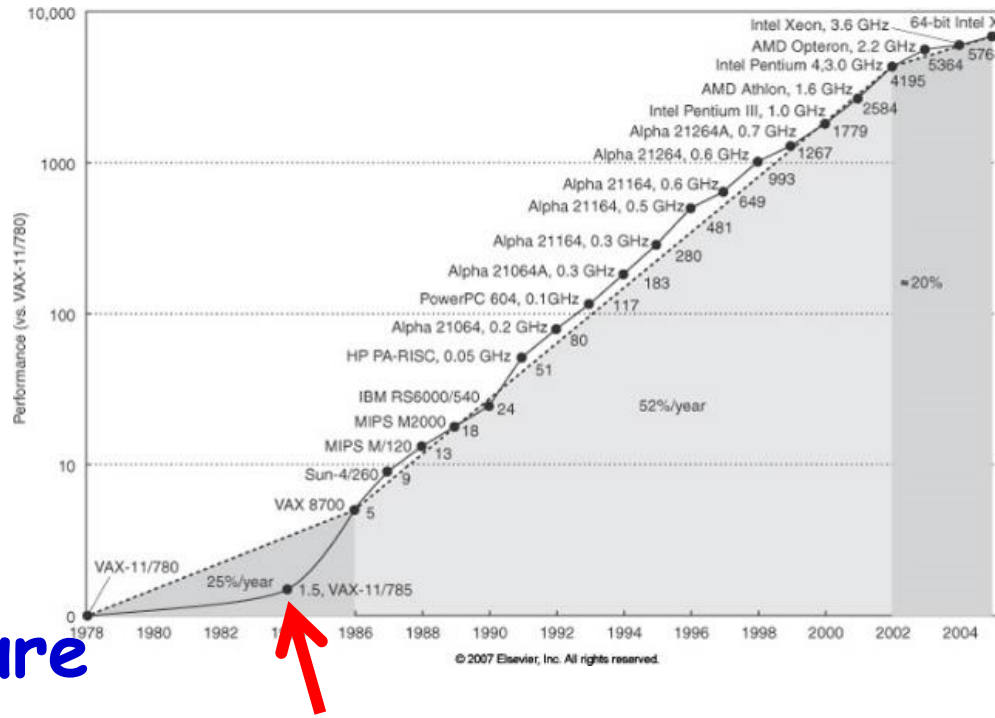
Lect 2

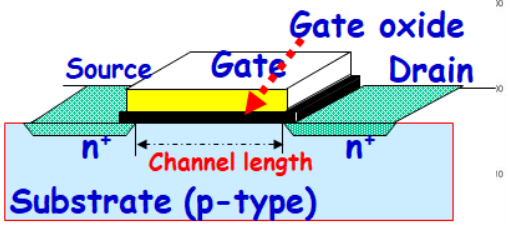
Where From Have the Performance Improvements Come?

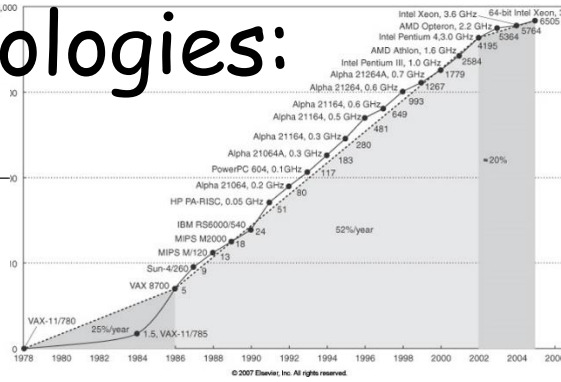
- **Technology**
  - More transistors per chip
  - Faster logic
- **Processor Organization**
  - Effective and deep pipelines
  - Parallel execution units
- **Instruction Set Architecture**
  - Reduced Instruction Set Computers (RISC)
  - Multimedia extensions
  - Explicit parallelism
- **Compiler technology**
  - Finding more parallelism in code
  - Greater levels of optimization



How Did Processor Performance Improve?

- Till 1980s, most performance improvements came from innovative manufacturing technologies:
  - VLSI
  - Reduction in feature size



