

Fundamentals of Computer Systems

Transistors, Gates, and ICs

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Semiconductor

sem-i-con-duc-tor

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

Periodic Table of the Elements

1 IA TIA	2 IIA ZA	Periodic Table of the Elements																18 VIIIA 8A																																																										
1 H Hydrogen 1.008	2 He Helium 4.003																	2 He Helium 4.003																																																										
3 Li Lithium 6.941	4 Be Beryllium 9.012																	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																																																					
11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948											19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80																																									
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 101.07	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29											55 Cs Cesium 132.905	56 Ba Barium 137.327	57 Fr Francium 223	58-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.384	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222																														
																		87 Ra Radium 226	88-103 Actinide Series	104 Rf Rutherfordium 261	105 Db Dubnium 262	106 Sg Seaborgium 263	107 Bh Bohrium 264	108 Hs Hassium 265	109 Mt Meitnerium 266	110 Ds Darmstadtium 267	111 Rg Roentgenium 268	112 Cn Copernicium 269	113 Uut Ununtrium 270	114 Fl Flerovium 271	115 Uup Ununpentium 272	116 Lv Livermorium 273	117 Uus Ununseptium 274	118 Uuo Ununoctium 275	119 Ts Tennessine 276	120 Og Oganesson 277											89 La Lanthanum 138.905	90 Ce Cerium 140.12	91 Pr Praseodymium 140.908	92 Nd Neodymium 144.24	93 Pm Promethium 144.913	94 Sm Samarium 150.36	95 Eu Europium 151.964	96 Gd Gadolinium 157.25	97 Tb Terbium 158.925	98 Dy Dysprosium 162.50	99 Ho Holmium 164.930	100 Er Erbium 167.255	101 Tm Thulium 168.934	102 Yb Ytterbium 173.054	103 Lu Lutetium 174.967	104 Ac Actinium 227	105 Th Thorium 232.038	106 Pa Protactinium 231.036	107 U Uranium 238.029	108 Np Neptunium 237.048	109 Pu Plutonium 244.064	110 Am Americium 243.061	111 Cm Curium 247.070	112 Bk Berkelium 247.070	113 Cf Californium 251.08	114 Es Einsteinium 252.083	115 Fm Fermium 257.10	116 Md Mendelevium 258.10	117 No Nobelium 259.10	118 Lr Lawrencium 260.10

Legend:

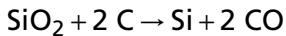
- Alkali Metal
- Alkaline Earth
- Transition Metal
- Semimetal
- Nonmetal
- Basic Metal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

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Sand into Silicon



Silica a.k.a. SiO_2 a.k.a. Quartz

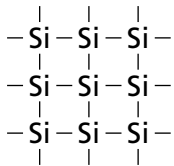


Elemental, amorphous silicon



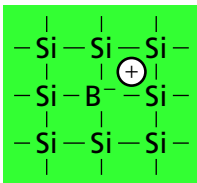
Monocrystalline
Silicon Ingot

Doping Silicon Makes It a Better Conductor



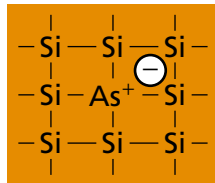
Undoped (pure)
silicon crystal

Not a good
conductor



p-type (doped)
silicon:

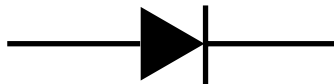
boron atom steals
a nearby electron



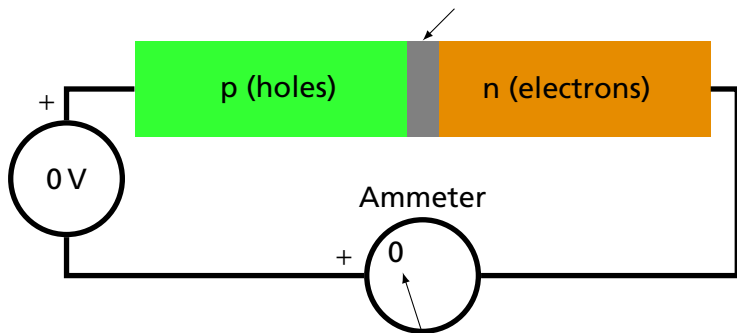
n-type (doped)
silicon:

arsenic's extra
electron jumps loose

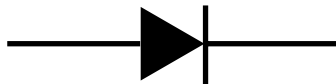
A PN Junction aka A Diode



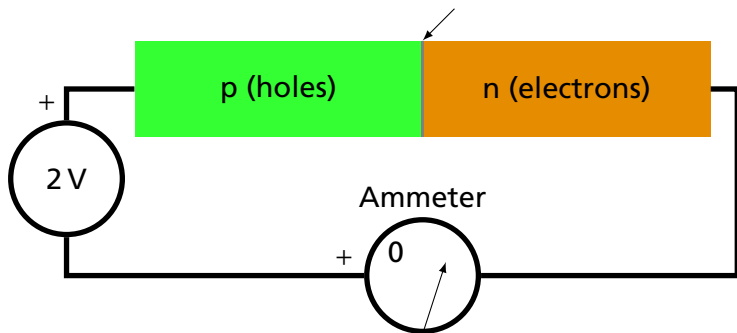
Depletion region



A PN Junction aka A Diode

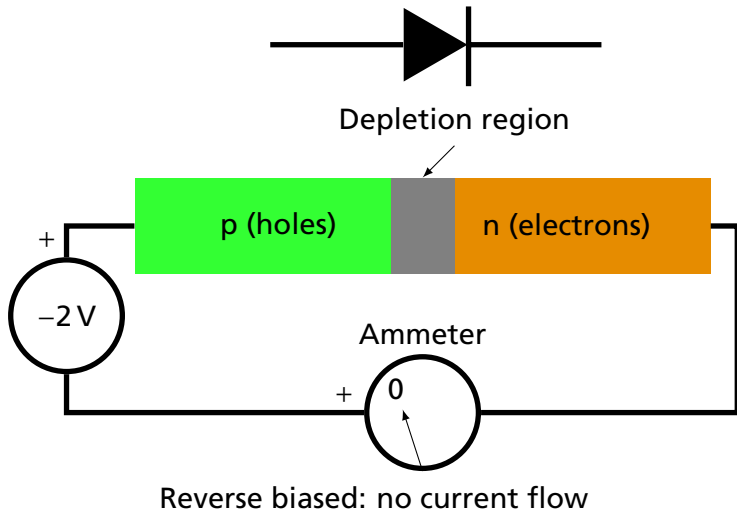


Depletion region

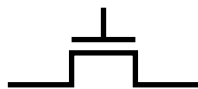


Forward biased: current flows

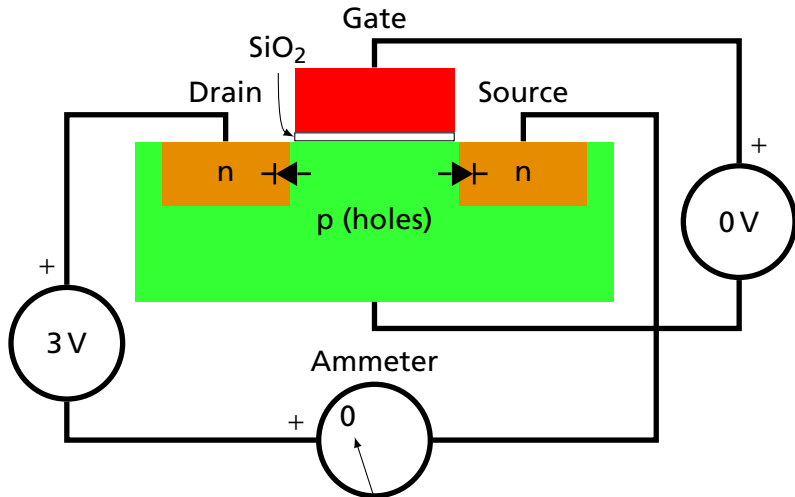
A PN Junction aka A Diode



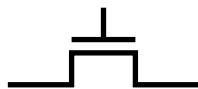
An N-Channel MOS Transistor



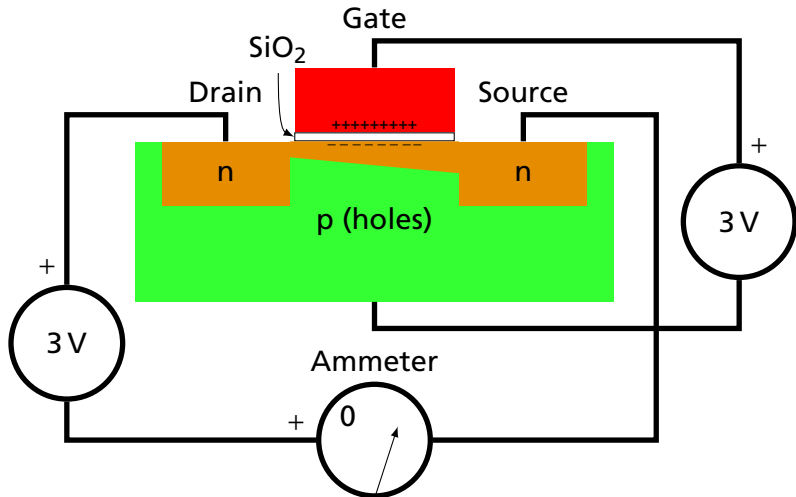
Gate at 0V: Off



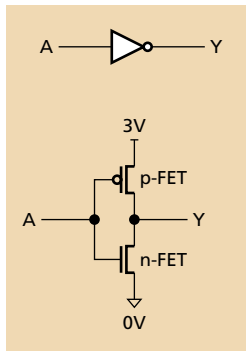
An N-Channel MOS Transistor



Gate positive: On



The CMOS Inverter

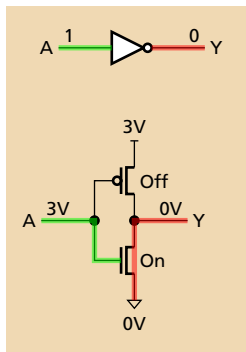


An inverter is built from two MOSFETs:

An n-FET connected to ground

A p-FET connected to the power supply

The CMOS Inverter



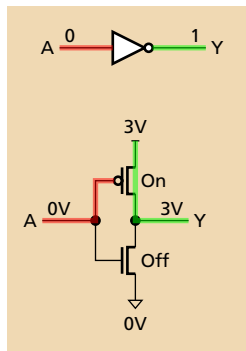
When the input is near the power supply voltage ("1"),

