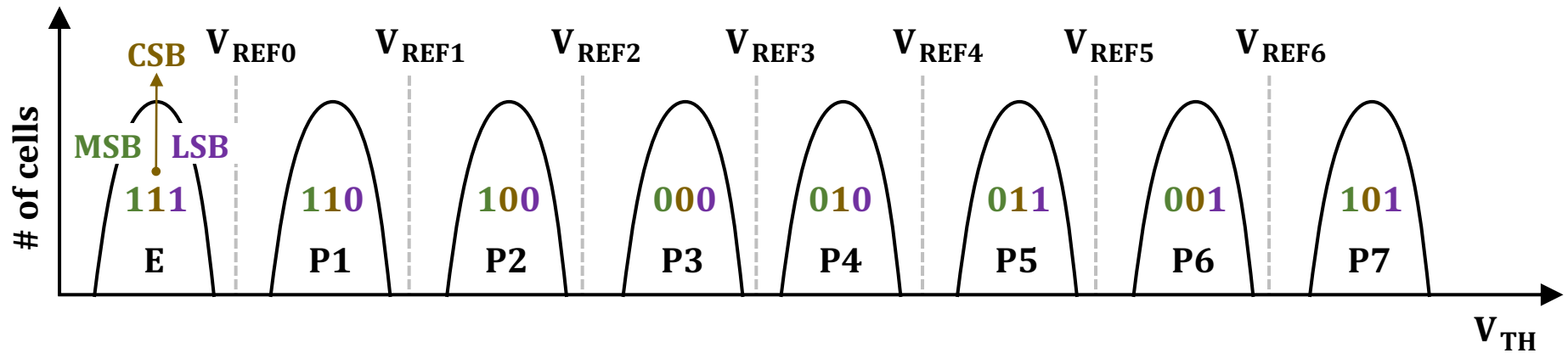
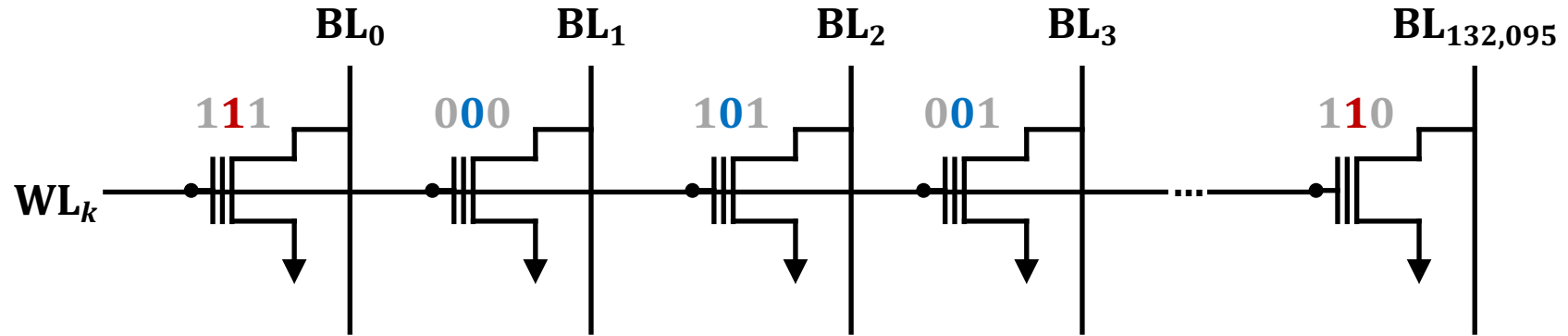
Basic Operation: Page Read

- Sensing the current through BLs



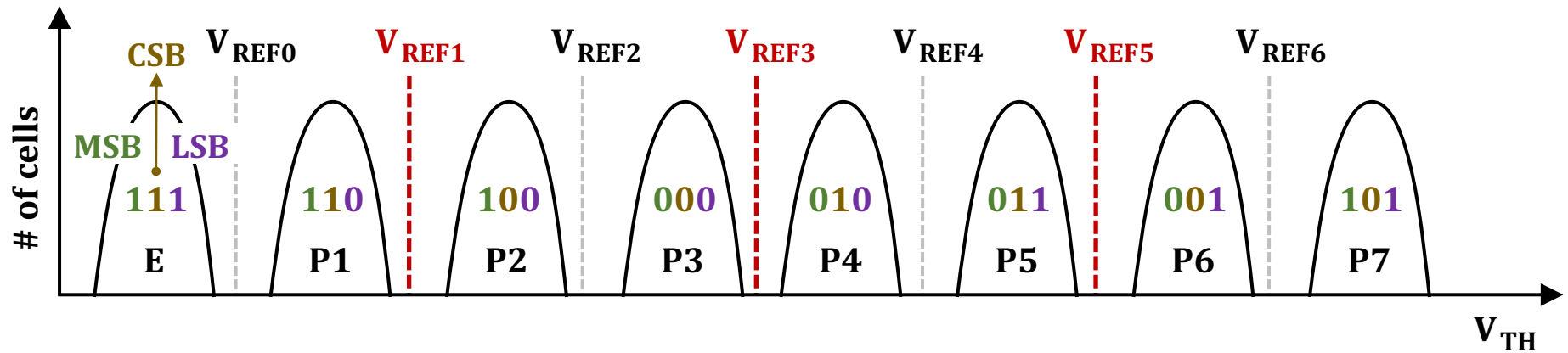
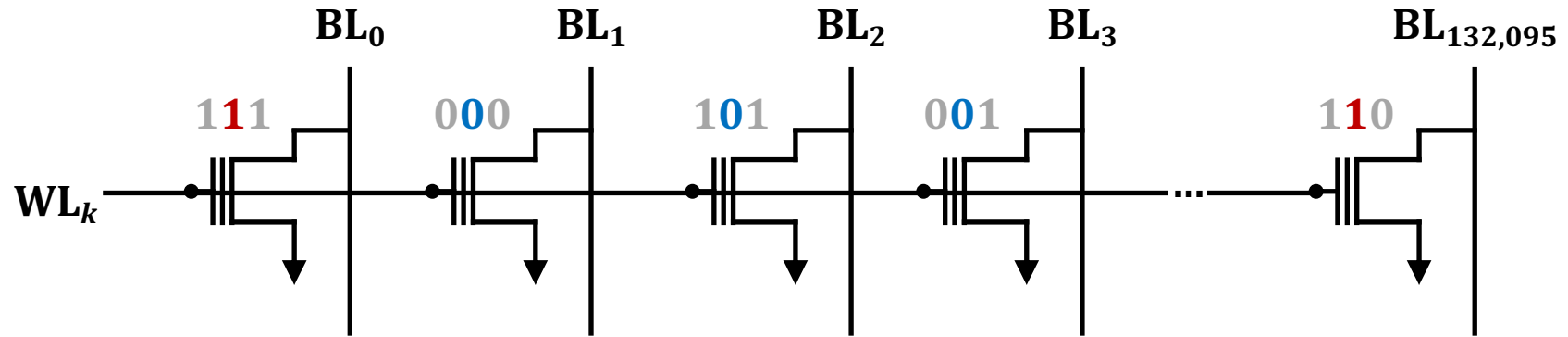
