Solid State Devices
Section 32
Modern MOSFET

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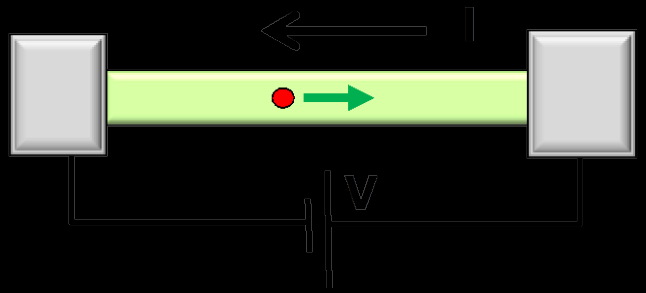
nanoHUB

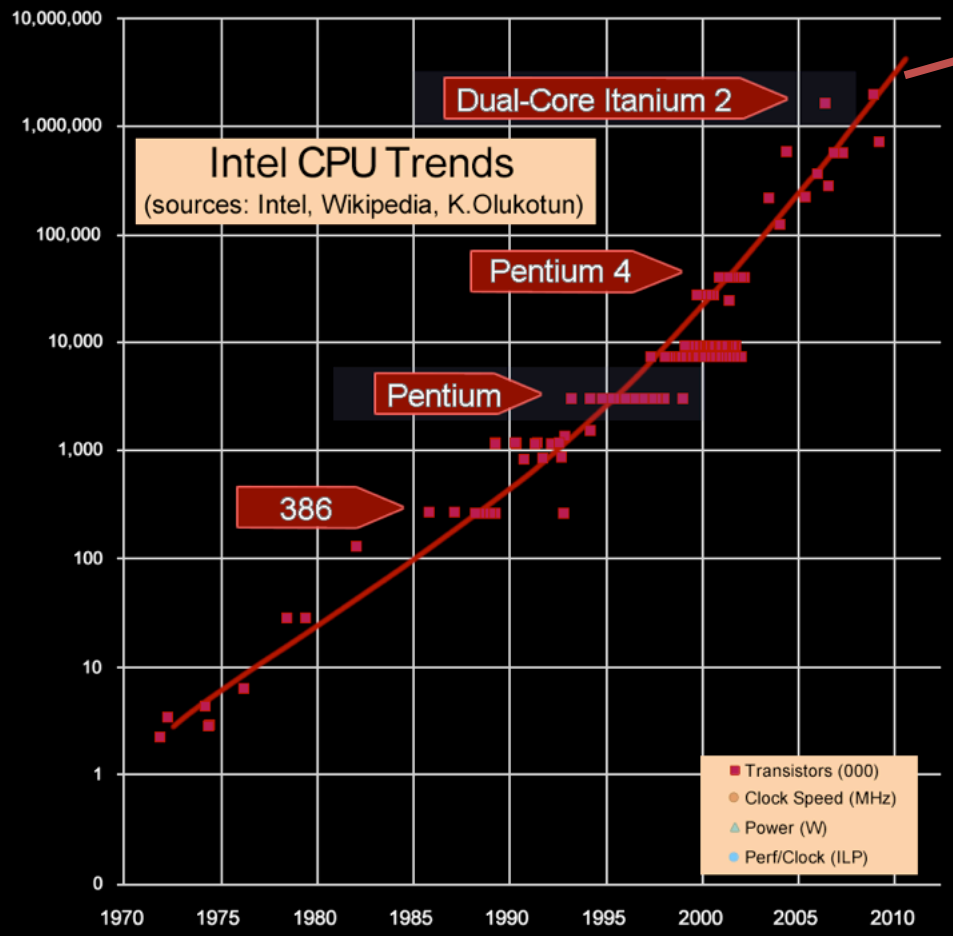
Section 32
Modern MOSFET



$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area

Moore's Law Forever?

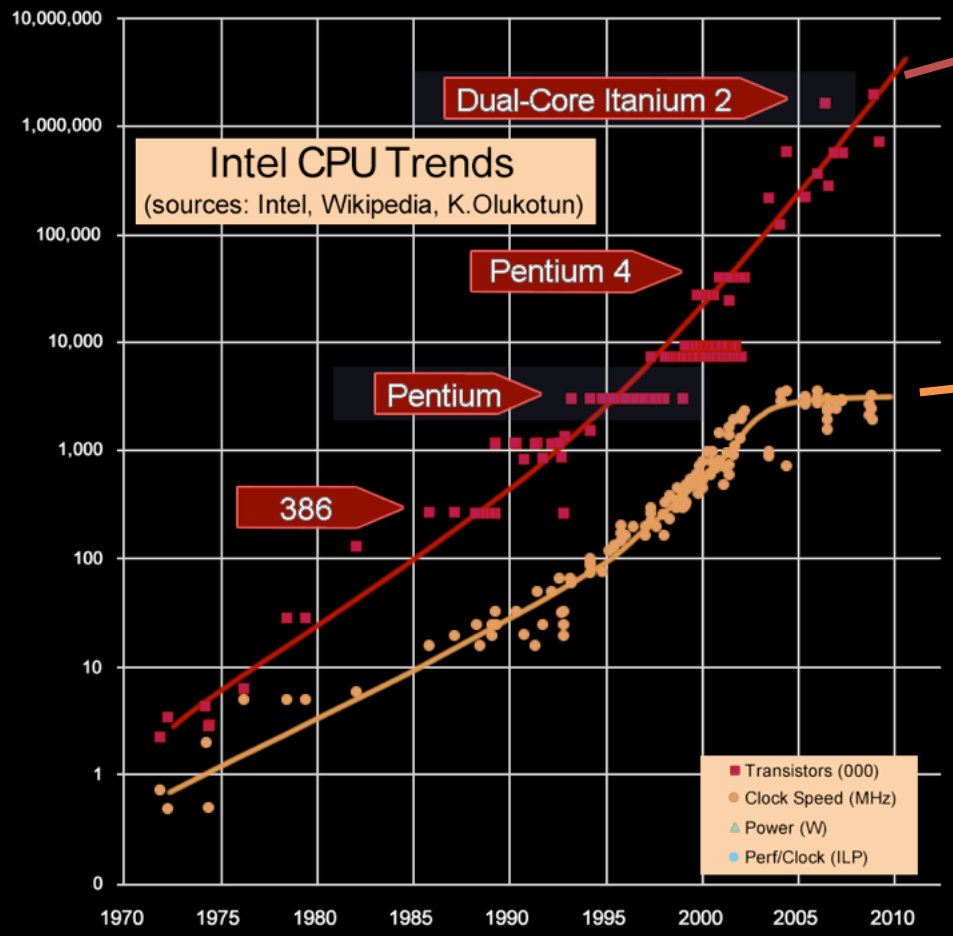


Number of transistors:
Moore's law is continuing

http://jai-on-asp.blogspot.com

2005: free lunch is over, updated 2009

CPU's are not getting faster!



Number of transistors:
Moore's law is continuing

Clock speed:
no longer scaling

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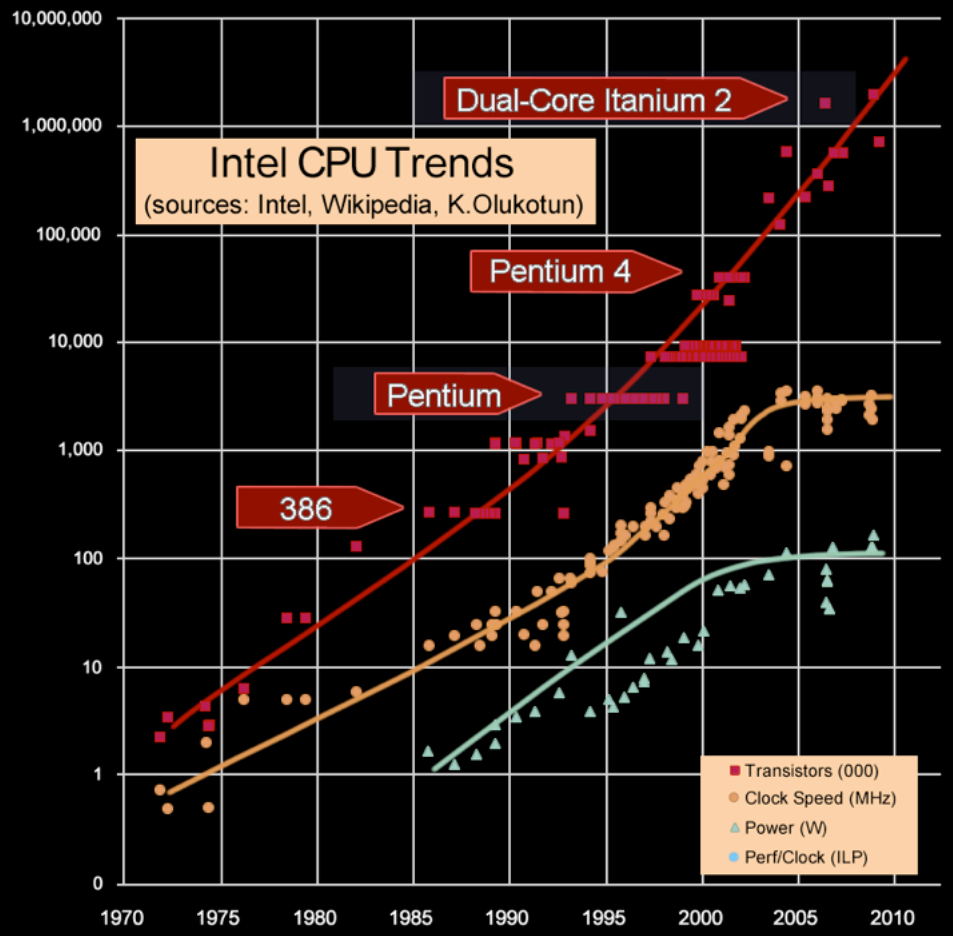
Power is the Limit!



