The science that drives modern computers.

COS 116, Spring 2010

Adam Finkelstein

Changing face of manufacturing

1936

"Modern Times"

Late 20th century

Silicon wafer fabrication

20th century science and IT: a match made in heaven?

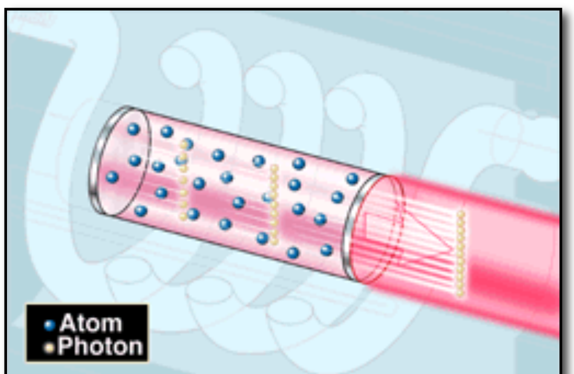
"These are the days of miracles and wonders." – Paul Simon, Graceland

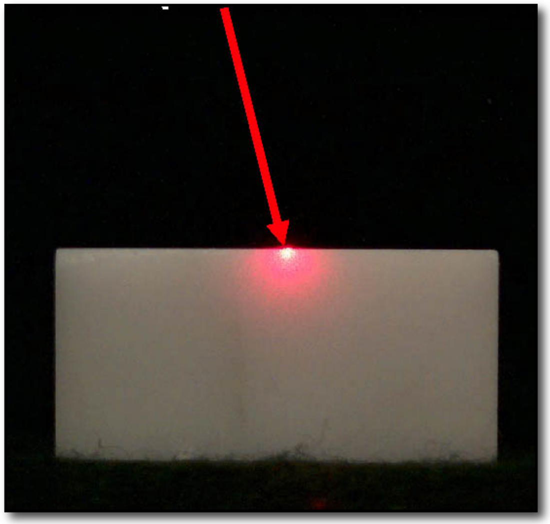
Main theme in this lecture:

Scientific Advances→ Ability to control matter precisely
→ Amazing products/computers

Example of precise control of matter: Lasers

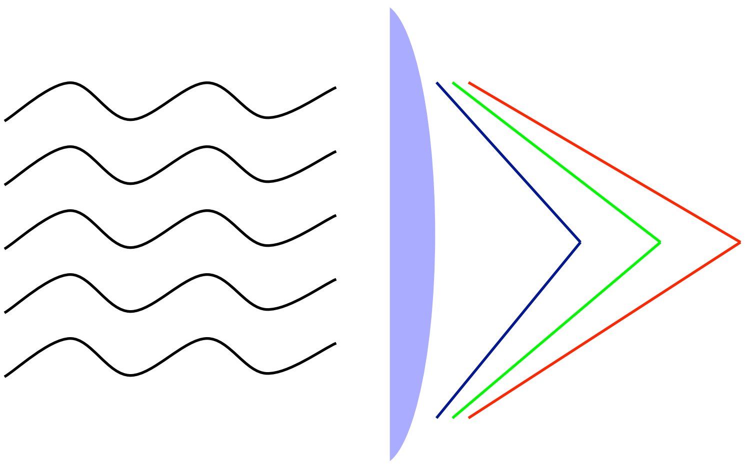
- Quantum mechanics (wave-particle duality, quantization of energy, etc.)
- Ability to create light of a single frequency ("laser")





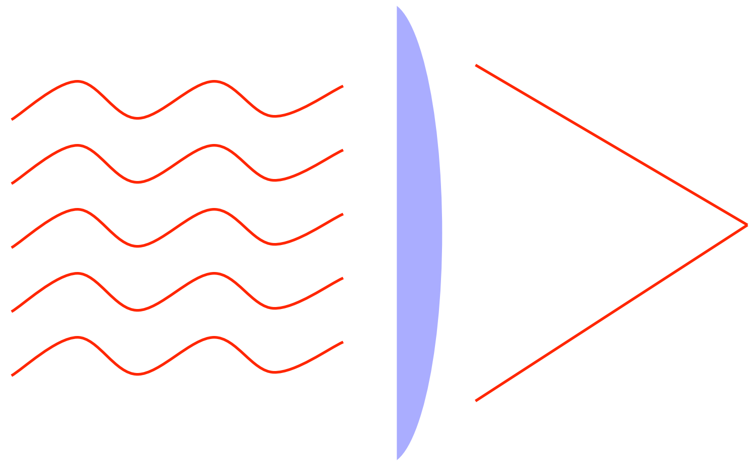
Why lasers are so useful: Accurate focusing

- White light



- Different colors focus at different points – "smudge"

- Laser



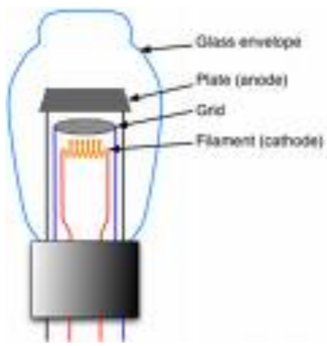
- Focus at single point

Silicon Chip manufacturing

"A picture is worth a billion gates."