the p-FET is turned off;

the n-FET is turned on, connecting the output to ground ("0").

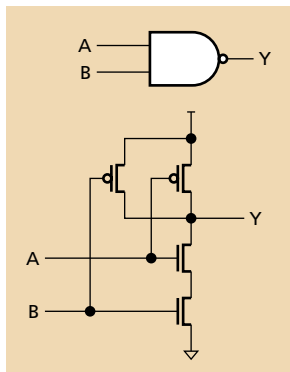
n-FETs are only good at passing 0's

The CMOS Inverter



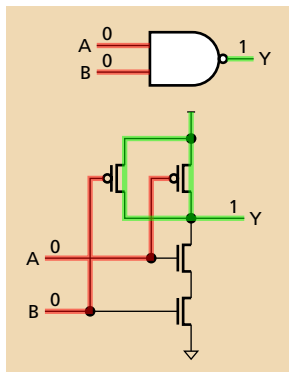
When the input is near ground ("0"), the p-FET is turned on, connecting the output to the power supply ("1"); the n-FET is turned off. p-FETs are only good at passing 1's

The CMOS NAND Gate



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

The CMOS NAND Gate

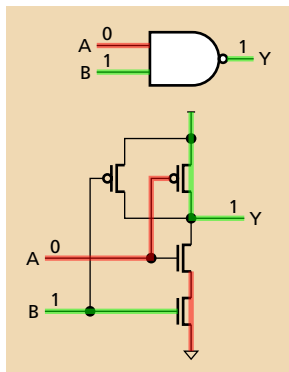


Both inputs 0:

Both p-FETs turned on

Output pulled high

The CMOS NAND Gate



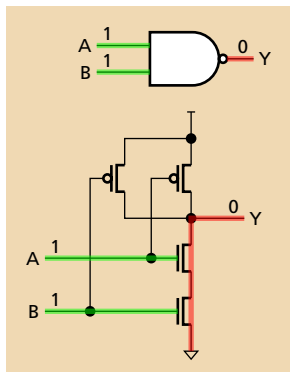
One input 1, the other 0:

One p-FET turned on

Output pulled high

One n-FET turned on, but does not control output

The CMOS NAND Gate



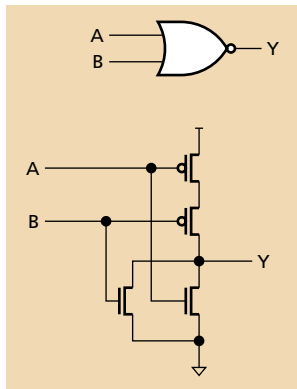
Both inputs 1:

Both n-FETs turned on

Output pulled low

Both p-FETs turned off

The CMOS NOR Gate



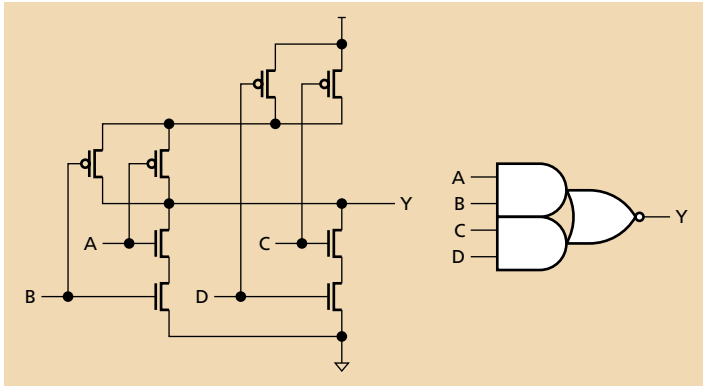
Two-input NOR gate:

two n-FETs in parallel;

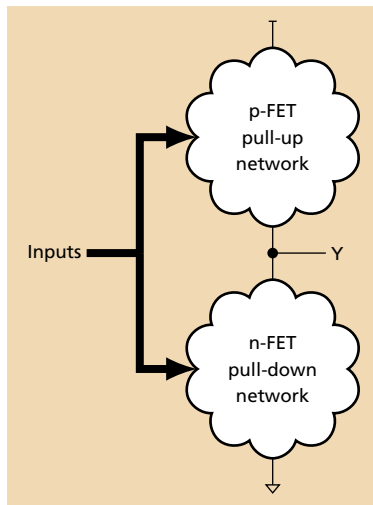
two p-FETs in series.

Not as fast as the NAND gate
because n-FETs are faster than
p-FETs

A CMOS AND-OR-INVERT Gate



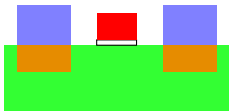
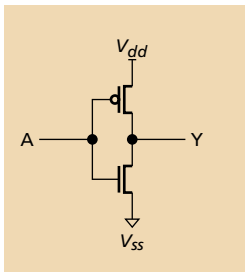
Static CMOS Gate Structure



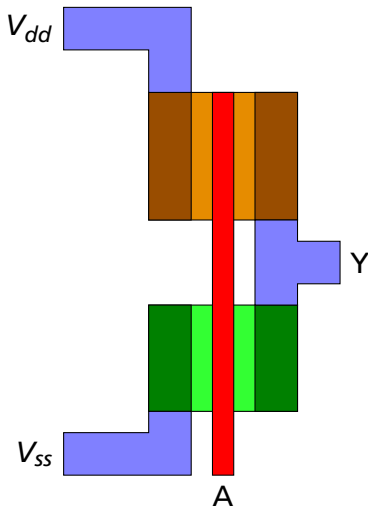
Pull-up and Pull-down networks must be complementary; exactly one should be connected for each input combination.

Series connection in one should be parallel in the other

CMOS Inverter Layout



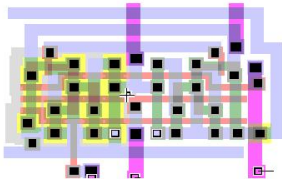
Cross Section Through
N-channel FET



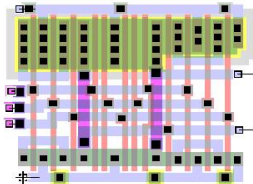
Top View

Full Adder Layouts

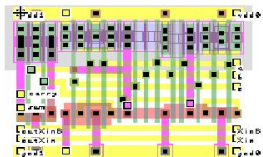
fa_ly_mini_jk size: 60 $\cdot 40\mu\text{m}$ (1.2 μm CMOS)



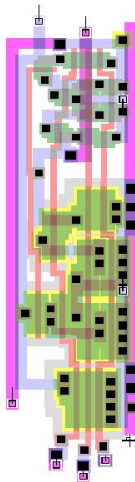
fa_ly_opt1 size: 63 $\cdot 50\mu\text{m}$ (1.2 μm CMOS)