Number of transistors:
Moore's law is continuing

Clock speed:
no longer scaling

Power:
today's limitation
~100W

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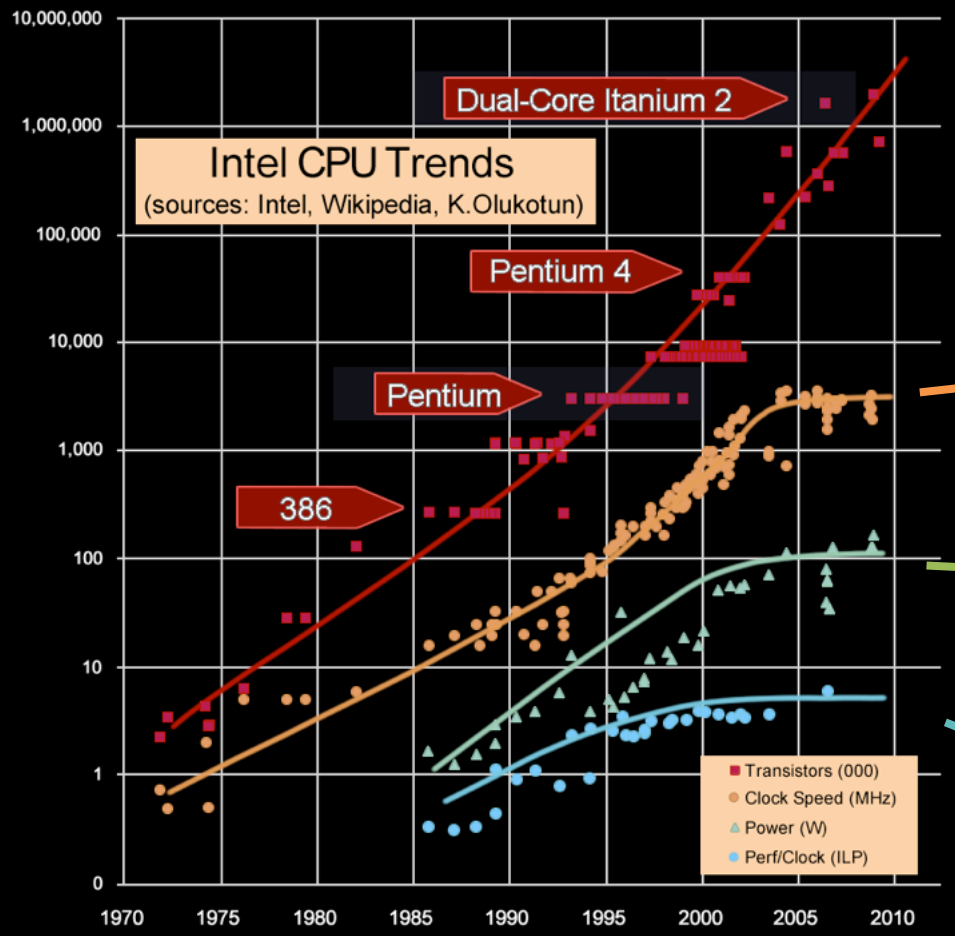
Limited Performance Improvements



Number of transistors:
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Clock speed:
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Power:
today's limitation
~100W

Performance Gain:
limited

Supply voltage (Vdd) stopped scaling at around 2003

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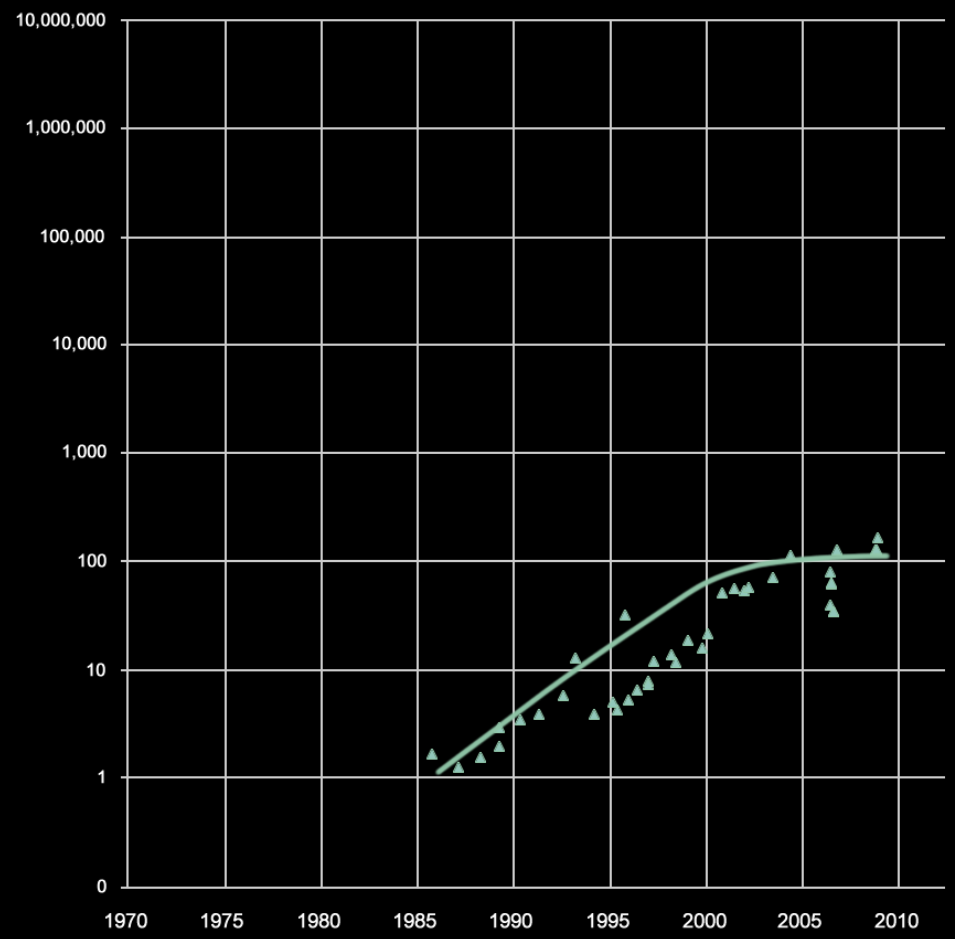
What is Special about 100W ?



