The Limitations of Silicon & the Collapse of Moore's Law

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Why Silicon?

The Metal-Oxide-Semiconductor field-effect transistor (MOSFET), commonly referred to as the transistor. Constructed mainly from silicon, it is the essential building block of millions of electronic devices worldwide. Even though there are more effective semiconductors silicon is one of the most plentiful element in the known universe, and therefore the cheapest semiconductor.

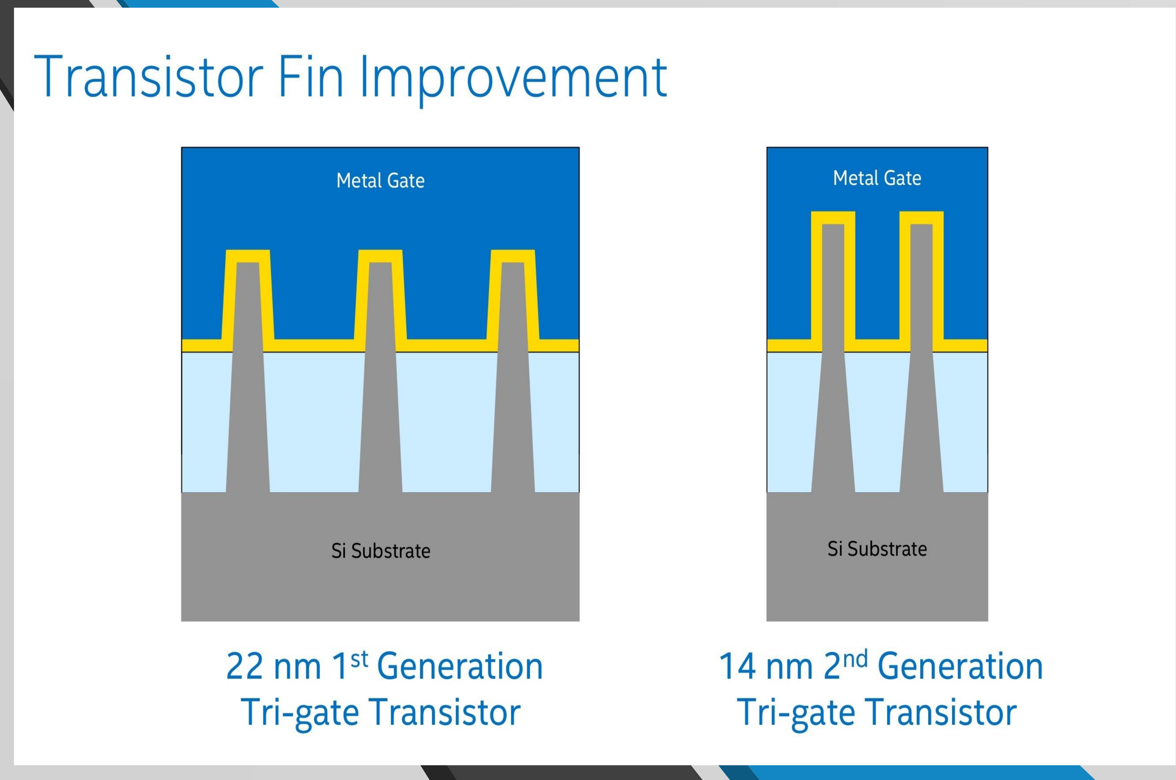
The Evolution of Silicon Chips

Moore's Law

- In 1965 Gordon Moore predicted that the density of circuit components would double approximately every year
- In 1975 he revised this rate to be approximately every two years
- Carver Mead coined and popularized the term Moore's Law
- It is likely that within the decade the current design of transistors will no longer keep pace with Moore's Law

Number of Transistors in Consumer Chips

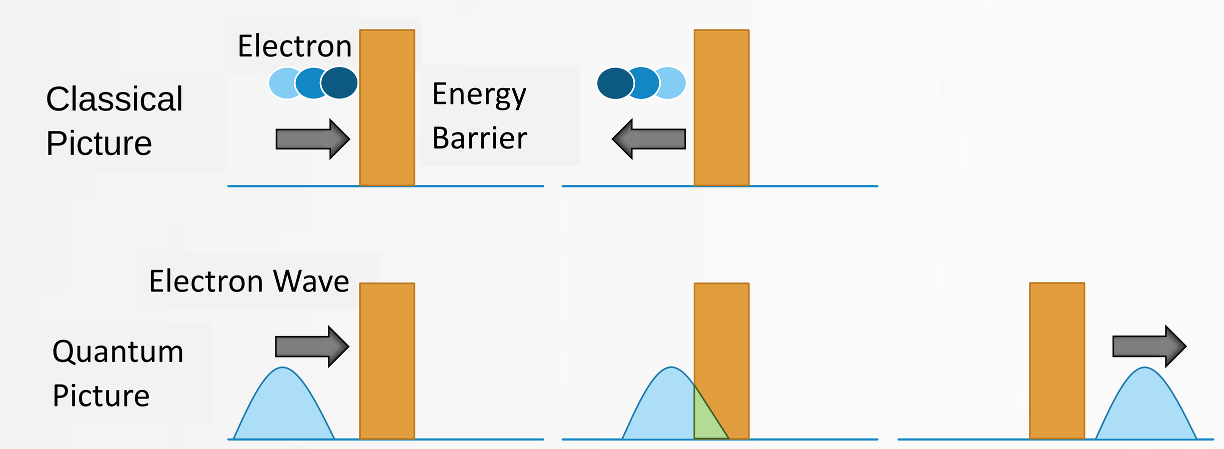
- Intel's i7 4790k shipped in 2014 with 1.4 billion transistors, with a total surface area of 177 mm^2
  - 7.9 million transistors per square mm
  - Used a 22 nm manufacturing process
- Intel's i7 6700k shipped in 2015 with 1.75 billion transistors, with a total surface area of 122 mm^2
  - 14.3 million transistors per square mm
  - Used a 14 nm manufacturing process



The Effects of Quantum Tunneling

What is Quantum Tunneling?