Fact: Modern chips are manufactured using a process similar to photography

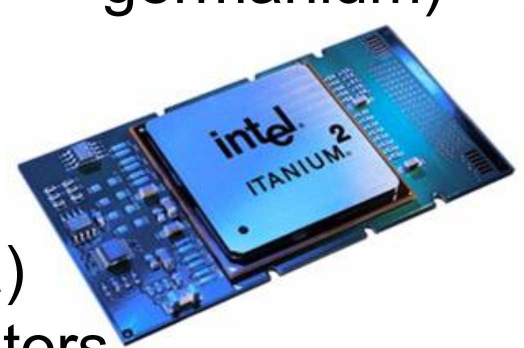
Timeline



Vacuum Tube
Triode (1908)

Transistor
1947
(silicon,
germanium)

Very Large Scale
Integrated (VLSI)
Circuits; 1970s--
(> 1,000 transistors
per chip)

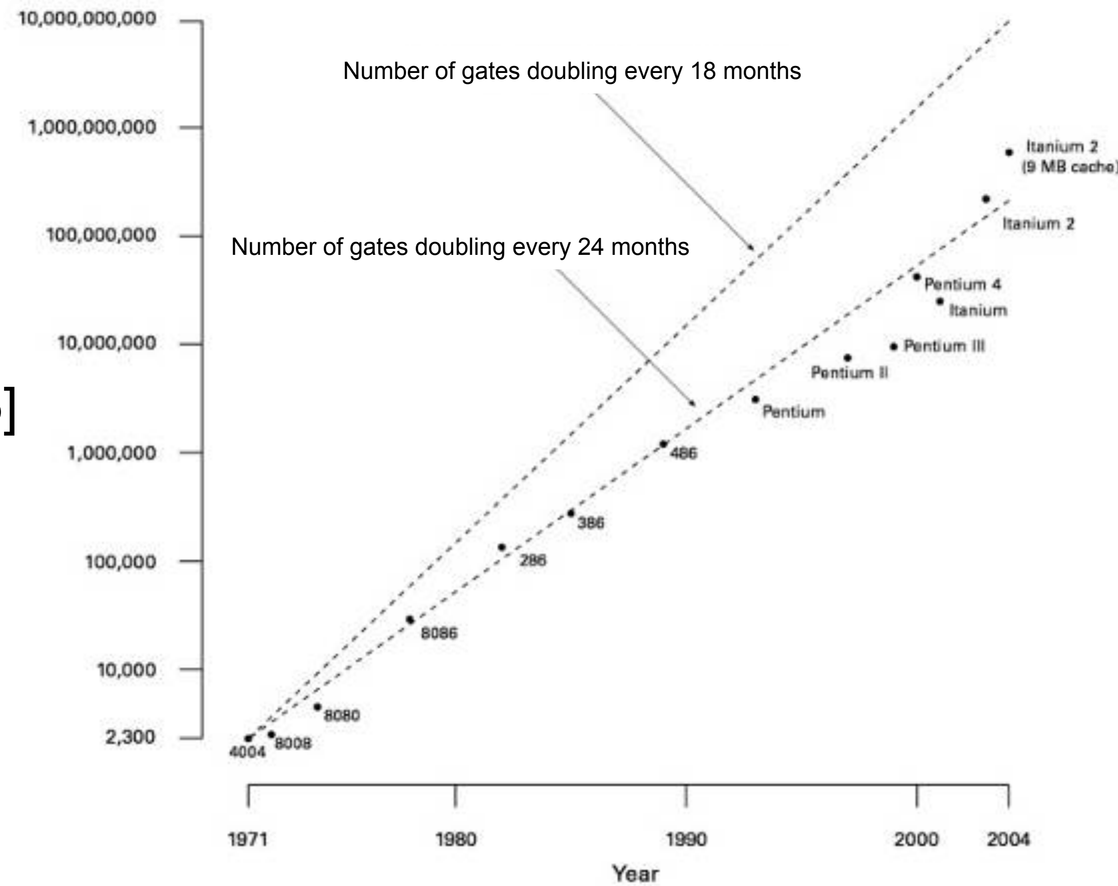


Intel Itanium (Tukwila)
2008: 2 billion transistors

Moore's Law

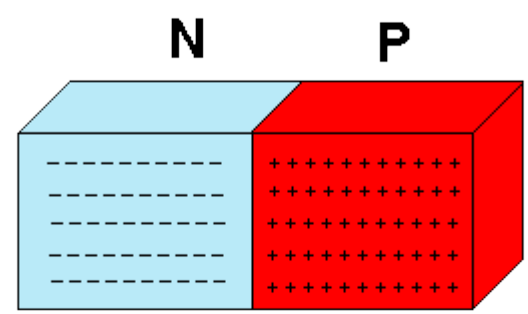