Power:
today's limitation
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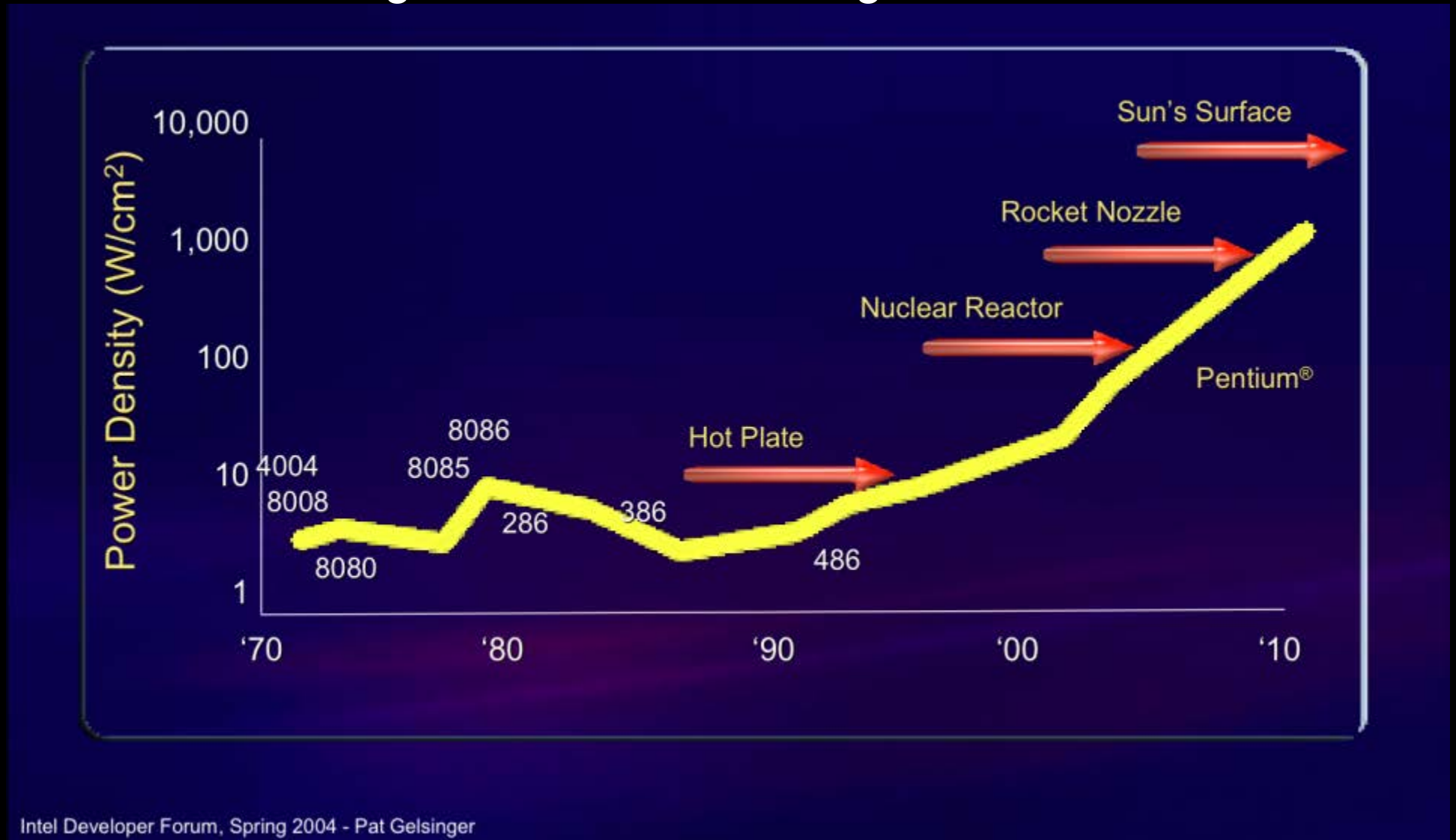
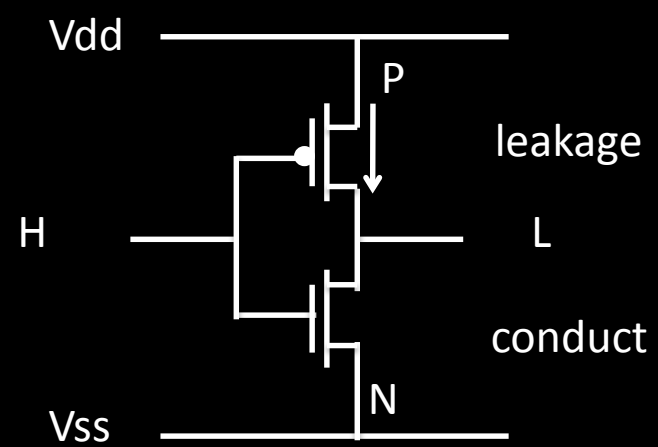
Intel (Fun) Projection from 2004

How do we burn power?

Switching Circuits & Leakage => Transistors



CMOS Inverter



Dynamic / Switching Power:

- Charging a capacitor network

$$P \propto f\ C_L\ V_{dd}^2$$

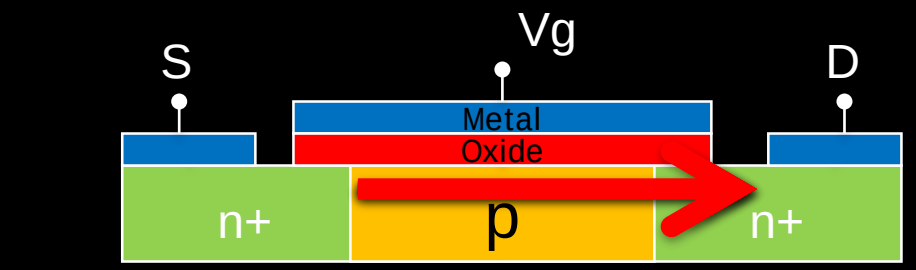
- Reduce frequency ☹
- Reduce capacitance
  => device size 😐
- Reduce voltage ☺

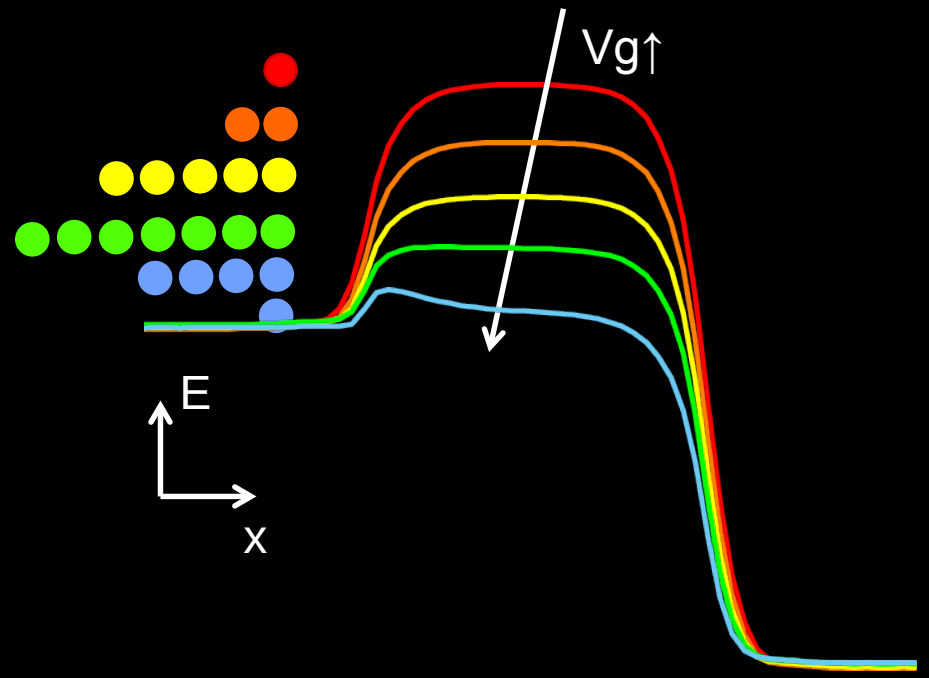
Static Power:

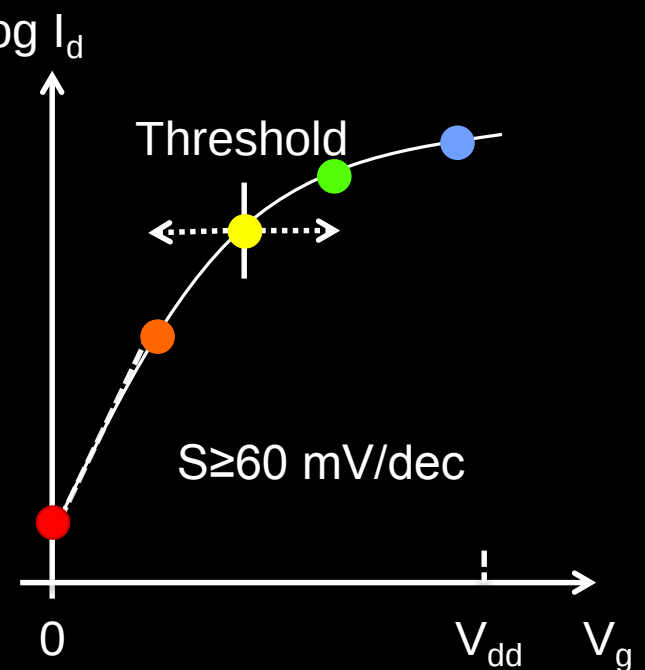
- Leakage through transistors

$$P \propto I_{OFF} \propto 1/\exp\left(\mathrm{V_{dd}}\right)$$ ☹

“Fundamental” Limit







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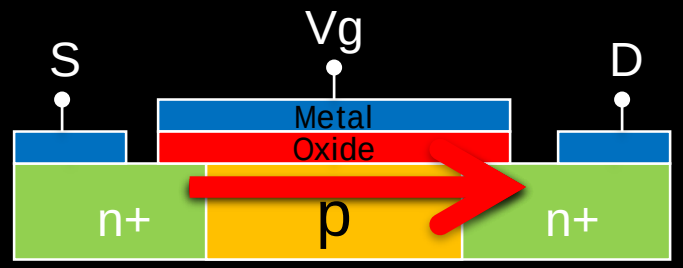
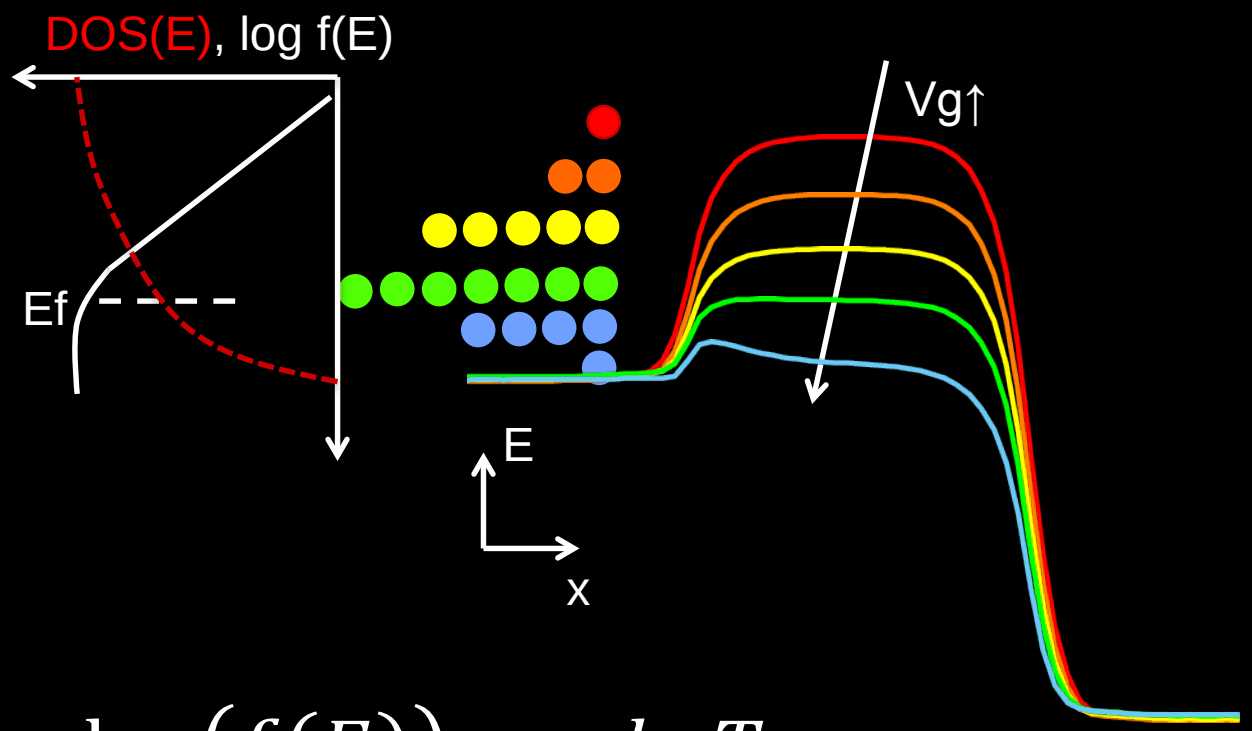
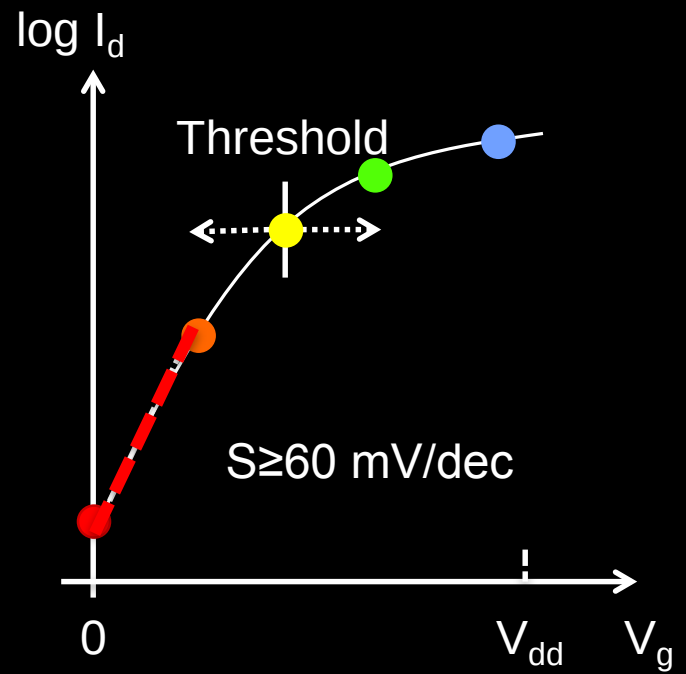






$$\log\left(f(E)\right) \propto -k_B T$$

$$S = 2.3m\left(k_B T/q\right)\ \frac{\text{mV}}{\text{dec}}$$

$$m = \left(1 + C_D/C_{OX}\right) \geq 1$$

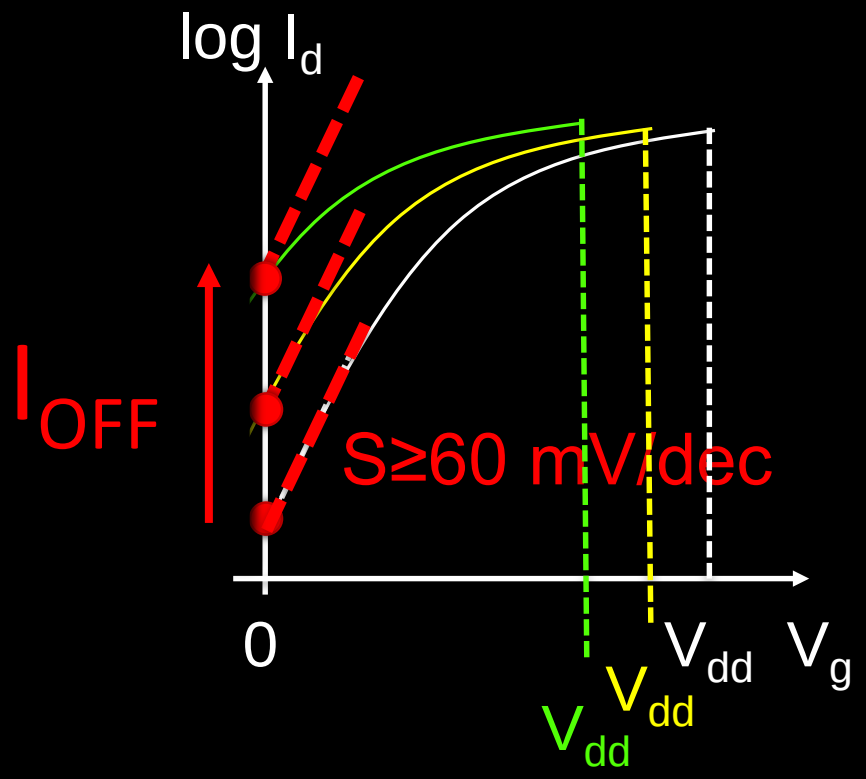
Device Scaling for Performance

Dynamic / Switching Power:

➢Charging a capacitor network

$$P \propto f \ C_L V_{dd}^2$$

➢Reduce supply voltage



Static Power:

➢Leakage through transistors

$$P \propto I_{OFF} \propto 1/\exp(V_{DD})$$

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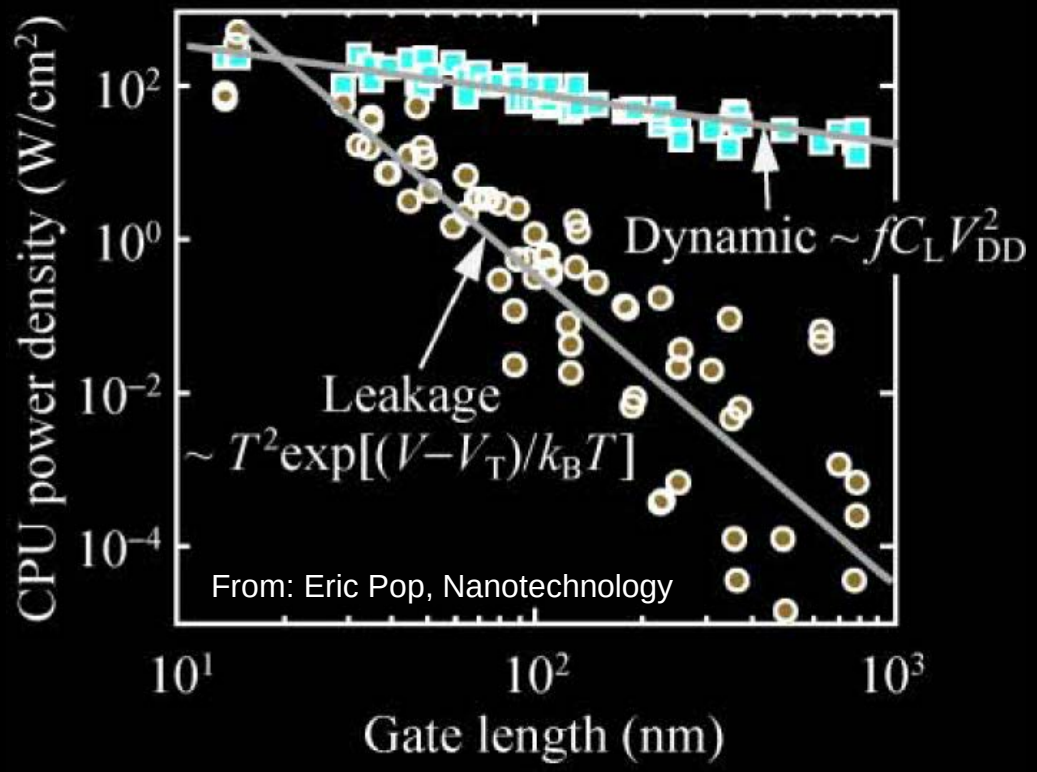