- The ability for a particle to surmount obstacles that its energy would not allow under classical physics
- Due to electrons exhibiting the properties of both waves and electrons
- The thinner the barrier and the higher the particle's initial energy, the higher the probability for tunneling to occur

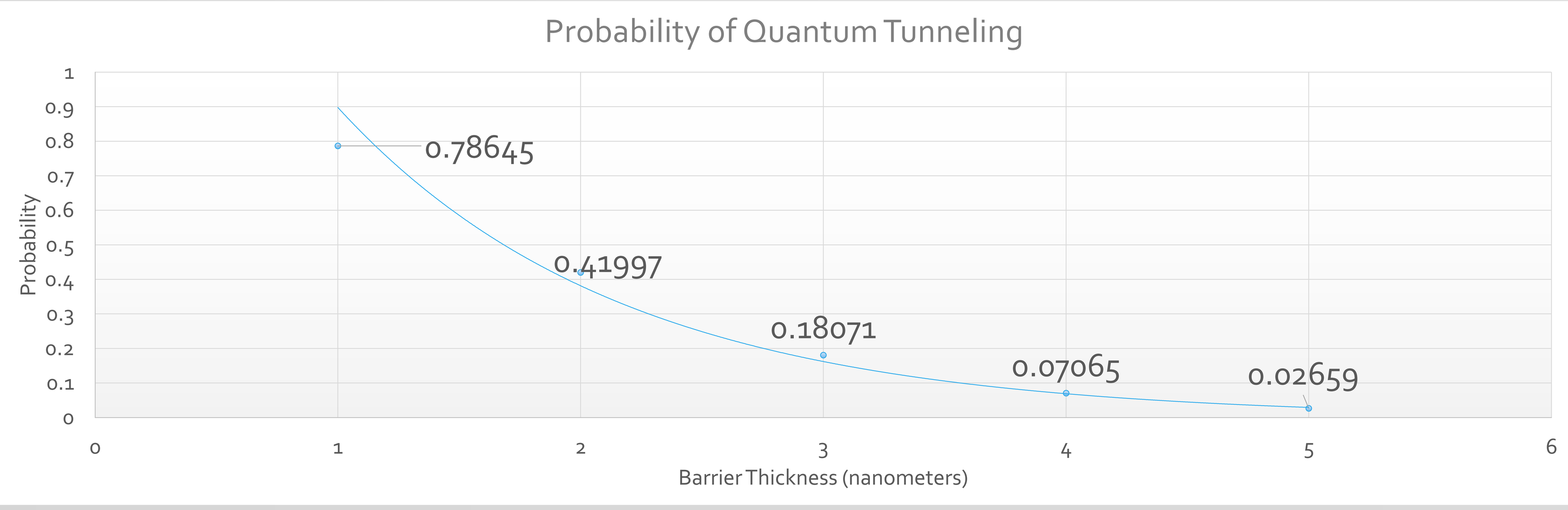


Why does it Impede Transistors?

- By varying voltage in MOSFET we can control the number of electrons that leave the source
- When Quantum tunneling occurs we lose that control of electrons

Probability of Quantum Tunneling

- At extremely low temperatures at distances of less than 5 nm between
  - Under standard voltages electron tunneling would happen unimpeded constantly
- At standard operation temperatures at distances of less than 5 nm
  - The probability of an electron tunnelling through a single, thin barrier is given by
    - $T(E) = \frac{1}{1+\left(\frac{k_b^2+k_w^2}{2k_b k_w}\right)^2 sinh^2(k_b L)}$
  - If we take a barrier potential of 1 eV this will gives us Kb = 2 nm^-1
  - If E = V/2 we can assume that kw = kb
    - $T(E) = \frac{1}{1+sinh^2(k_b L)}$



Counters to Tunneling

Carbon Nanotubes

- Graphene is a one-atom-thick sheet of carbon in a hexagonal array, and are used in the construction of nanotubes
- Graphene was used in late 2016 to produce a transistor gate of 1 nanometer thickness
- With the use of MoS2 (Molybdenum disulfide) in the carbon sheet the flow of electrons was properly controlled at this thickness
  - This was because the electrons flowing in the MoS2 have a much higher effective mass
  - Proving that the construction of sub-5nm gates is possible
- Is currently incredibly expensive and difficult to produce even one transistor of this design (let alone billions on a single chip)

Quantum Computing

- Utilizes qubits, which utilize the theory of superposition to represent both 0 and 1 at the same time
- Need to be cooled below 15 millikelvin to operate properly
  - This is .015 degrees kelvin above absolute zero
- The largest barrier to quantum computing is the suppression of decoherence
  - Decoherence is the fact that a quantum particle will only appear as a wave function when measured
  - With the use of magnetic fields the accuracy of quantum computers, based on IBM's publically accessible quantum computer, has reached an accuracy of 99.6% in answer consistency

Alternatives to Silicon

III-V Chips

- Standard silicon chip layered with an element from columns III or V on the periodic table
  - III-V semiconductors have a higher electron mobility than silicon, resulting in faster switching transistors

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