Technology advances so that number of gates per square inch doubles every 18 months.

[Gordon Moore 1965]

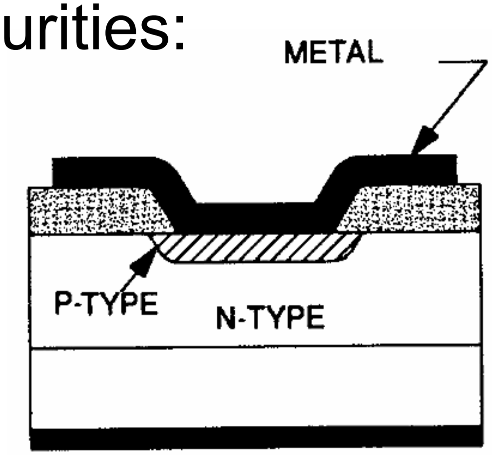


Implementation of a gate in a modern chip

- Semiconductor:
  not as good a conductor as metals,
  not as bad as wood
  - Example: silicon

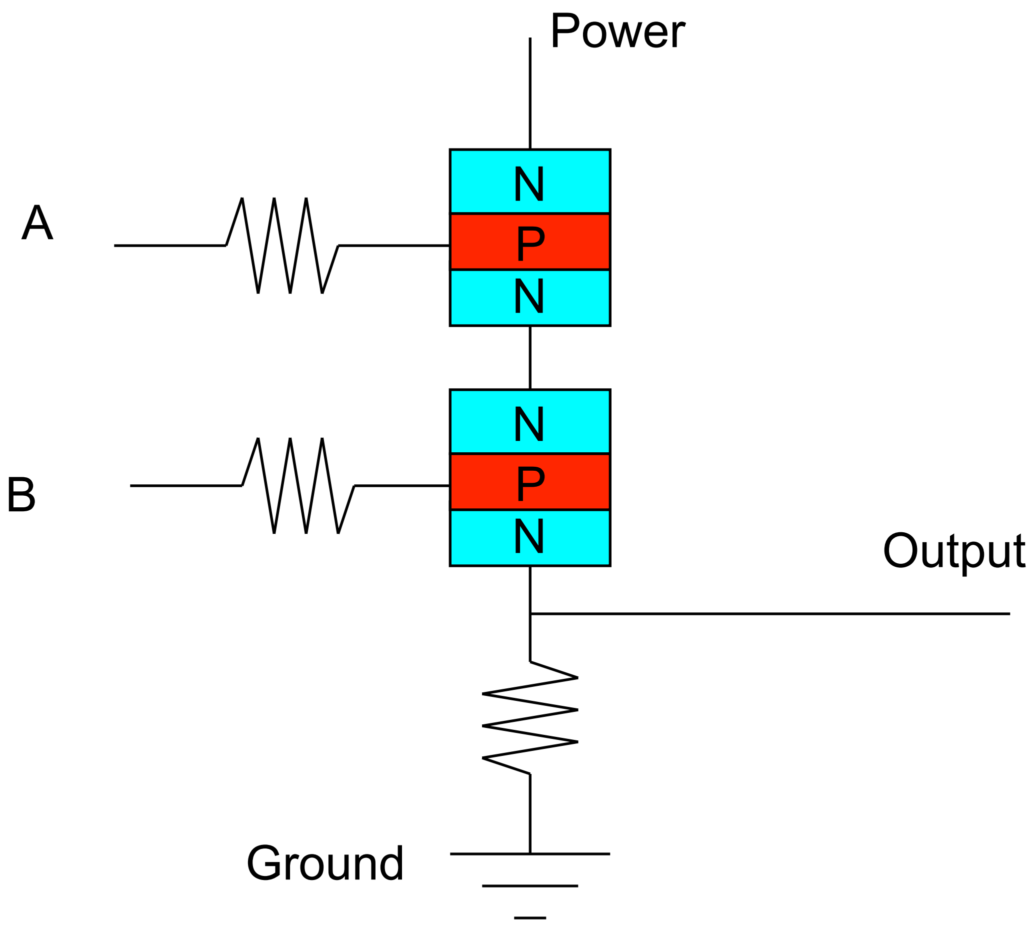


- Doped semiconductor:
  semiconductor with some (controlled) impurities:
  p-type, n-type