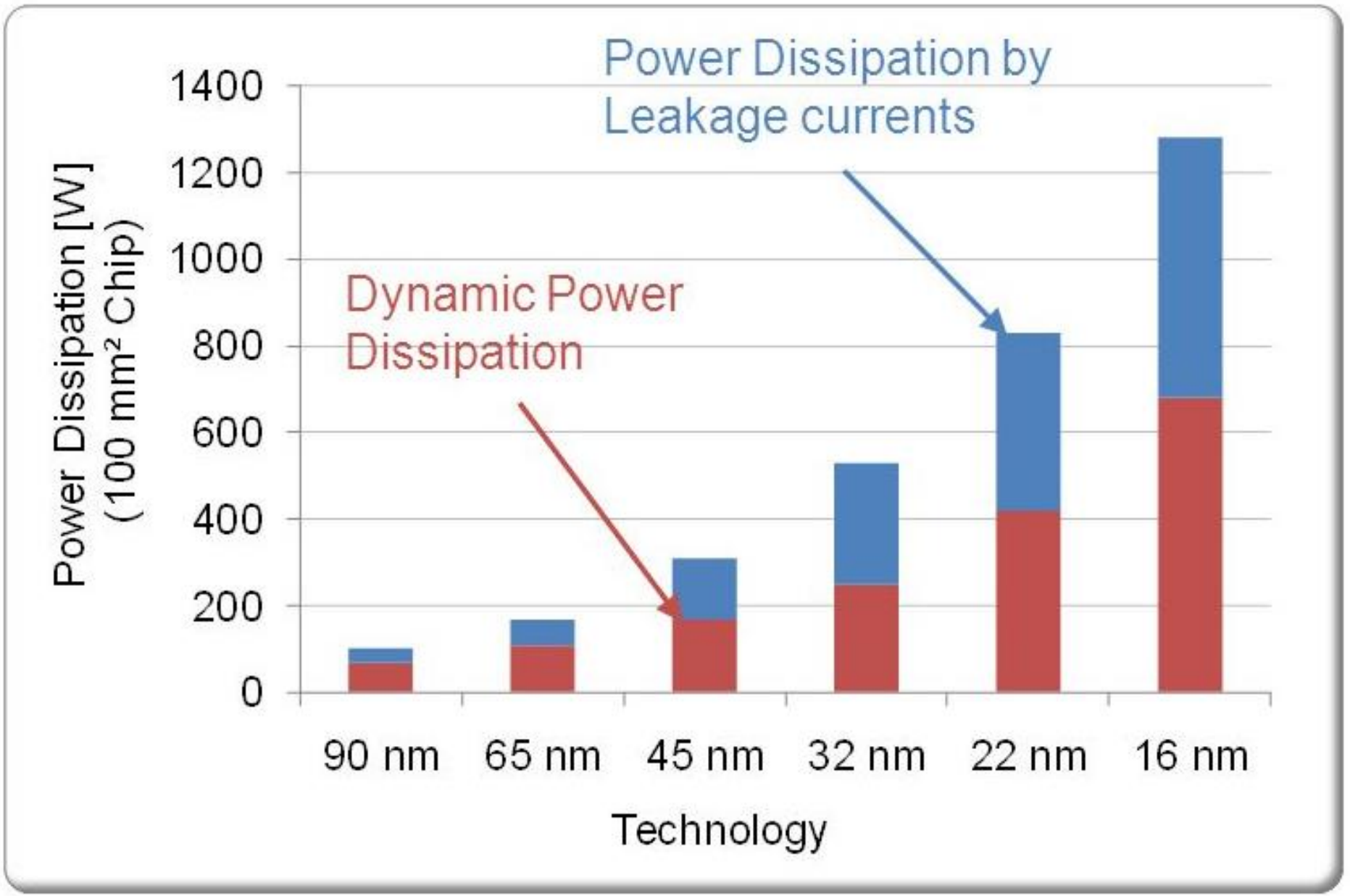


- **Improvements due to innovating manufacturing technologies have slowed down since 1980s:**
  - Smaller feature size gives rise to increased resistance, capacitance, propagation delays **and leakage**.
  - **Larger power dissipation.**

What is the power consumption of core i7 processor?

