Semiconductor

noun
1. a substance, such as silicon or germanium, with electrical conductivity intermediate between that of an insulator and a conductor
2. a semiconductor device
Sand into Silicon

Silica a.k.a. SiO$_2$ a.k.a. Quartz

$$\text{SiO}_2 + 2 \text{ C} \rightarrow \text{Si} + 2 \text{ CO}$$

Elemental, amorphous silicon

Monocrystalline Silicon Ingot
Doping Silicon Makes It a Better Conductor

**Undoped (pure) silicon crystal**

Not a good conductor

**p-type (doped) silicon**

boron atom steals a nearby electron

**n-type (doped) silicon**

extra electron on arsenic atom jump loose
A PN Junction aka A Diode

Depletion region

p (holes)  n (electrons)

Ammeter

0 V
A PN Junction aka A Diode

Depletion region

Forward biased: current flows
A PN Junction aka A Diode

- Depletion region
- Reverse biased: no current flow

Diagram:
- p (holes)
- n (electrons)
- Ammeter

-2 V

Reverse biased: no current flow
An N-Channel MOS Transistor

Gate at 0V: Off

Ammeter

Gate

SiO₂

Drain

Source

3V

0V

p (holes)
An N-Channel MOS Transistor

Gate positive: On

SiO₂

Drain

Source

p (holes)

Ammeter

3 V

3 V
An inverter is built from two MOSFETs:
An n-FET connected to ground
A p-FET connected to the power supply
The CMOS Inverter

When the input is near the power supply voltage ("1"),
the p-FET is turned off;
the n-FET is turned on, connecting the output to ground ("0").
n-FETs are only good at passing 0’s
When the input is near ground ("0"), the p-FET is turned on, connecting the output to the power supply ("1"); the n-FET is turned off. p-FETs are only good at passing 1’s
The CMOS NAND Gate

Two-input NAND gate:
two n-FETs in series;
two p-FETs in parallel
The CMOS NAND Gate

Both inputs 0:
Both p-FETs turned on
Output pulled high
The CMOS NAND Gate

One input 1, the other 0:
One p-FET turned on
Output pulled high
One n-FET turned on, but does not control output
The CMOS NAND Gate

Both inputs 1:
Both n-FETs turned on
Output pulled low
Both p-FETs turned off
The CMOS NOR Gate

Two-input NOR gate:
- two n-FETs in parallel;
- two p-FETs in series.

Not as fast as the NAND gate because n-FETs are faster than p-FETs.
A CMOS AND-OR-INVERT Gate
Static CMOS Gate Structure

Pull-up and Pull-down networks must be complementary; exactly one should be connected for each input combination.

Series connection in one should be parallel in the other
Full Adder Layouts

fa_ly_mini_jk size: 60  ·  40μm (1.2μCMOS)

fa_ly_opt1 size: 63  ·  50μm (1.2μCMOS)

fa_ly_it size: 117  ·  31μm (1.2μCMOS)

Fulladd.L size: 37  ·  25μm (0.5μCMOS)

Intel 4004: The First Single-Chip Microprocessor

Announcing a new era of integrated electronics

4001: 256-byte ROM + 4-bit IO port
4002: 40-byte RAM
4003: 10-bit shift register
4004: 740 kHz 4-bit CPU w/ 45 instructions (2300 transistors)