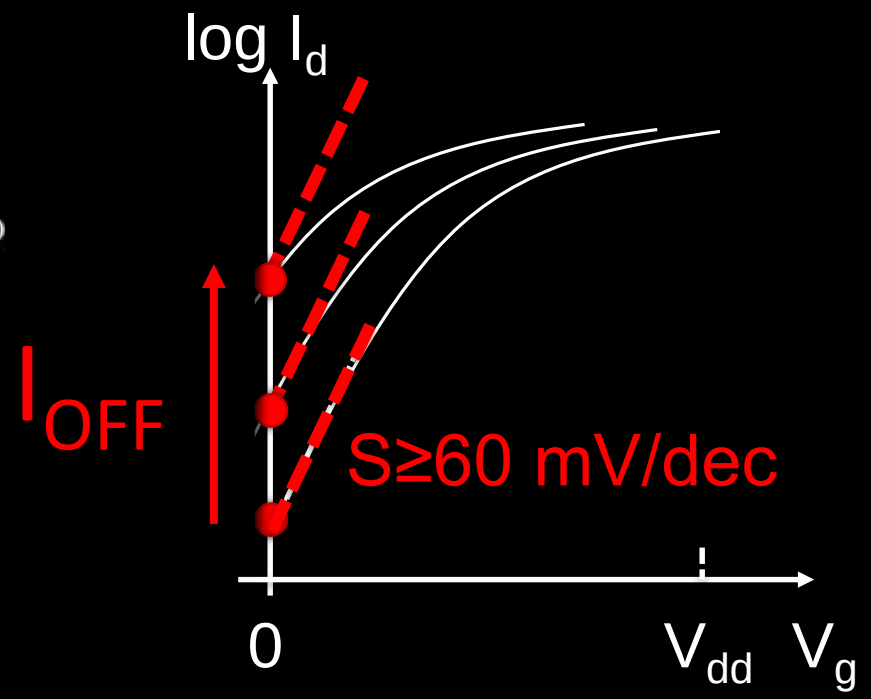

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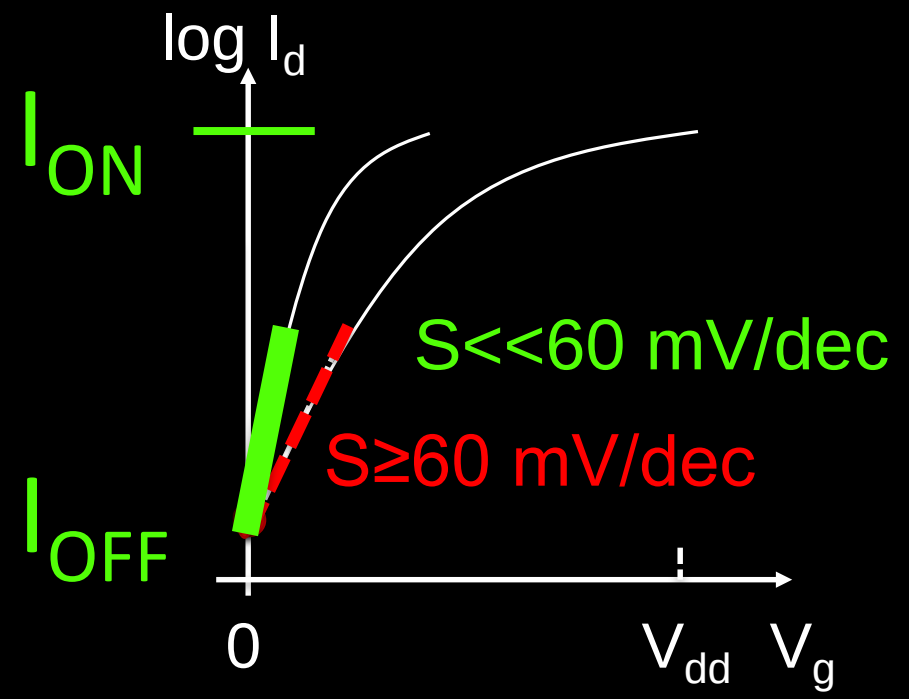
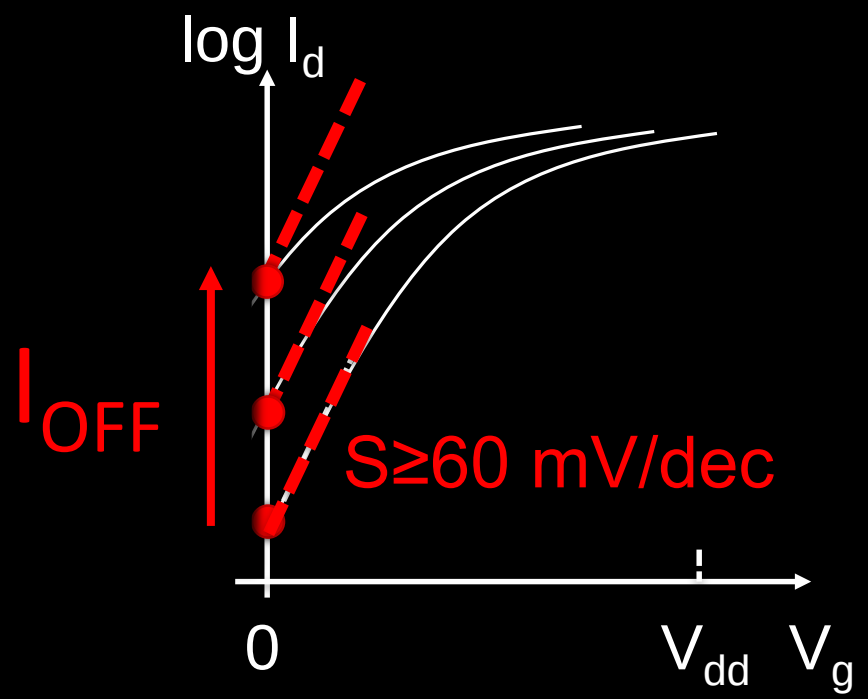


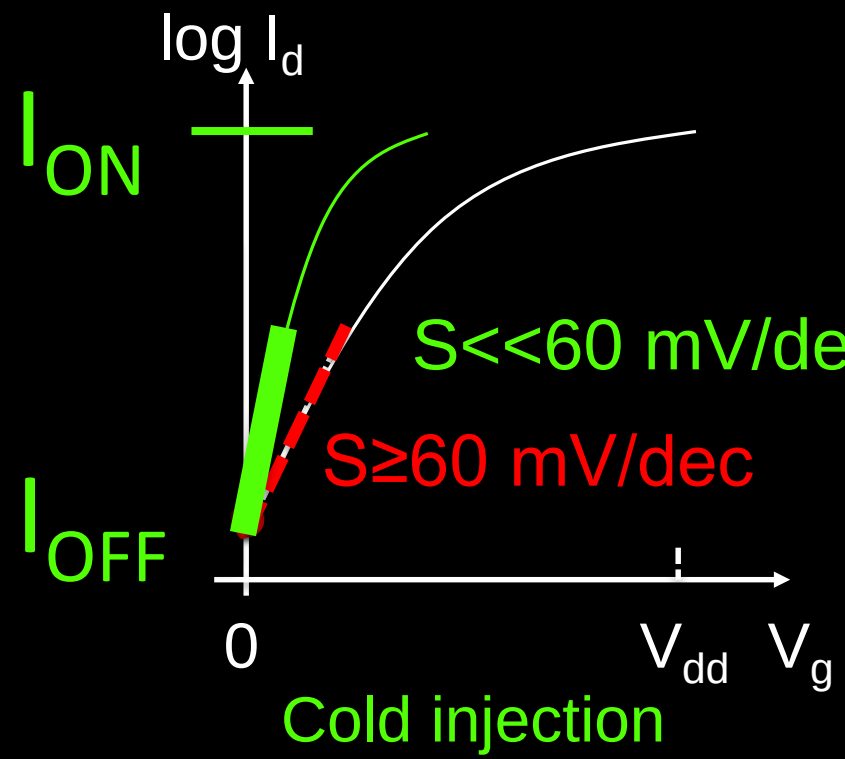


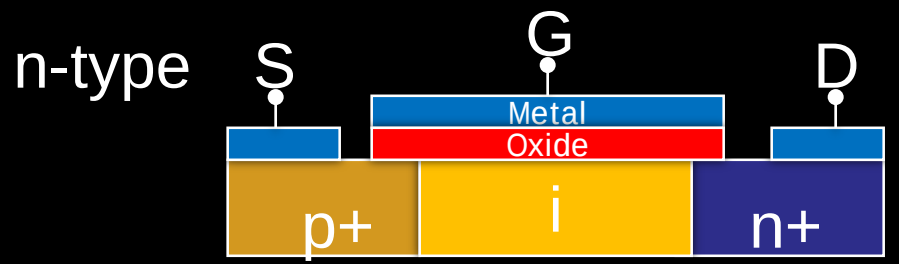
Static Power:

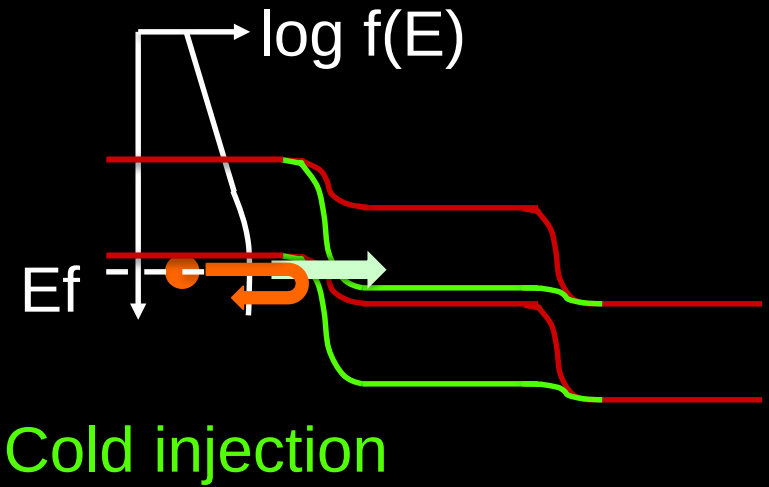
➢ Leakage through transistors

$$P \propto I_{OFF} \propto \cancel{1/\exp(V_{DD})}$$

Need a Different Switch







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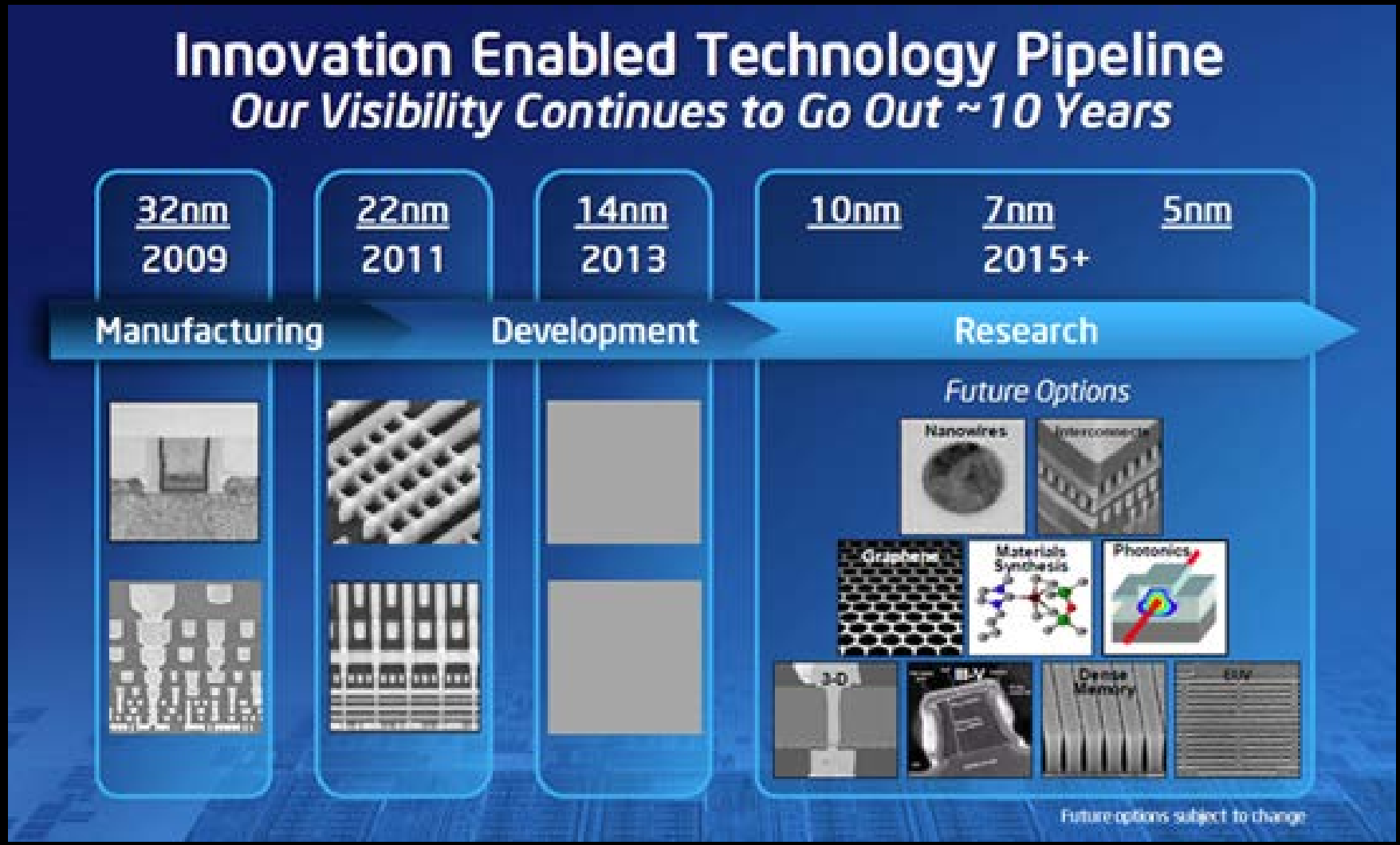
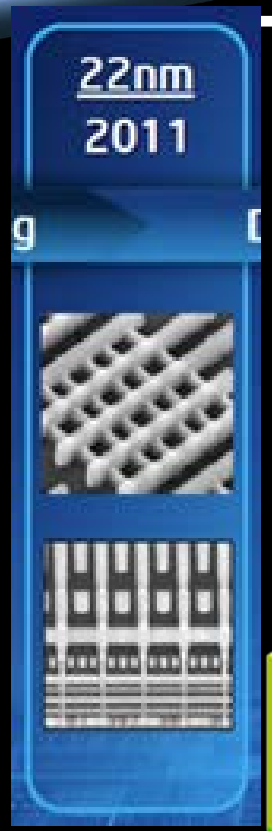
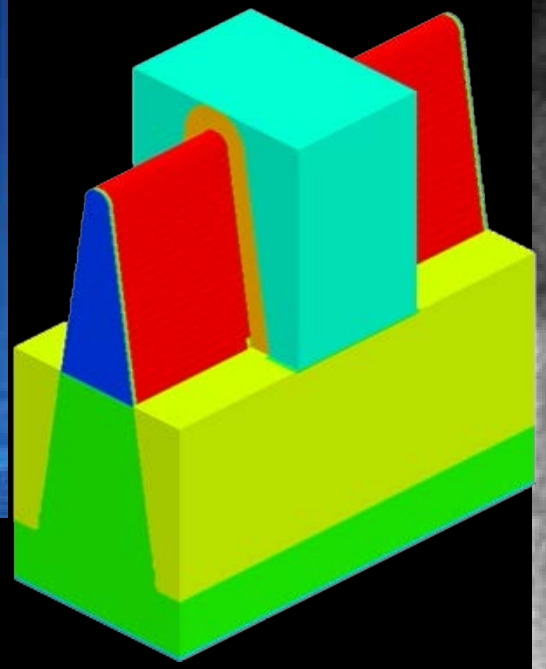
Intel Roadmap