Roughly 100 watts when in use and 40 watts idle…

IC Power Consumption Trends



Source: S. Borkar (Intel),

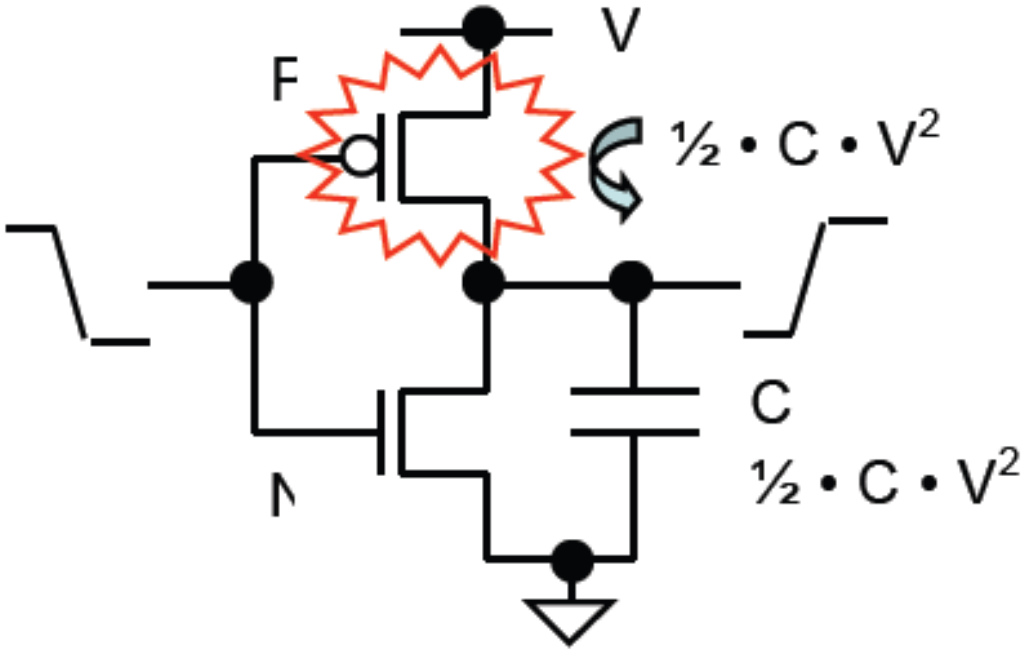
Power Consumption in a Processor

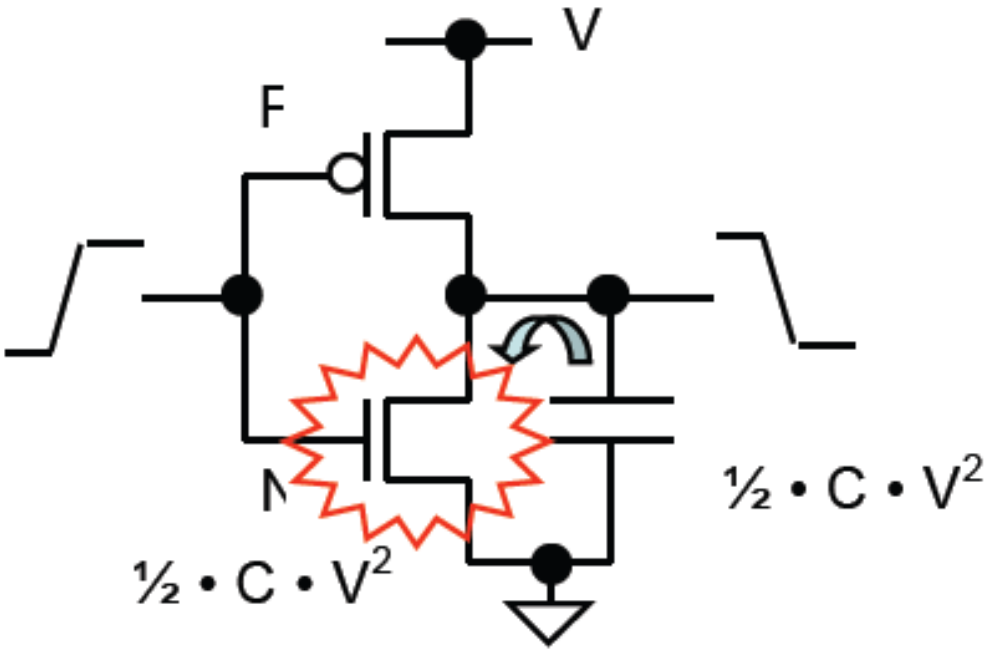
- Power=Dynamic power + Leakage power
- Dynamic power = Number of transistors x capacitance x voltage^2 x frequency
- Leakage power is rising and will soon match dynamic power.

	Pentium	P-Pro	P-II	P-III	P-4
Year	1993	95	97	99	2000
Transistors	3.1M	5.5M	7.5M	9.5M	42M
Clock Speed	60M	200M	300M	500M	1.5G

