Nanotechnology: An Alchemist’s Dream

When silicon particles become smaller than 3 nm, they behave like gallium arsenide, a different material.

3 nm: Band gap begins to change
Quantum Well Laser

Electrons in the Conduction Band

p-type

n-type

Holes in the Valence Band

CD / DVD player, Checkout scanner

Alferov Kroemer
Nobel Prize in Physics 2000
The gate turns the electron flow from source to drain on/off. A negative charge on the gate repels electrons from the channel.
Moore’s Law

Silicon technology grows exponentially (density, performance/price, ...)

Logarithmic scale

Data Storage Density

Areal Density, Mb/\text{inch}^2

Year

IBM Ed Grochowski
Exponential and Logarithm

Linear growth: Same amount *added* each year

Exponential growth: Same *multiplier* each year
(Moore’s law, compound interest, bacteria, …)
Fast growth, gets out of control if unchecked.

Logarithm and exponential neutralize each other.
The exponential function $10^x$ moves a number $X$ into the exponent, the logarithm brings it back down: $\log[10^X] = X$

Use a logarithmic scale to plot an exponential, converting it into a line.
Exponential Growth: Bacteria and World Population

Fig.s 7.24, 7.28

Normal (linear) plot:
Cannot handle large range of values.

Log scale plot:
Straight line indicates exponential growth.
The Silicon Technology Roadmap

Intel was already down to a gate oxide only five silicon layers thick. Electrons leaking across the gate oxide consumed 1/3 of the power. The problem was fixed by finding new “high k” insulators and depositing them one atom layer at a time.

<table>
<thead>
<tr>
<th>1st Production</th>
<th>1997</th>
<th>1999</th>
<th>2001</th>
<th>2003</th>
<th>2005</th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Generation</td>
<td>0.25μm</td>
<td>0.18μm</td>
<td>0.13μm</td>
<td>90 nm</td>
<td>65 nm</td>
<td>45 nm</td>
<td>32 nm</td>
<td>22 nm</td>
</tr>
<tr>
<td>Wafer Size (mm)</td>
<td>200</td>
<td>200</td>
<td>200/300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Inter-connect</td>
<td>Al</td>
<td>Al</td>
<td>Cu</td>
<td>Cu</td>
<td>Cu</td>
<td>Cu</td>
<td>Cu</td>
<td>?</td>
</tr>
<tr>
<td>Channel</td>
<td>Si</td>
<td>Si</td>
<td>Si</td>
<td>Strained Si</td>
<td>Strained Si</td>
<td>Strained Si</td>
<td>Strained Si</td>
<td>Strained Si</td>
</tr>
<tr>
<td>Gate dielectric</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>High-k</td>
<td>High-k</td>
<td>High-k</td>
</tr>
<tr>
<td>Gate electrode</td>
<td>Poly-silicon</td>
<td>Poly-silicon</td>
<td>Poly-silicon</td>
<td>Poly-silicon</td>
<td>Poly-silicon</td>
<td>Metal</td>
<td>Metal</td>
<td>Metal</td>
</tr>
</tbody>
</table>
Intel's Transistor Technology Breakthrough Represents Biggest Change to Computer Chips In 40 Years

Intel Producing First Processor Prototypes With New, Tiny 45 Nanometer Transistors, Accelerating Era of Multi-Core Computing

SANTA CLARA, Calif., Jan. 27, 2007

First fundamental change to basic transistor in forty years

YORKTOWN HEIGHTS, NY - 27 Jan 2007: IBM (NYSE: IBM) today announced it has developed a long-sought improvement to the transistor — the tiny on/off switch that serves as the basic building block of virtually all microchips made today.

Working with AMD and its other development partners Sony and Toshiba, the company has
In Pursuit of the Ultimate Storage Medium:

1 Bit = 1 Atom

Silicon Surface

CD-ROM

Density × 1 000 000
When will we be down to atoms?

If Moore's Law continues to hold...

250 Terabit/inch$^2$

Year 2038
Biological Length Scales

DNA
- 3.4 nm pitch
- 10 base pairs
- 2 nm
- 11 nm

Virus
- 300 nm
- 18 nm
Molecular Motors: Contraction of a Muscle

Muscle fiber 1 (moving)

Filament carrying fiber 1

ATP = Fuel
ADP = Exhaust

Walking protein molecule

Muscle fiber 2 (fixed)
The Wisconsin Discovery Institutes  (Nano + Bio + Info + Medical)
"Disruptive technologies"

Clayton Christensen
Harvard Business School

A business model for nanotechnology: start with niche applications, then break into mass markets.

Figure 3. Successful disruptors target smaller, “green space” markets instead of stretching toward existing, larger markets.