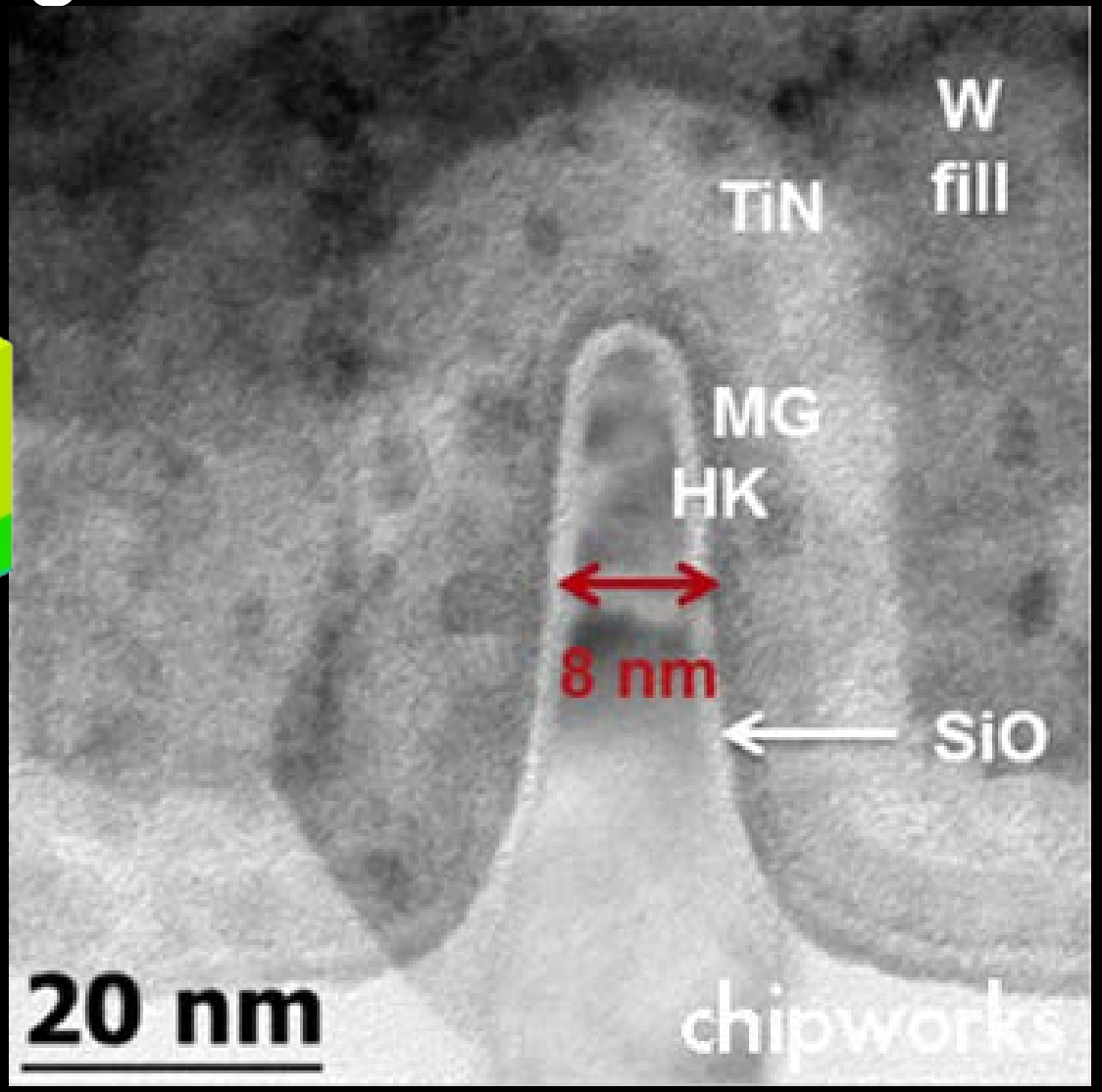


Today: non-planar 3D devices
Better gate control!





Intel 22nm finFET



http://www.goldstandardsimulations.com/index.php/news/blog_search/simulation-analysis-of-the-intel-22nm-finfet/

http://www.chipworks.com/media/wpmu/uploads/blogs.dir/2/files/2012/08/Intel22nmPMOSfin.jpg

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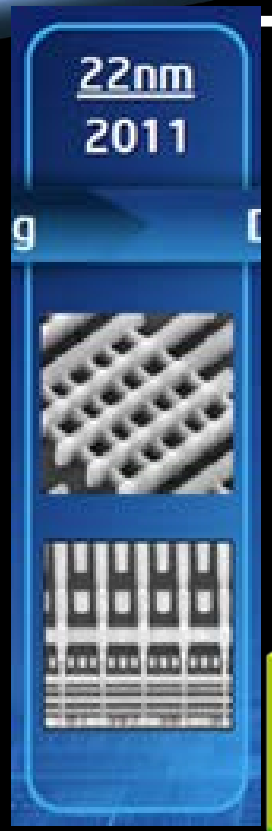

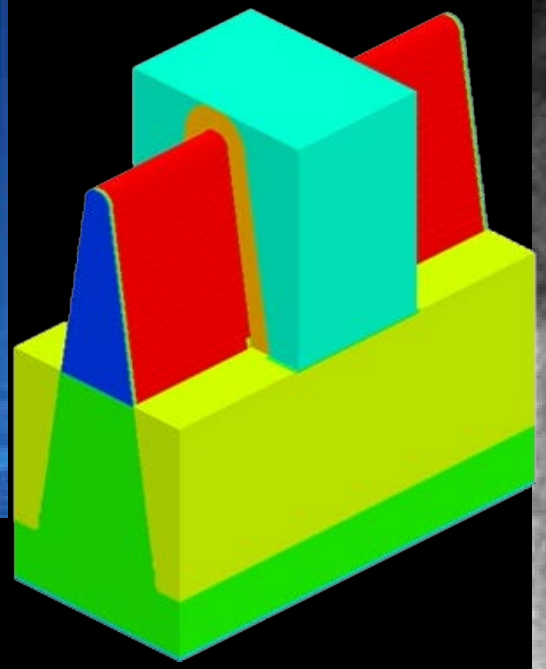

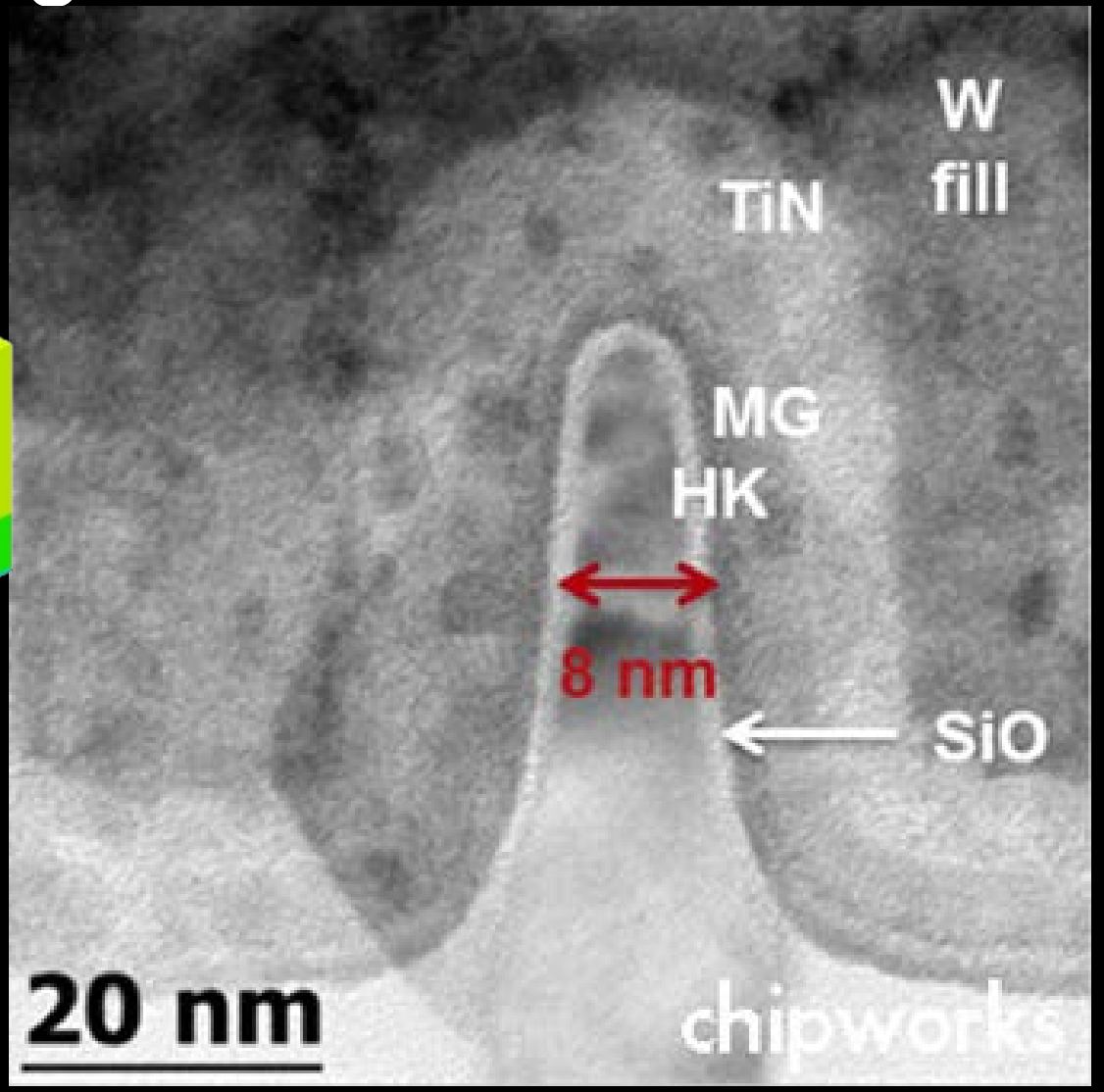

22nm = 176 atoms

8nm = 64 atoms

http://www.goldstandardsimulations.com/index.php/news/blog_search/simulation-analysis-of-the-intel-22nm-finfet/