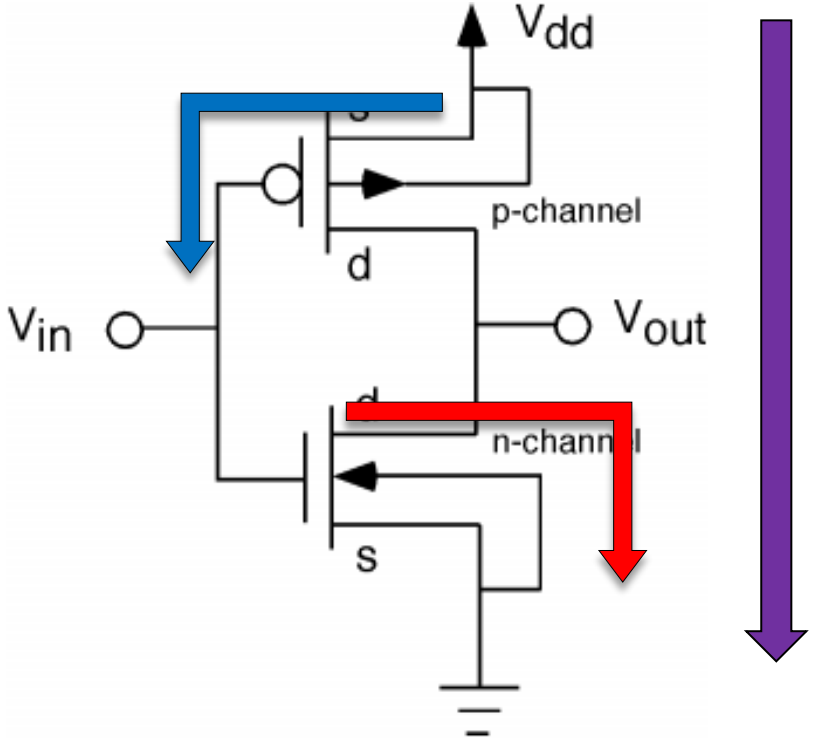
Switching Power

$$P = a \cdot C \cdot V^2 \cdot f$$

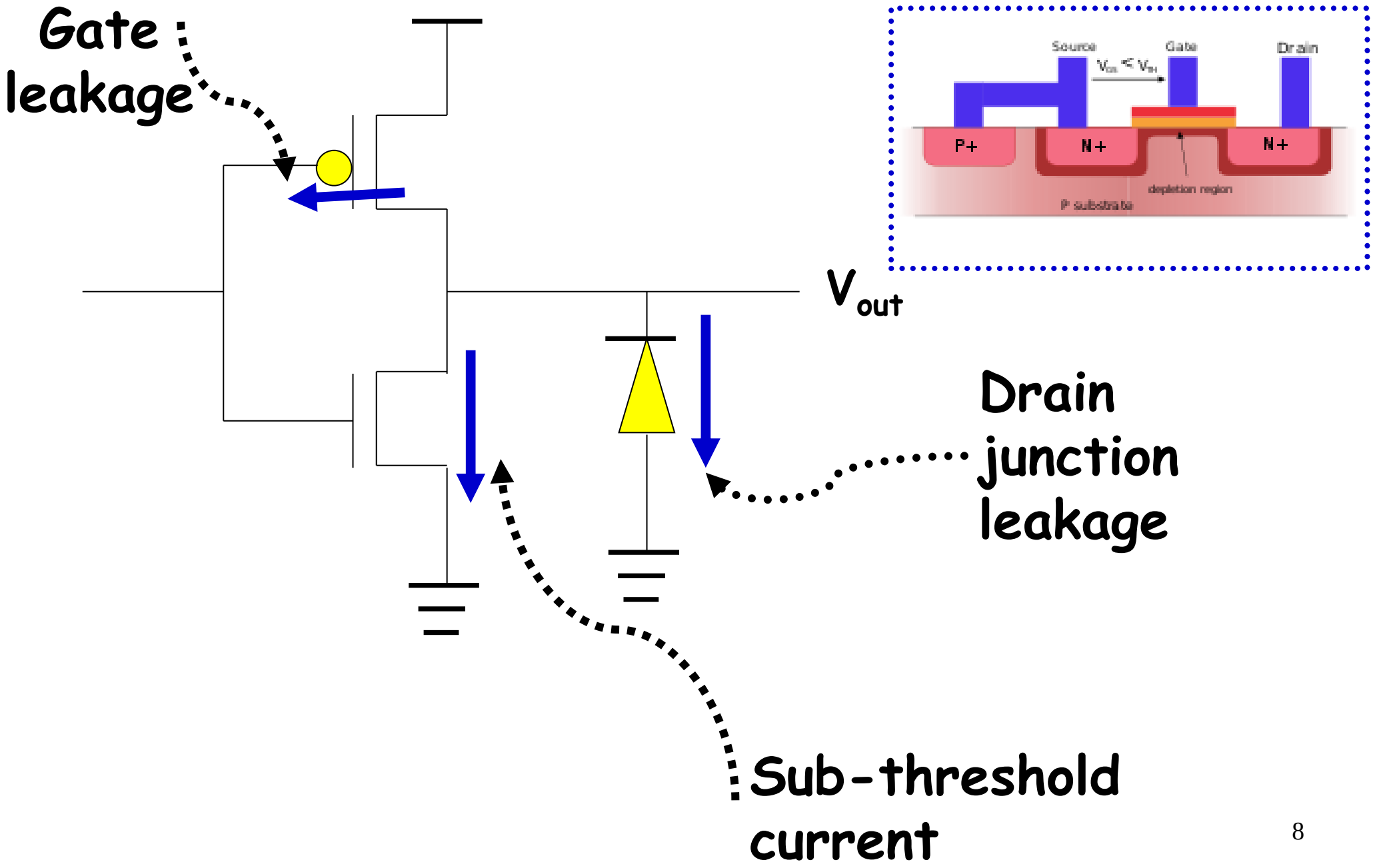




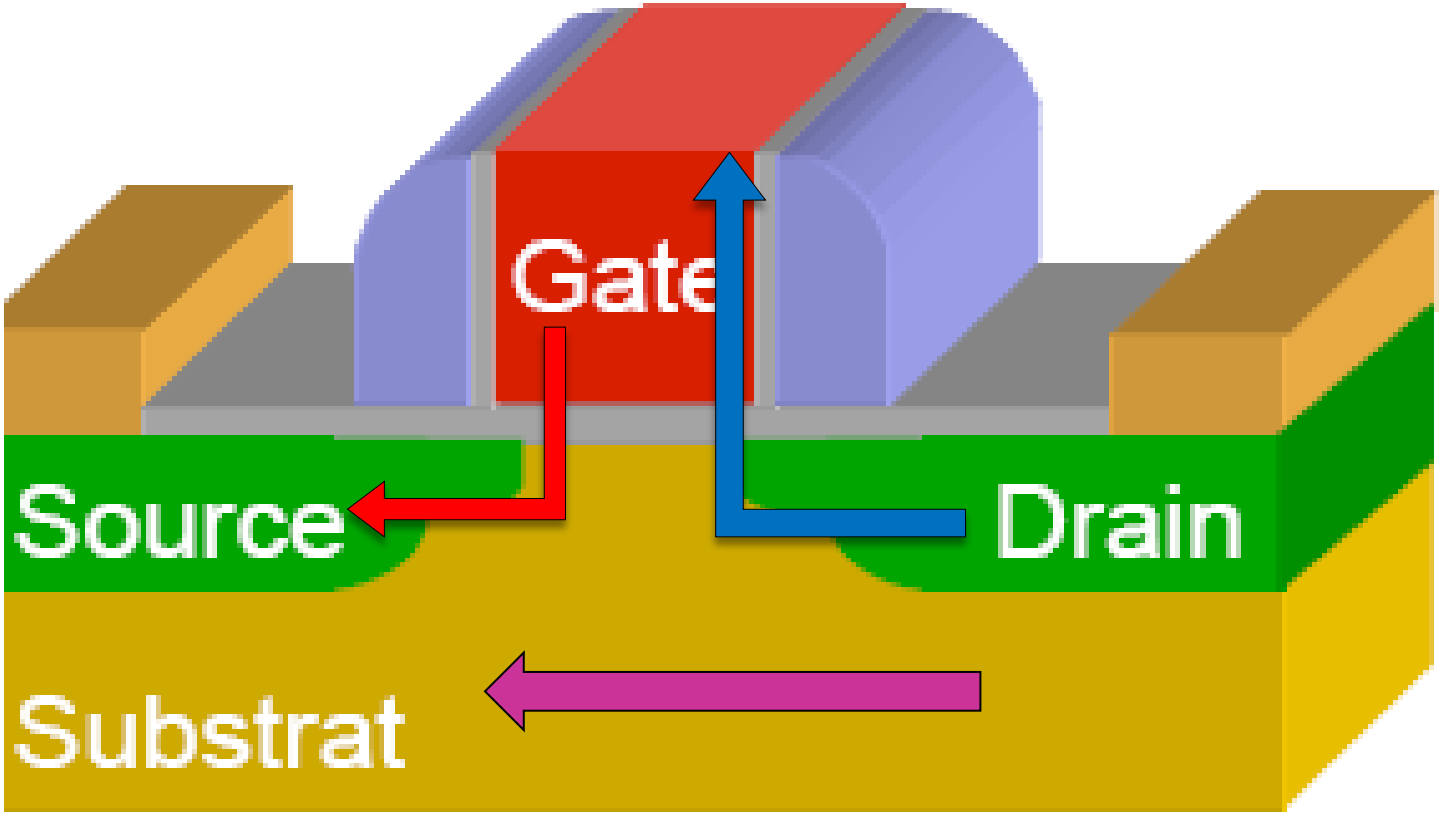
Static power



Static Power

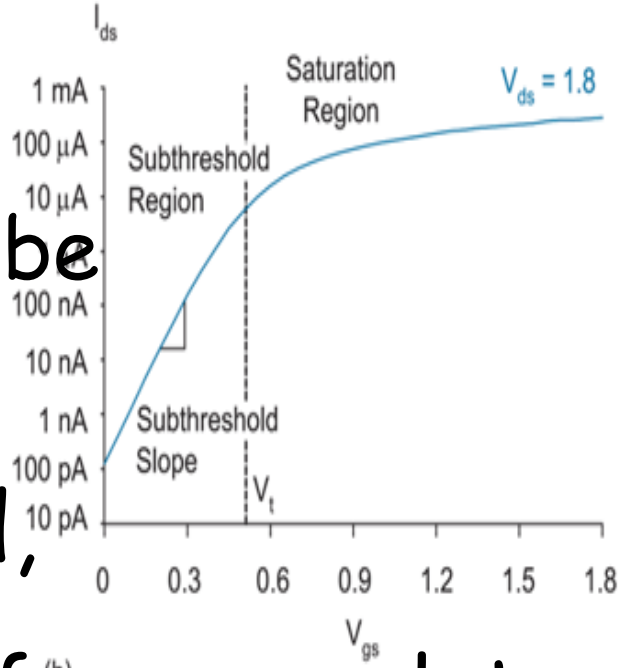


Leakage Currents



Sub-threshold Leakage

- As MOSFET geometries shrink:
  - Voltage applied to the gate must be reduced to maintain reliability.