Fulladd L size: 37 $\cdot 26\mu\text{m}$ (0.5 μm CMOS)



fa_ly_itt size: 117 $\cdot 31\mu\text{m}$ (1.2 μm CMOS)



From <http://book.huihoo.com/design-of-vlsi-systems/>

Intel 4004: The First Single-Chip Microprocessor

**Announcing
a new era
of integrated
electronics**



**A micro-
programmable
computer
on a chip!**

Intel introduces an integrated CMOS complete with a ROM for program memory, address and data registers, an accumulator and a single-chip random access memory. It's one of a family of four chips that comprise the MCS-4 micro-computer system - the first solution to bring you the power and flexibility of a dedicated general-purpose computer on one chip in as little as one dual in-line package.

MCS-4 is a general-purpose computing and control solution for low-cost, high-reliability, utility, scientific, measuring systems, remote control systems and portable control systems.

The heart of any MCS-4 system is a Type 4004 CPU, which contains a complete set of 45 instructions, floating-point and binary Type 4001 ROM, an on-chip program and data memory plus a fully functioning program-programmed controller. To take you step with Type 4004, Intel has developed a family of Type 4000 registers to expand the system's flexibility.

Using its complete set of 45 instructions, floating-point and binary Type 4001 ROM, an on-chip program and data memory plus a fully functioning program-programmed controller, Intel's complete on-chip programmable ROM, Type 4004, may be substituted for the Type 4004 micro-programmed ROM.

MCS-4 systems interface easily with switches, keyboards, displays, teleprinters, printers, modems, A/D converters and other popular peripherals.

The MCS-4 family is now in stock at Intel's Santa Clara headquarters and at our regional headquarters in Europe and Japan. In the U.S., call your local Intel representative for technical information and literature. In Europe, contact Intel at Avenue Louise 214, B-1050 Brussels, Belgium. Phone 32(2)231. In Japan, contact Intel Japan, Ltd., Parkside Plaza Bldg., 8th F., 2-2-1, Shinjuku-ku, Shinjuku-Ku, Tokyo 102. Phone 81(3)433-4741.

Intel Corporation now produces micro-computers, microprocessors and microperipherals at 3065 Avenida de las Americas, San Jose, Costa Rica. Phone 506(2) 228-7000.

**intel
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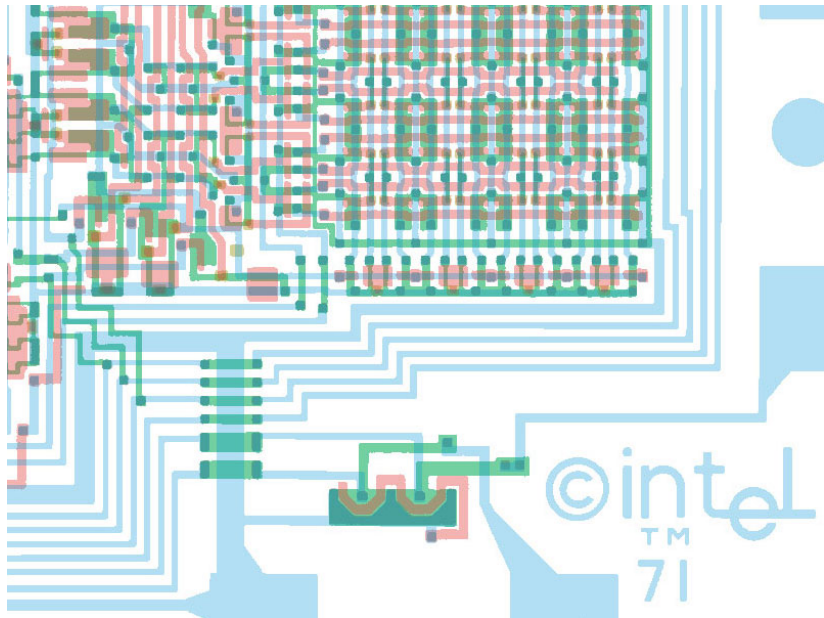
4001: 256-byte ROM + 4-bit IO port

4002: 40-byte RAM

4003: 10-bit shift register

4004: 740 kHz 4-bit CPU w/ 45 instructions (2300 transistors)

Intel 4004 Masks



Intel 4004 Die Photograph