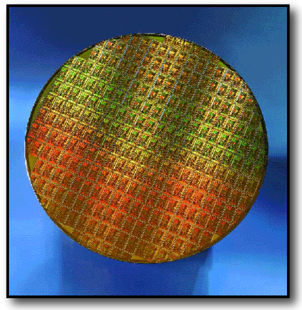
- Switch: p-n junction

Example: an AND gate

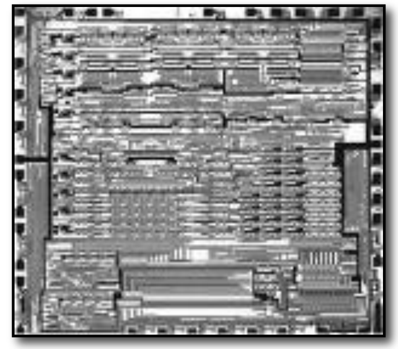


Chip Fabrication

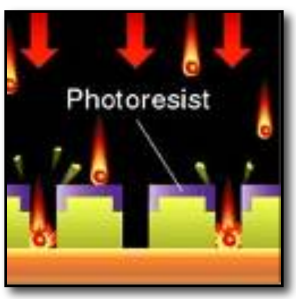
Grow silicon
ingots



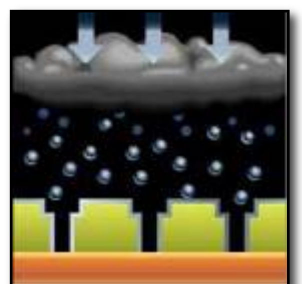
Cut wafers
and polish



Create mask



Coat wafer with light
sensitive chemicals
and project mask onto it



Coat with chemicals
that remove parts
unexposed to light

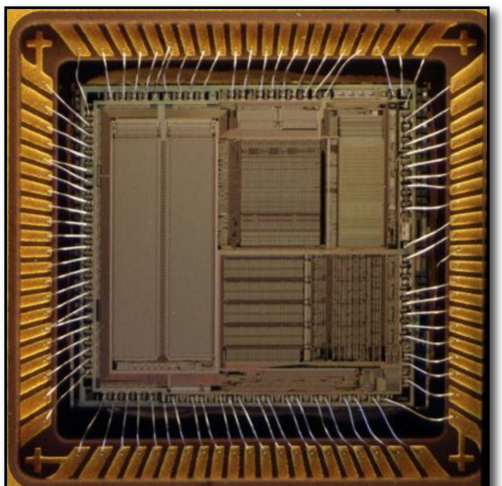
Repeat to add
metal channels
(wires) and
insulation;
many layers!

Aside: Lasik eye correction

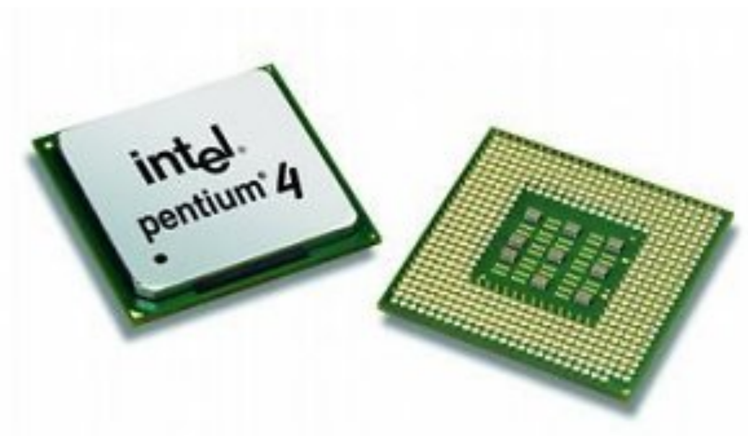
Uses laser invented for chip fabrication

