

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 H Hydrogen 1.008	2 IIA He Helium 4.003																	18 VIIIA Ar Argon 39.948																		
3 IIIA Li Lithium 6.941	4 IVA Be Beryllium 9.012																	19 IIIA K Potassium 39.098	20 IIIA Ca Calcium 40.078																	36 VIIIA Kr Krypton 83.80
5 IIA Na Sodium 22.990	6 IIIA Mg Magnesium 24.305	7 IVB Sc Scandium 44.956	8 VB Ti Titanium 47.88	9 VIB V Vanadium 50.942	10 VIIB Cr Chromium 51.996	11 VIIIB Mn Manganese 54.938	12 VIIIB Fe Iron 55.845	13 VIIIB Co Cobalt 58.933	14 VIIIB Ni Nickel 58.693	15 VIIIB Cu Copper 63.546	16 VIIIB Zn Zinc 65.38	17 IIIB Al Aluminum 26.982	18 IIIB Si Silicon 28.086	19 IIIB P Phosphorus 30.974	20 IIIB S Sulfur 32.06	21 IIIB Cl Chlorine 35.453	22 IIIB Ar Argon 39.948																			
19 IIA K Potassium 39.098	20 IIA Ca Calcium 40.078	21 IIIB Sc Scandium 44.956	22 IIIB Ti Titanium 47.88	23 IIIB V Vanadium 50.942	24 IIIB Cr Chromium 51.996	25 IIIB Mn Manganese 54.938	26 IIIB Fe Iron 55.845	27 IIIB Co Cobalt 58.933	28 IIIB Ni Nickel 58.693	29 IIIB Cu Copper 63.546	30 IIIB Zn Zinc 65.38	31 IIIA Ga Gallium 69.723	32 IIIA Ge Germanium 72.64	33 IIIA As Arsenic 74.922	34 IIIA Se Selenium 78.96	35 IIIA Br Bromine 79.904	36 IIIA Kr Krypton 83.80																			
37 IA Rb Rubidium 85.468	38 IIA Sr Strontium 87.62	39 IIIB Y Yttrium 88.906	40 IIIB Zr Zirconium 91.224	41 IIIB Nb Niobium 92.906	42 IIIB Mo Molybdenum 95.94	43 IIIB Tc Technetium 98.906	44 IIIB Ru Ruthenium 101.07	45 IIIB Rh Rhodium 102.906	46 IIIB Pd Palladium 106.36	47 IIIB Ag Silver 107.868	48 IIIB Cd Cadmium 112.411	49 IIIA In Indium 114.818	50 IIIA Sn Tin 118.710	51 IIIA Sb Antimony 121.757	52 IIIA Te Tellurium 127.6	53 IIIA I Iodine 126.905	54 IIIA Xe Xenon 131.29																			
55 IA Cs Cesium 132.905	56 IIA Ba Barium 137.327	57-71 IIIB La Lanthanides	72 IIIB Hf Hafnium 178.49	73 IIIB Ta Tantalum 180.948	74 IIIB W Tungsten 183.84	75 IIIB Re Rhenium 186.207	76 IIIB Os Osmium 190.23	77 IIIB Ir Iridium 192.22	78 IIIB Pt Platinum 195.084	79 IIIB Au Gold 196.967	80 IIIB Hg Mercury 200.59	81 IIIA Tl Thallium 204.384	82 IIIA Pb Lead 207.2	83 IIIA Bi Bismuth 208.980	84 IIIA Po Polonium 209	85 IIIA At Astatine 210	86 IIIA Rn Radon 222.018																			
87 IA Fr Francium 223	88 IIA Ra Radium 226	89-103 IIIB Ac Actinides	104 IIIB Rf Rutherfordium 261	105 IIIB Db Dubnium 262	106 IIIB Sg Seaborgium 263	107 IIIB Bh Bohrium 264	108 IIIB Hs Hassium 265	109 IIIB Mt Meitnerium 266	110 IIIB Ds Darmstadtium 267	111 IIIB Rg Roentgenium 268	112 IIIB Cn Copernicium 269	113 IIIA Uut Ununtrium 270	114 IIIA Fl Flerovium 270	115 IIIA Uup Ununpentium 271	116 IIIA Lv Livermorium 271	117 IIIA Uus Ununseptium 272	118 IIIA Uuo Ununoctium 273																			
89 IIIA La Lanthanum 138.905	90 IIIA Ce Cerium 140.12	91 IIIA Pr Praseodymium 140.908	92 IIIA Nd Neodymium 144.24	93 IIIA Pm Promethium 144.913	94 IIIA Sm Samarium 150.36	95 IIIA Eu Europium 151.964	96 IIIA Gd Gadolinium 157.25	97 IIIA Tb Terbium 158.925	98 IIIA Dy Dysprosium 162.50	99 IIIA Ho Holmium 164.930	100 IIIA Er Erbium 167.255	101 IIIA Tm Thulium 168.930	102 IIIA Yb Ytterbium 173.054	103 IIIA Lu Lutetium 174.967																						
95 IIIA Ac Actinium 227	96 IIIA Th Thorium 232.038	97 IIIA Pa Protactinium 231.036	98 IIIA U Uranium 238.029	99 IIIA Np Neptunium 237.048	100 IIIA Pu Plutonium 244.064	101 IIIA Am Americium 243.061	102 IIIA Cm Curium 247.070	103 IIIA Bk Berkelium 247.070	104 IIIA Cf Californium 251.08	105 IIIA Es Einsteinium 252.083	106 IIIA Fm Fermium 257.10	107 IIIA Md Mendelevium 258.10	108 IIIA No Nobelium 259.10	109 IIIA Lr Lawrencium 260.10																						