Basic Operation: Page Read - MLC

- Sensing the current through BLs



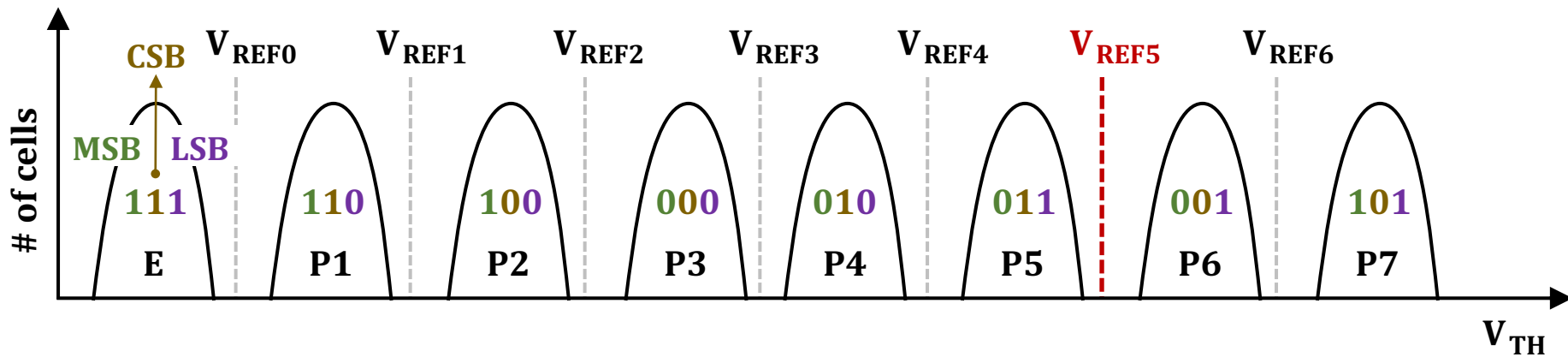
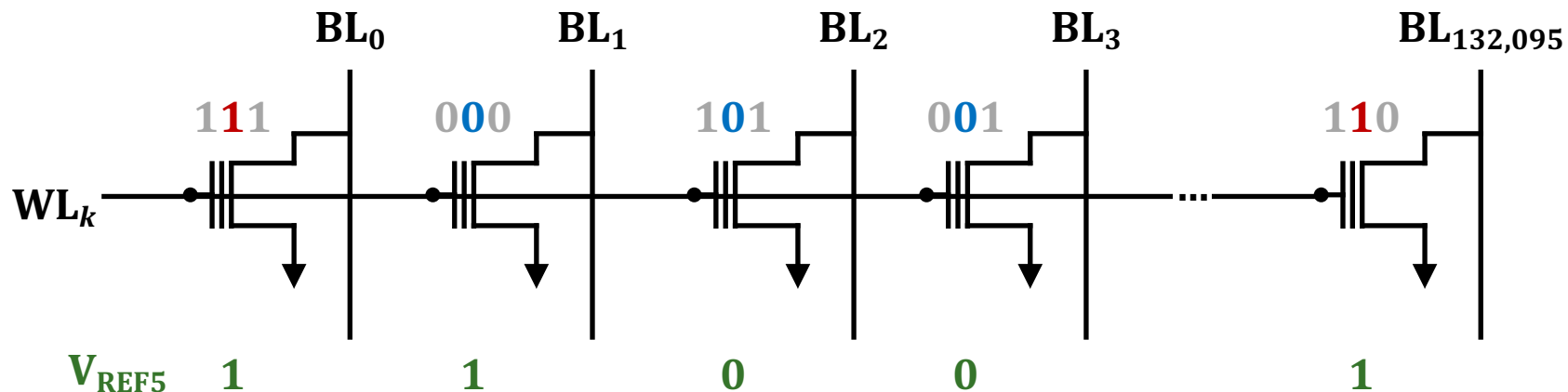
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