Class Material

- Last lecture
  - I/O, power distribution
- Today’s lecture
  - Flash memory
  - DRAM

Announcements

- Project phase 3 final report due Friday
  - Send posters and reports to mailing list
- Final exam
  - Wed. Dec. 12th, 8-11am, Room TBA (see piazza)
  - Review session: Tues. Dec. 11th (stay tuned)
- HKN surveys end of class today

Announcements

- GSI final review on Friday, Monday
- Look out for office hours announcements on the web
MOS NOR ROM Layout

Cell (9.5λ x 7λ)

Programming using the Active Layer Only

No contact to VDD or GND necessary; drastically reduced cell size
Loss in performance compared to NOR ROM

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MOS NAND ROM Layout

Cell (8λ x 7λ)

Programming using the Metal-1 Layer Only

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MOS NOR ROM Layout

Cell (9.5λ x 7λ)

Programming using the Active Layer Only

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MOS NAND ROM

Precharge devices

All word lines high by default with exception of selected row

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Floating Gate Transistor

Control gate

Floating gate

Thick tunneling oxide

Many other options ...

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Programmable-Threshold

\[ I_D = \begin{cases} 0 & \text{if } V_{GS} < V_{TH} \\ D_{V_I} & \text{if } V_{GS} = V_{TH} \\ 1 & \text{if } V_{GS} > V_{TH} \end{cases} \]

"0"-state

"1"-state

"ON"
**Floating-Gate Transistor Programming**

- **Avalanche injection**
  - 20 V
  - Removing programming voltage leaves charge trapped

- **Programming results in higher \( V_T \)**

**DRAM Cell Observations**

- **1T DRAM requires a sense amplifier**
- **Read-out of the 1T DRAM cell is destructive**
  - Need refresh
- **Lose a \( V_{TH} \) when writing a “1” into a DRAM cell**
  - Bootstrap the word lines to a higher value than \( V_{DD} \)

**Sense Amp Operation**

- Sense amp activated
- Word line activated

**1-Transistor DRAM Cell**

- Write \( C_s \) is charged or discharged by asserting \( WL \) and \( BL \).
- Read Charge redistribution takes place between bit line and storage capacitance

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<th>Voltage swing is small; typically &lt; 200 mV.</th>
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**Modern 1T DRAM Cells**

- Trench Cell
- Stacked-capacitor Cell
THE END

- This is just the beginning…