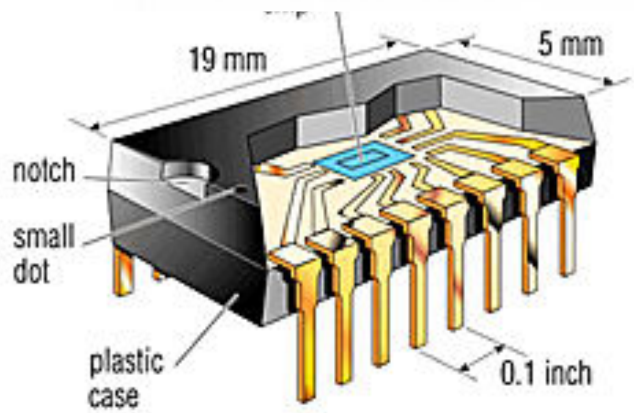
Chip Packaging

- Inside



- Outside

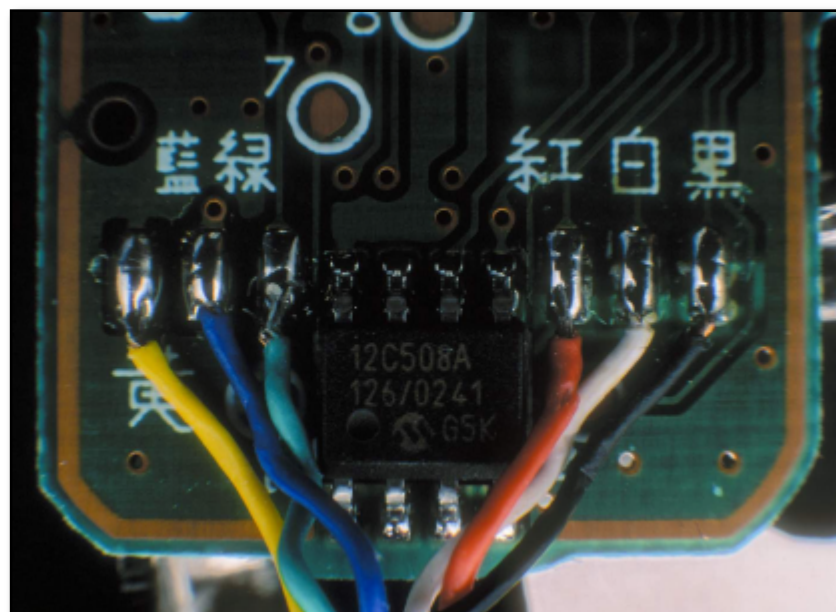




Life cycle of a microprocessor

Fact: Less than 1% of microprocessors sold are used in computers

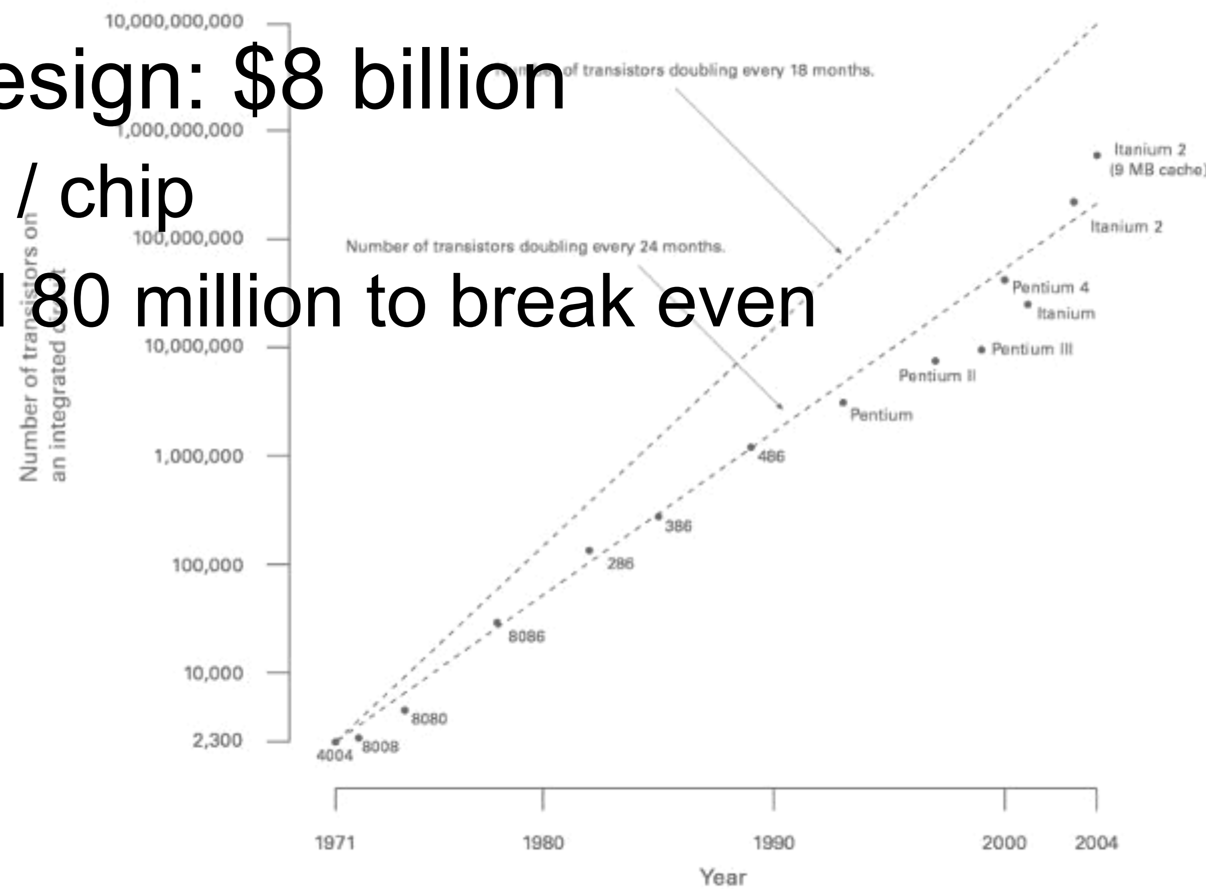
Inside an iPod Remote



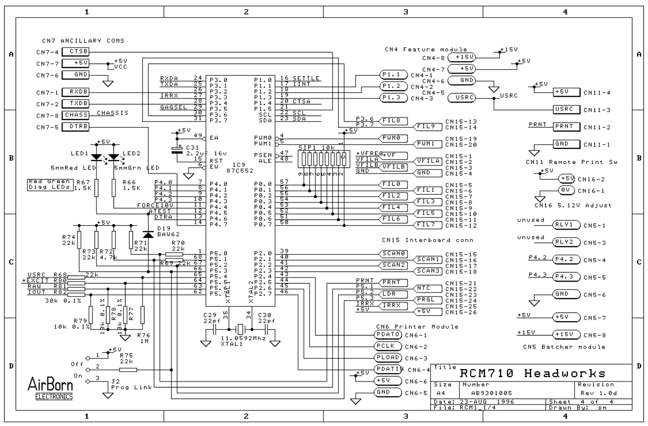
Why so few new CPU's?