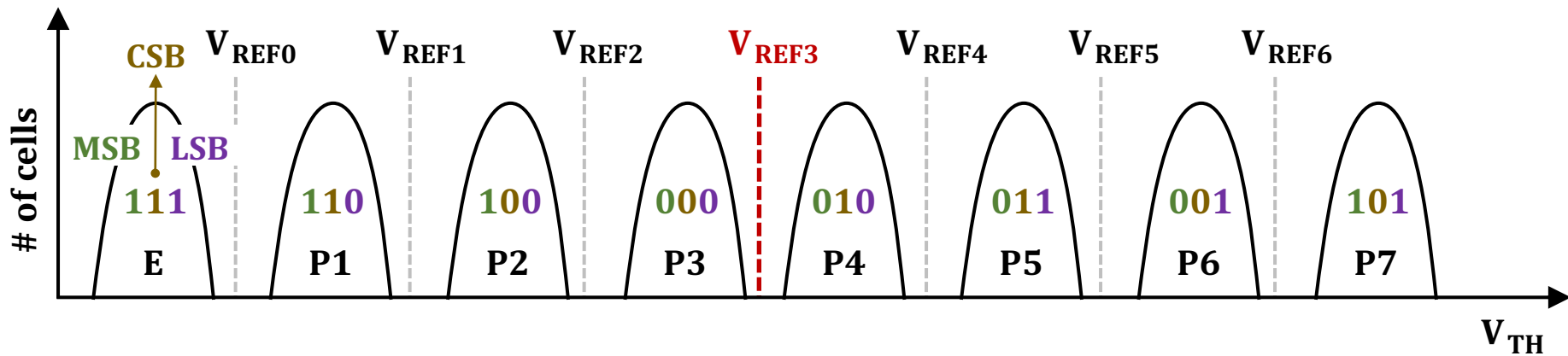
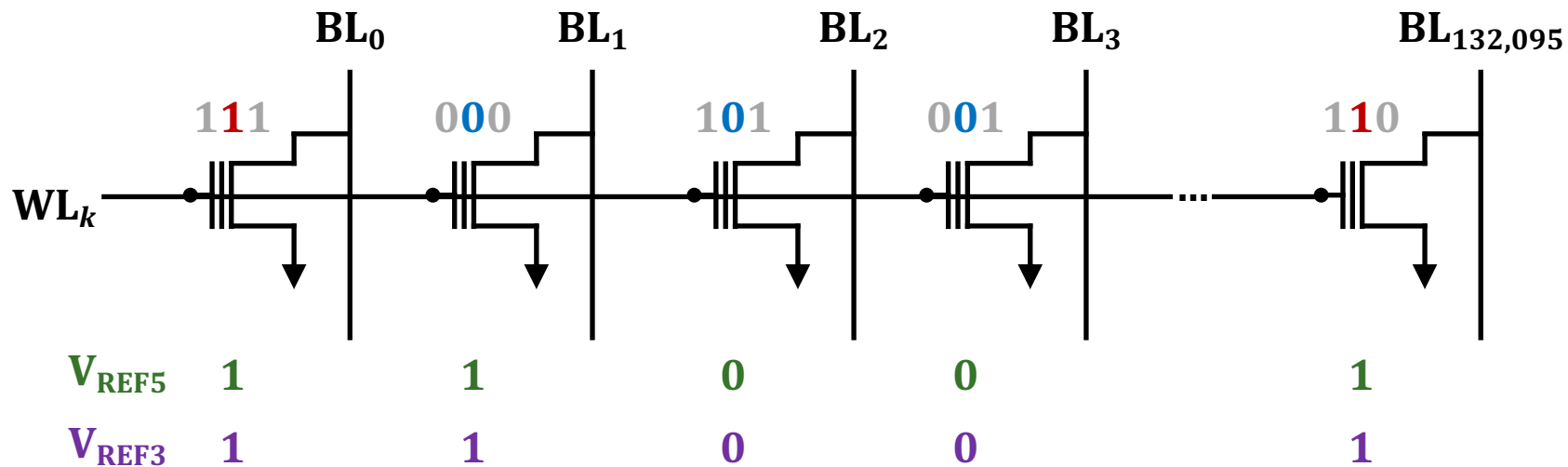
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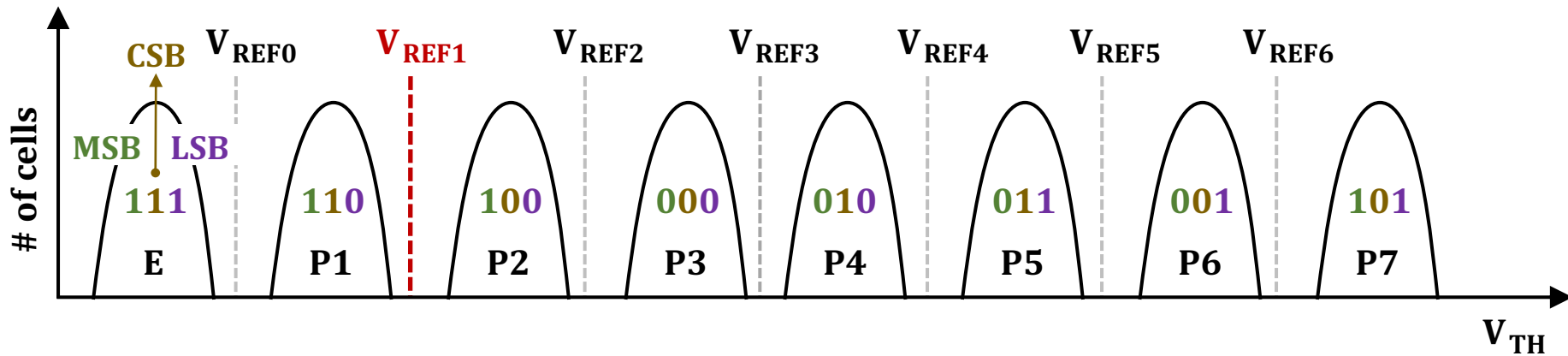