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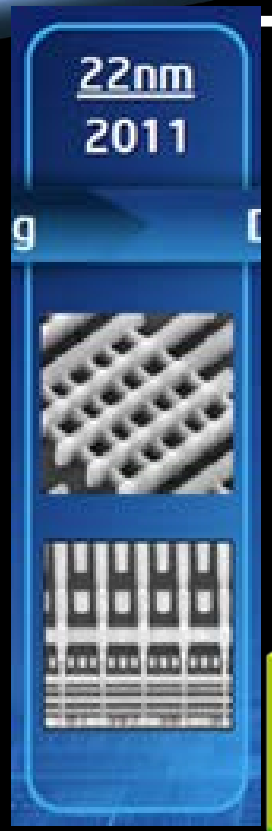
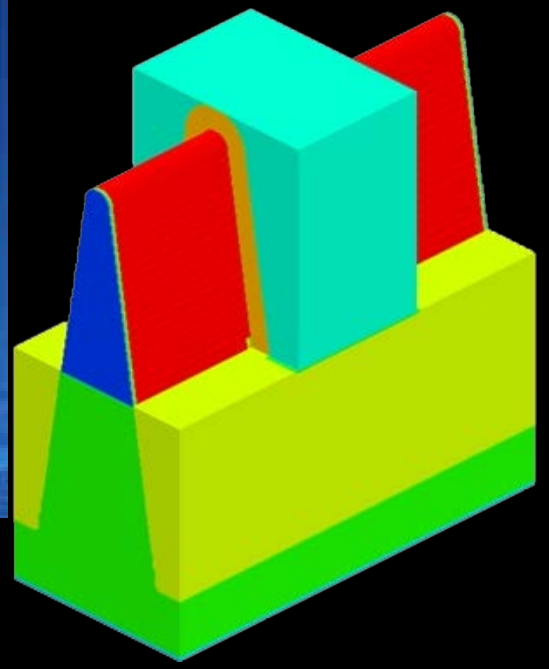
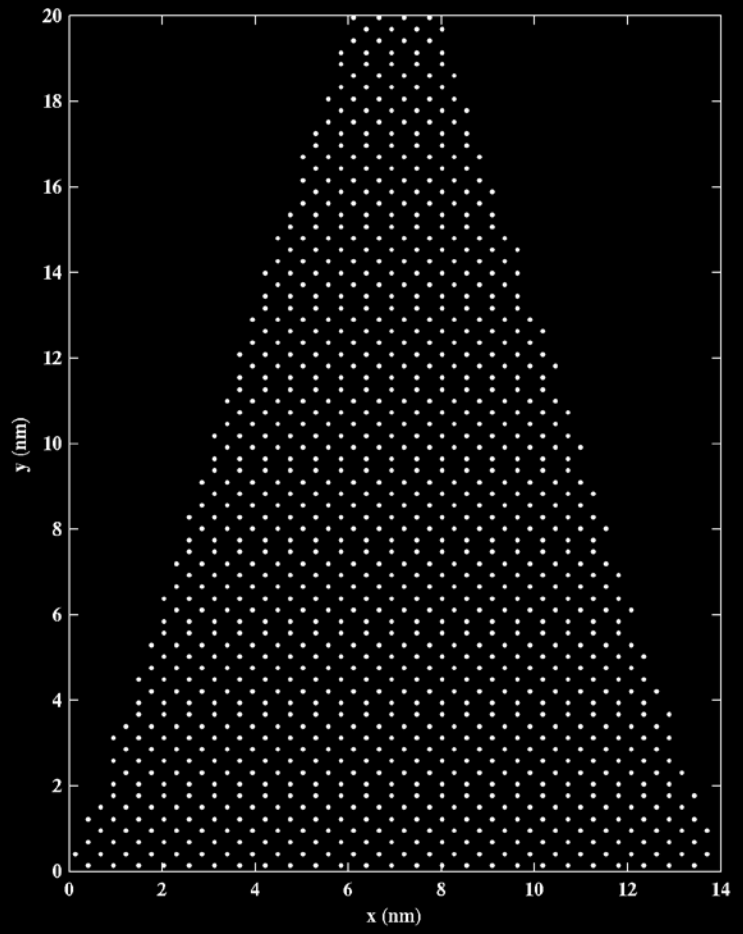




22nm = 176 atoms

8nm = 64 atoms

1,085 atoms



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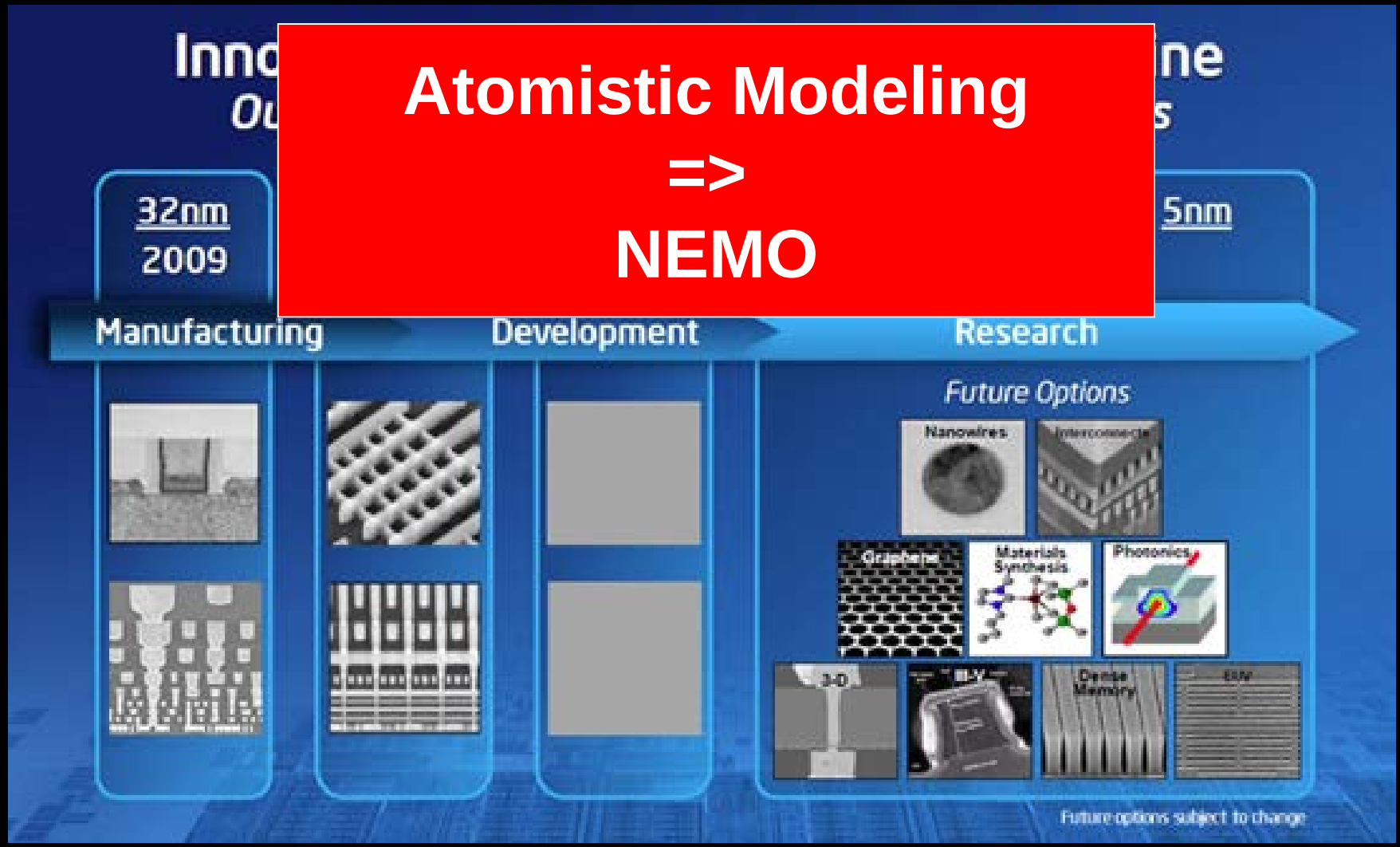
Roadmap of finite atoms!



Atomistic Modeling
=>
NEMO

nm Node	22	14	10	7	5
Node atoms	176	122	80	56	40
Critical atoms	64	44(?)	29(?)	20(?)	14(?)
Electrons	160-190	64-80	30-38	18-23	11-15

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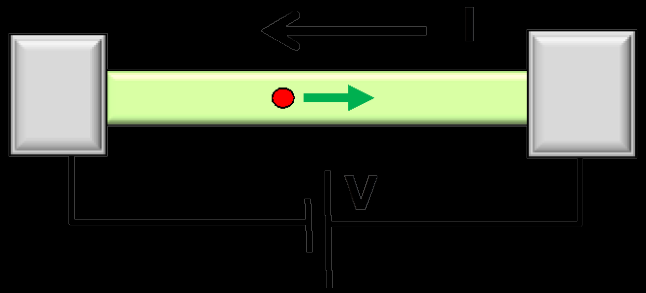

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