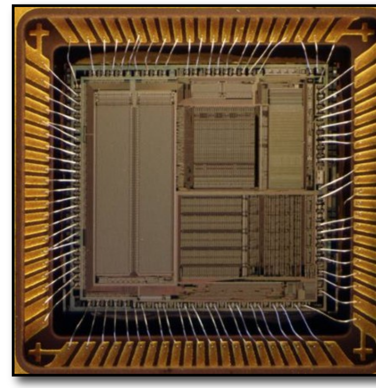
Cost of new design: $8 billion

- Profit: $100 / chip
- Need to sell 80 million to break even

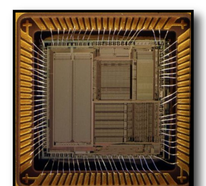


Engineering tradeoffs





36 months later...

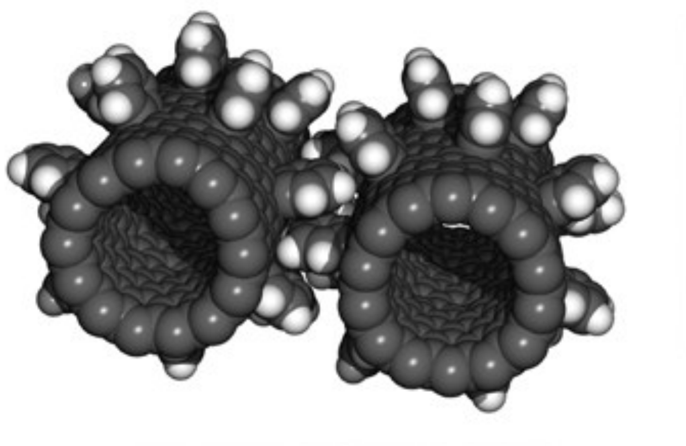


Half the size!

- Can run at twice the clock speed! (Why?)
- But: higher clock speeds → much more heat!