- As threshold voltage is reduced,
  - A transistor cannot be switched from complete turn-off to complete turn-on with the limited voltage swing available;
  - **Strong current is the "on" state and low current is the "off" state.**
  - **Subthreshold operation…**

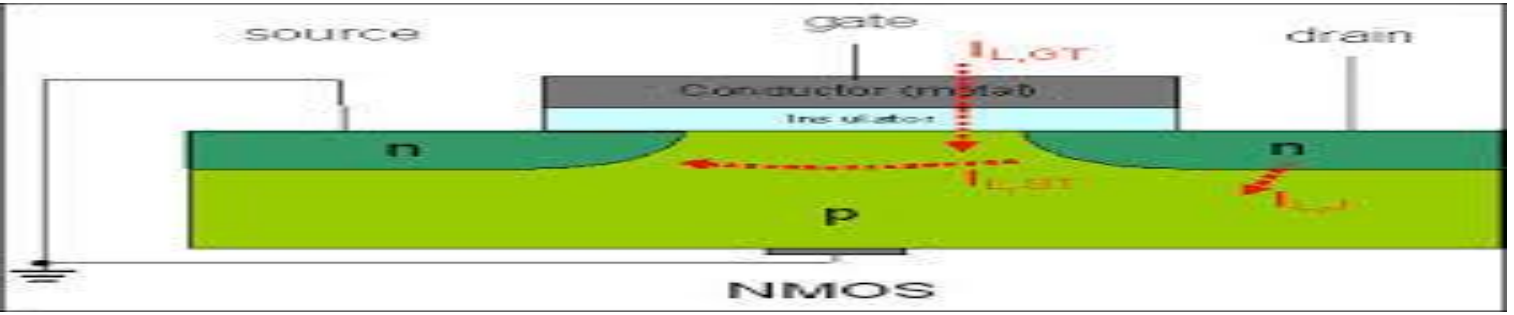


Gate Leakage: junction leakage and tunneling

Junction leakage: A reverse-biased p-n junction has some leakage.