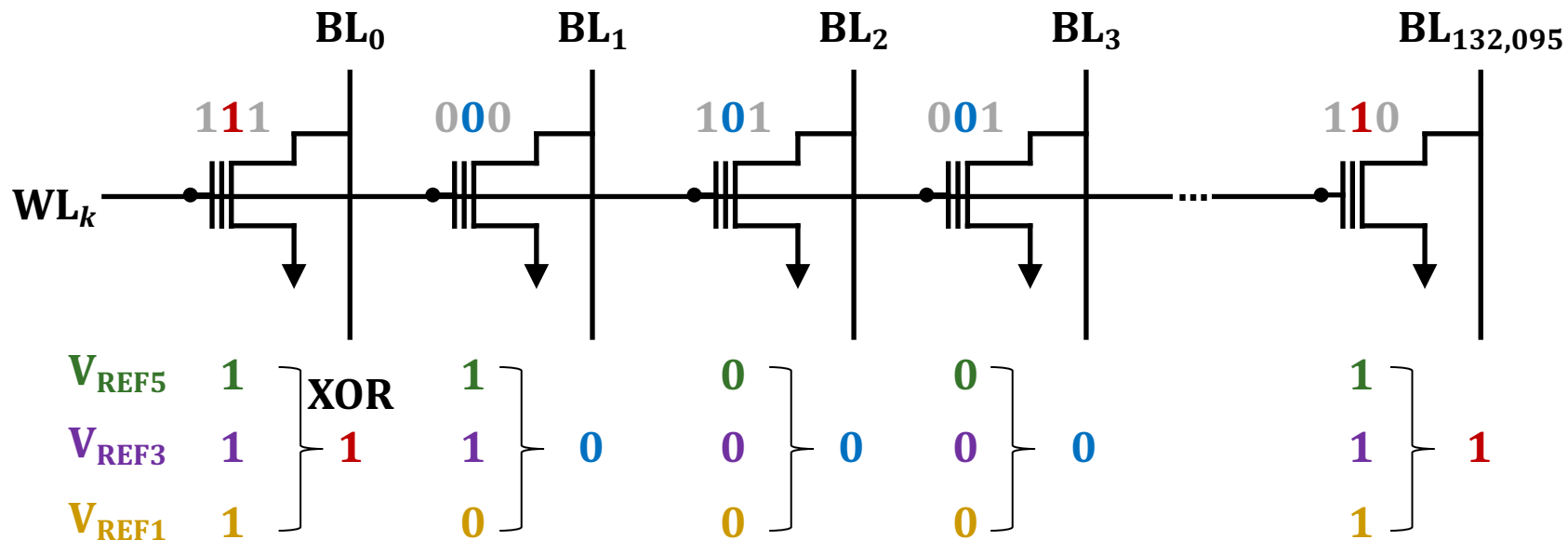
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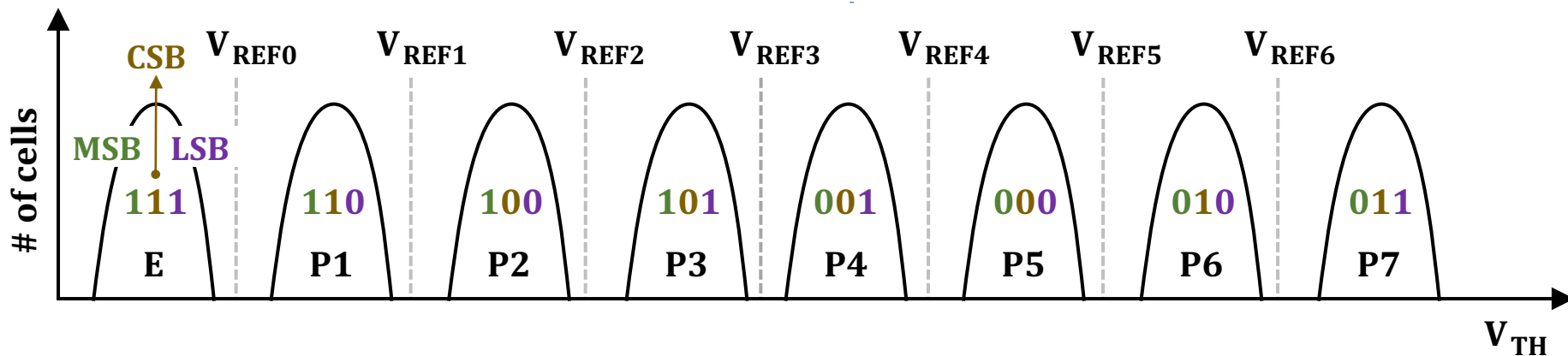
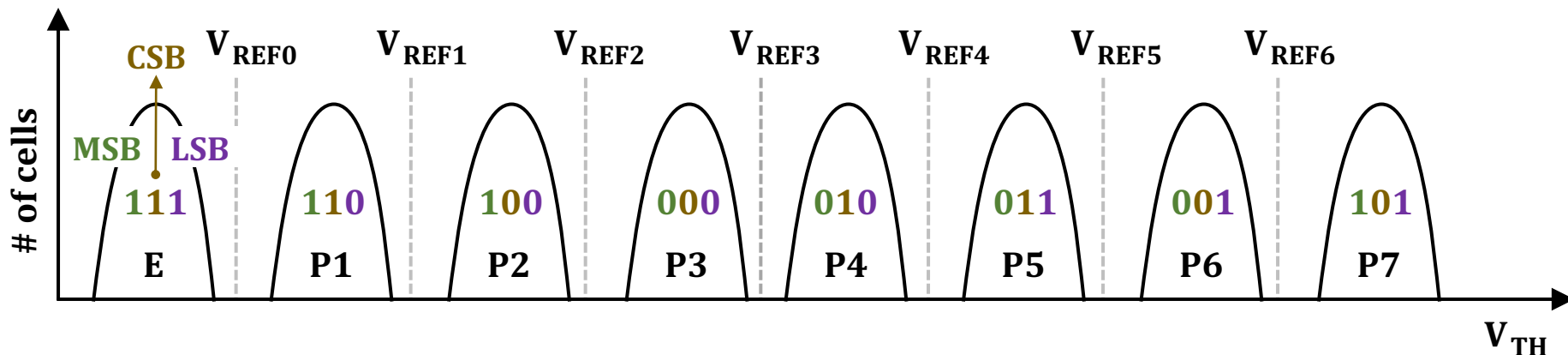
Basic Operation: Page Read - MLC

- Sensing the current through BLs



Basic Operation: Page Read – Takeaways

- MLC NAND flash memory requires an **in-chip XOR logic**
- Bit-encoding affects the read latency!
 - Compare # of sensing for CSB



Next Meetings

- We will provide more background on NAND flash memory
- We will discuss your progress in last week
 - Please contact us whenever you have any questions

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