Even more precise control of matter

Nanotechnology: manufacture of objects (machines, robots, etc.) at the atomic or molecular level (1-100 nanometers)



"nanogear"

Biocomputing: Implementing computers via interactions of biological molecules.

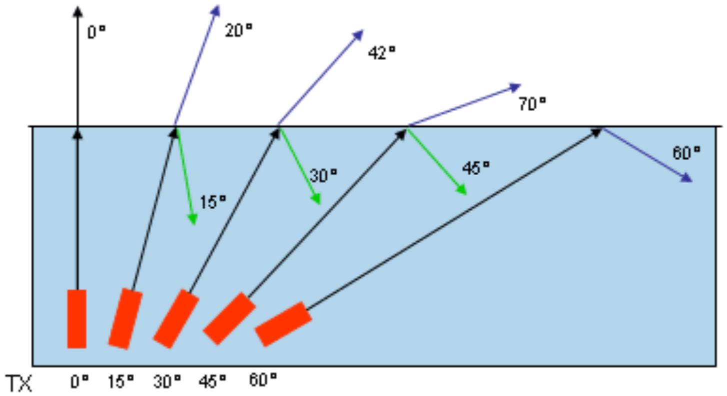
Another example of control of matter: the changing data cable

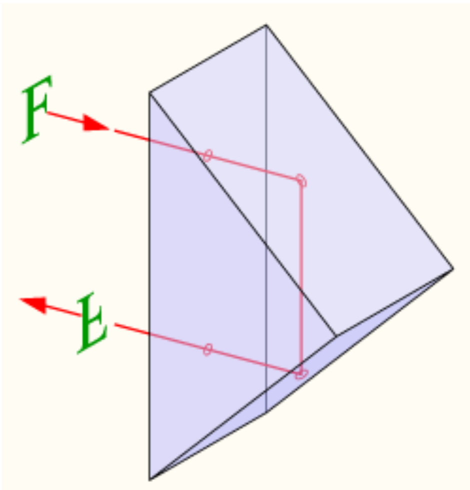
- Serial cable: 115 kb/s

- USB cable: 480 Mb/s (USB 2.0)