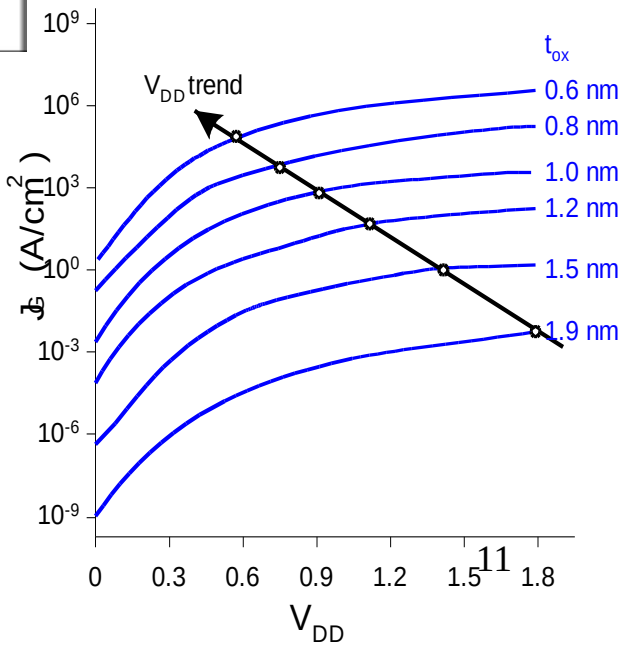
$$I_D = I_S\left(e^{\frac{V_D}{v_T}} - 1\right)$$

I_s depends on doping levels and area and perimeter of diffusion regions



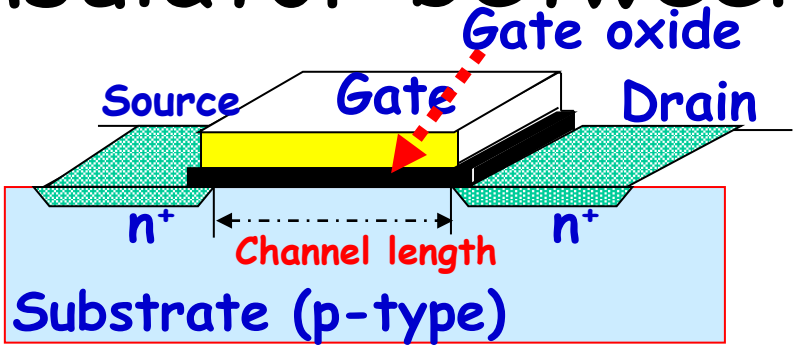
Tunneling leakage:

- Carriers may tunnel through very thin gate oxides
- Negligible for older processes



Tunnelling Leakage

- Gate oxide serves as insulator between the gate and channel.