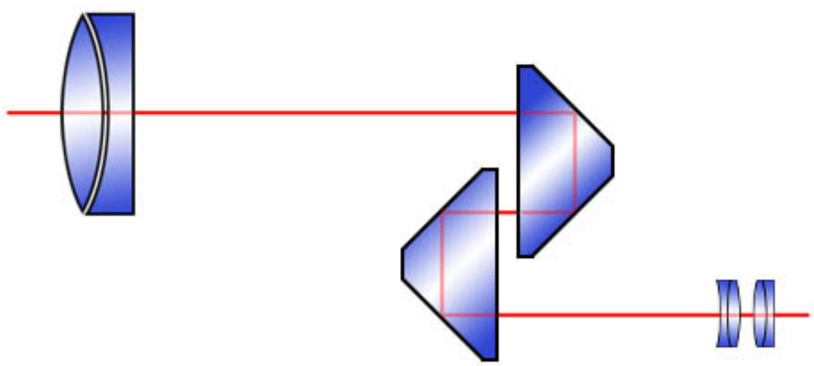
- Fiber optic cable: 40 Gb/s

Total Internal Reflection

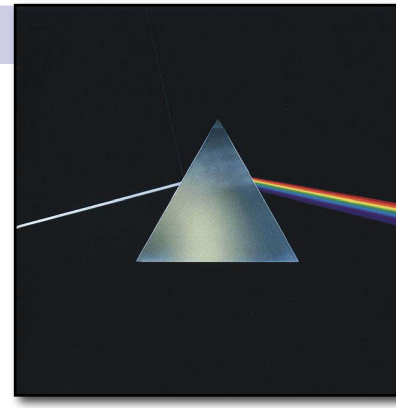




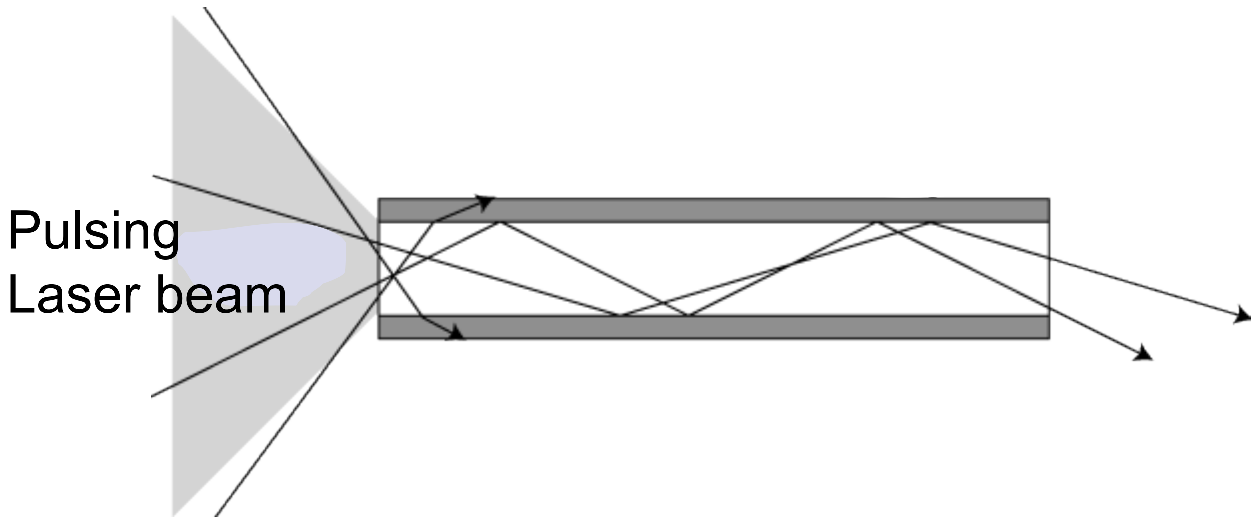
Porro Prism



How optical fibers work

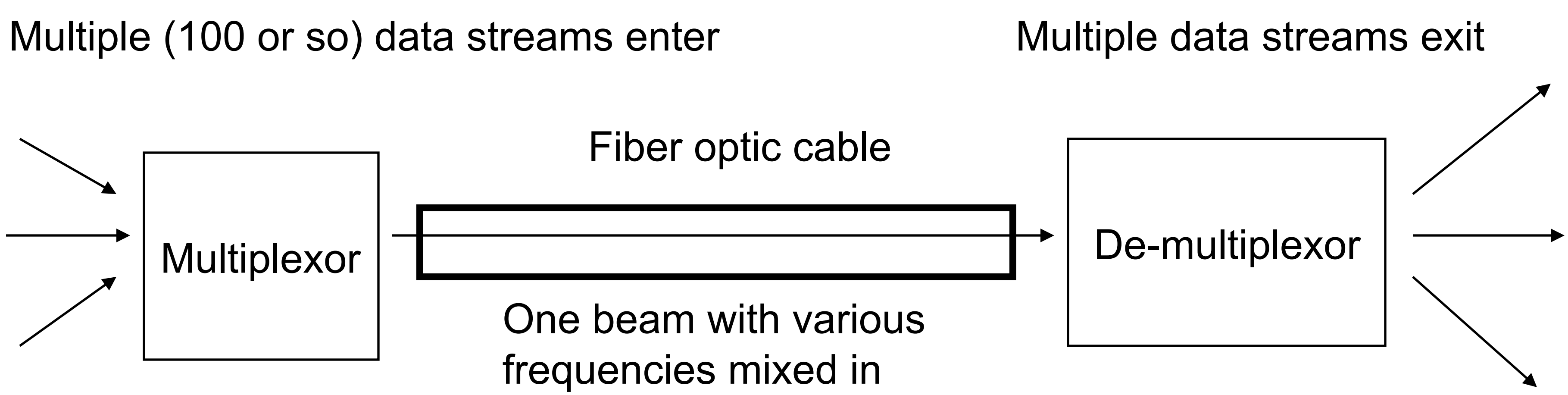


- Glass fiber: 10-40 billion bits/s



"Total internal reflection"

Wave Division Multiplexing (WDM)



- Transmission rates of trillion (“Tera”) bits/s

Thoughts about the 20th century

- What factors (historical, political, social) gave rise to this knowledge explosion?
- Will it continue in the future?

As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don't know
We don't know.

— D. Rumsfeld, Feb. 12, 2002

Are faster chips the answer to all problems in computing?

An Answer:

No! Halting problem is undecidable!

What about this <u>decidable</u> problem?

$$(A + B + C) \cdot (\overline{D} + F + G) \cdot (\overline{A} + G + K) \cdot (\overline{B} + P + Z) \cdot (C + \overline{U} + \overline{X})$$

- Does it have a satisfying assignment?
- What if instead we had 100 variables?
- 1000 variables?

We resume the discussion of these questions in the next lecture (P v NP)…