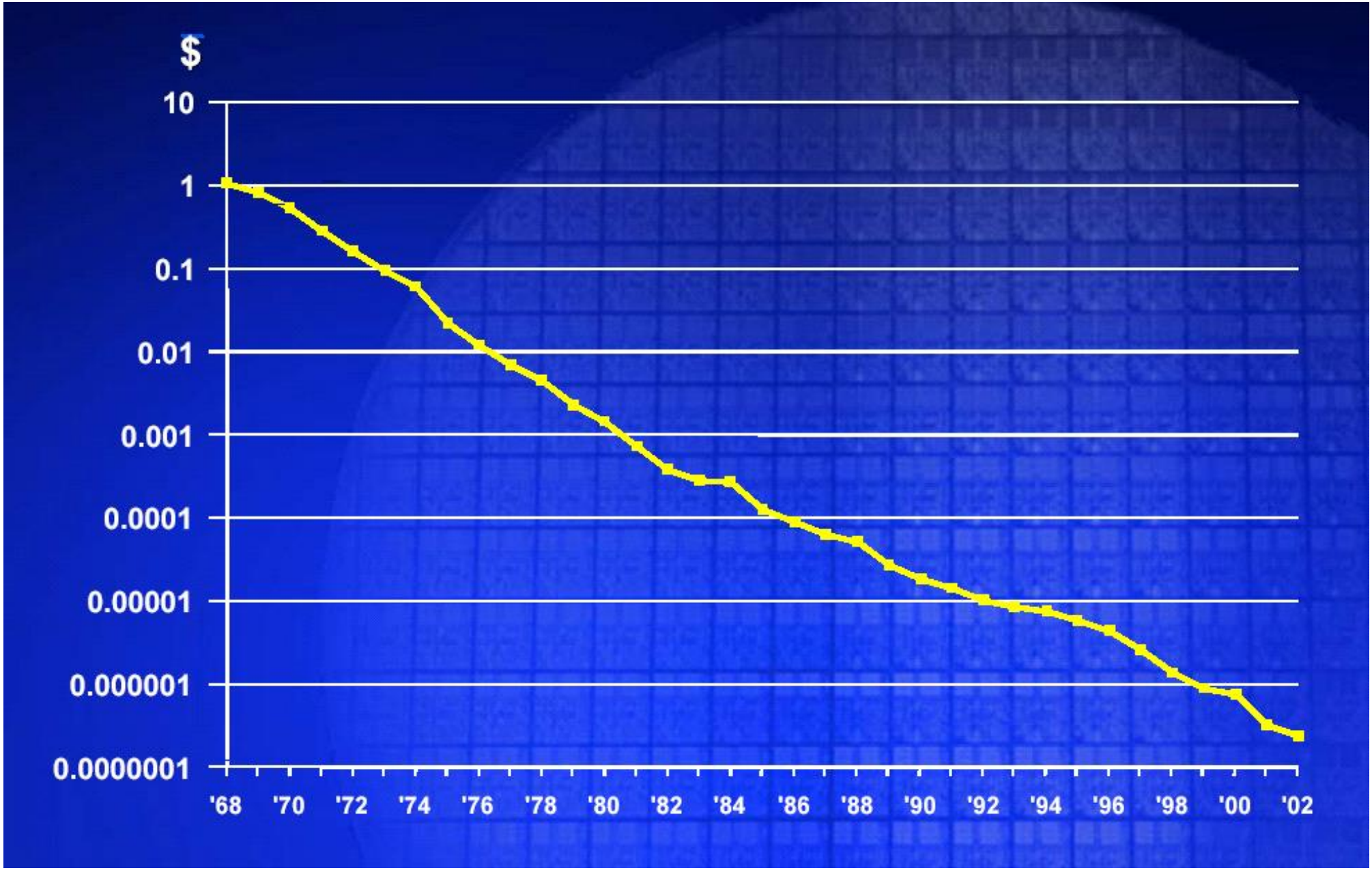


- However, gate oxide now has thickness of around 1.2 nm (about 5 atoms thick):
  - **Quantum mechanical phenomenon of electron tunneling occurs between gate and channel.**

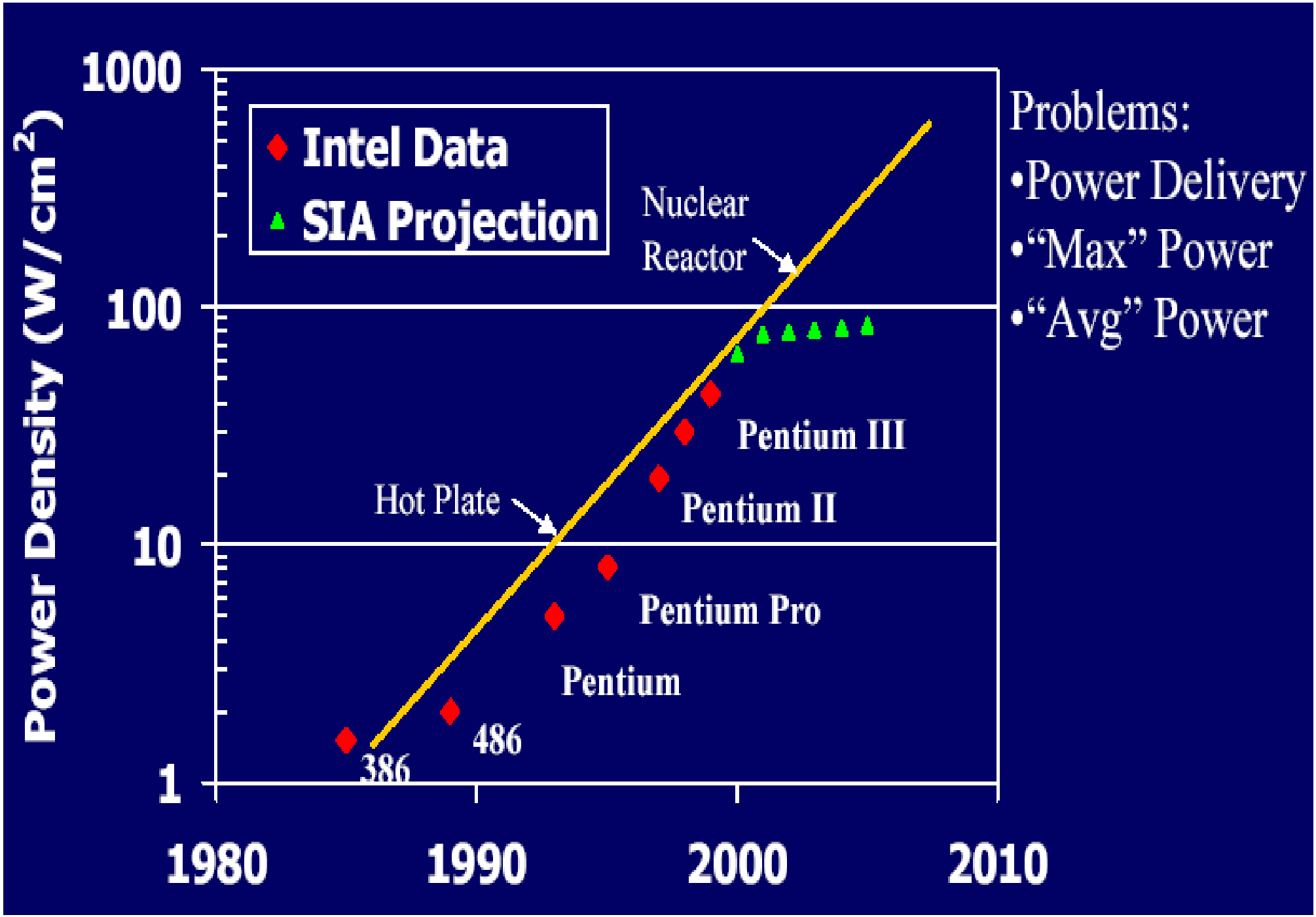
Dynamic Power

- Dynamic power in CMOS : Due to a transistor switching on and off
- Terms
  - C: capacitance of circuit
    - wire length, number and size of transistors
  - V: supply voltage
  - A: activity factor
  - f: frequency
- **Future: Power dissipation a major factor**

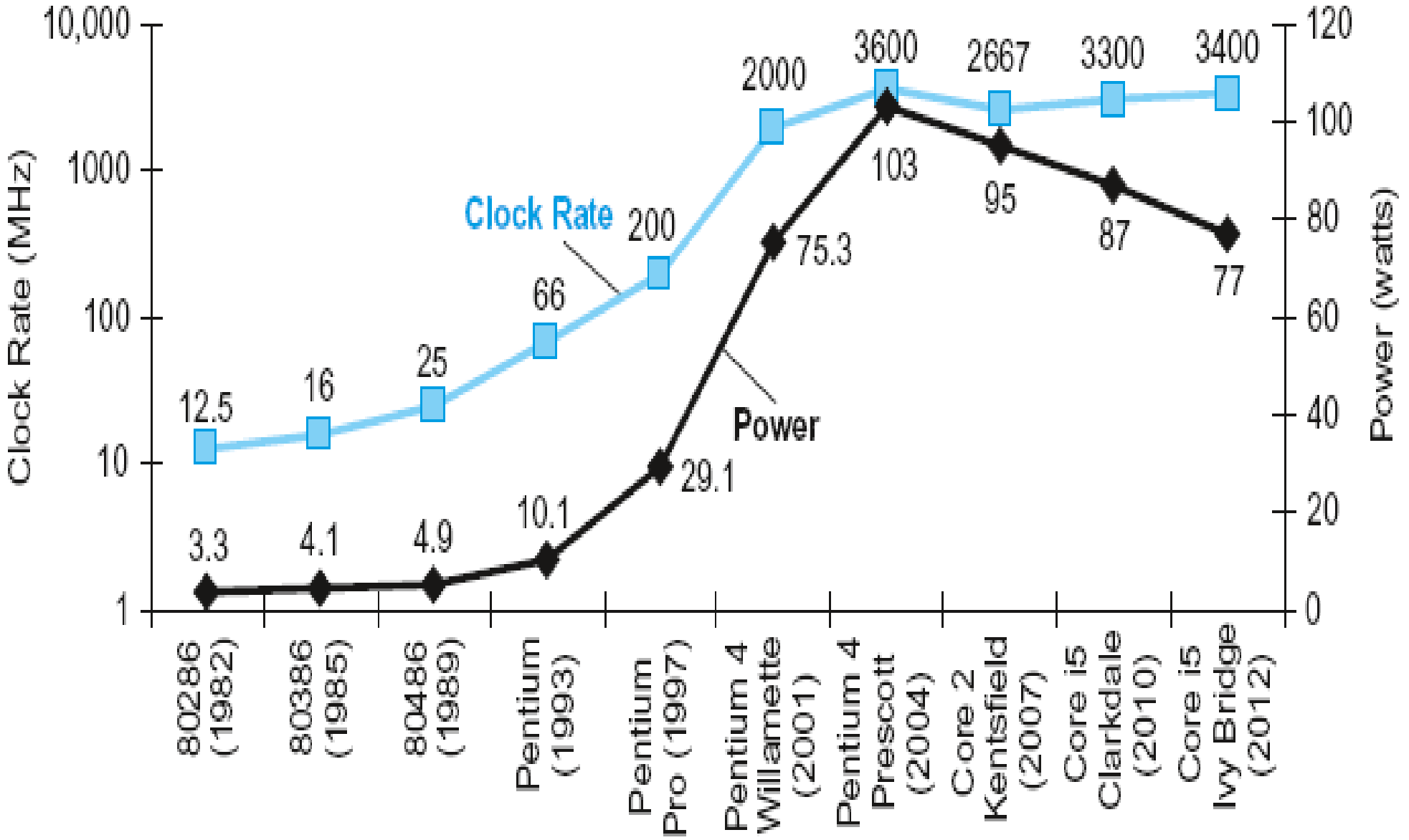
Average Transistor Cost Per Year



Power Density Trend



CMOS IC Power Trends



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