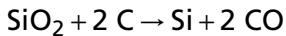
Legend:

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

Sand into Silicon



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

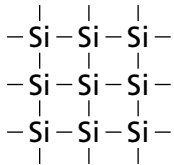


Elemental, amorphous silicon



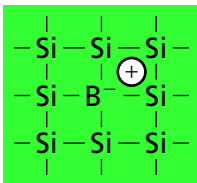
Monocrystalline
Silicon Ingot

Doping Silicon Makes It a Better Conductor



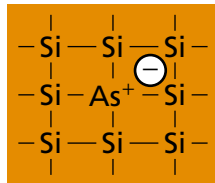
Undoped (pure)
silicon crystal

Not a good
conductor



p-type (doped)
silicon:

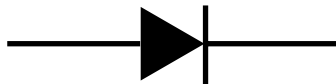
boron atom steals
a nearby electron



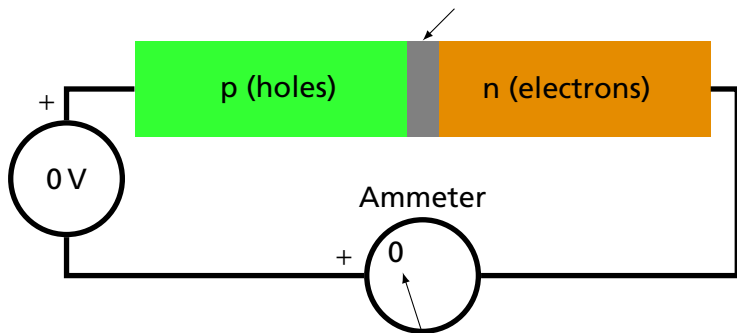
n-type (doped)
silicon:

arsenic's extra
electron jumps loose

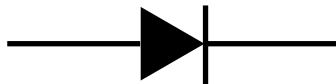
A PN Junction aka A Diode



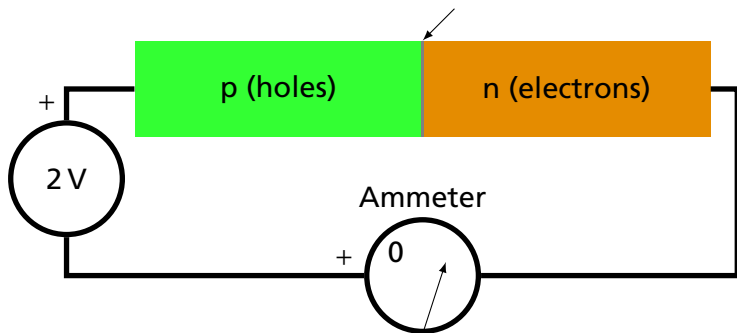
Depletion region



A PN Junction aka A Diode

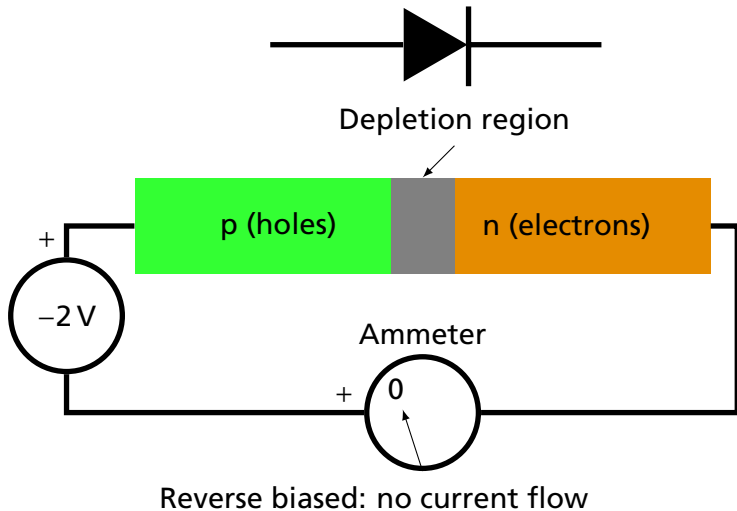


Depletion region

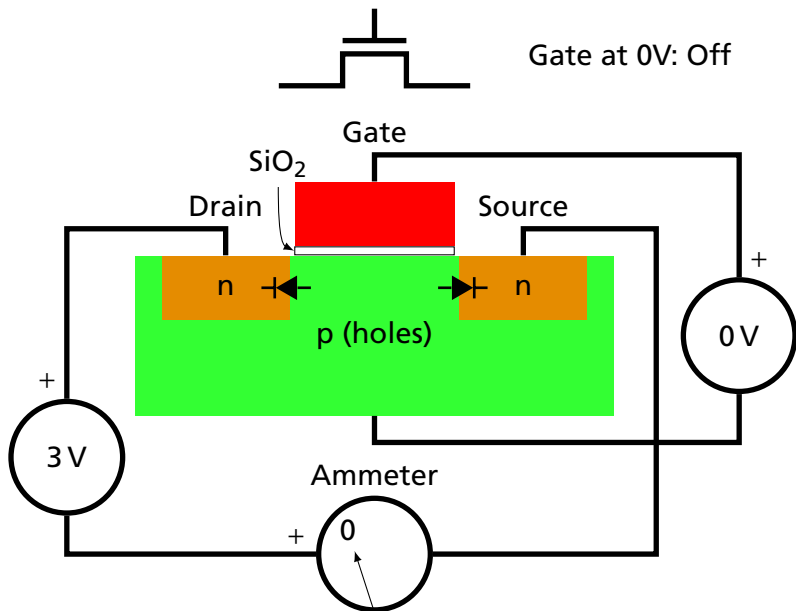


Forward biased: current flows

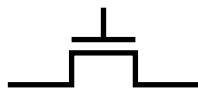
A PN Junction aka A Diode



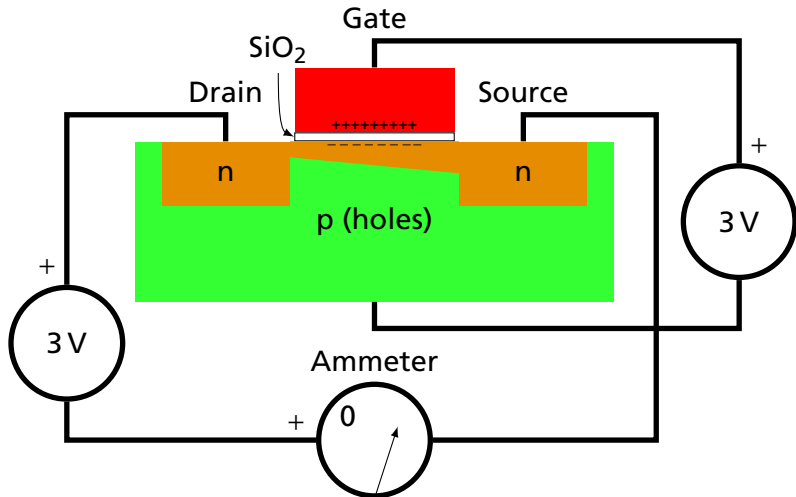
An N-Channel MOS Transistor



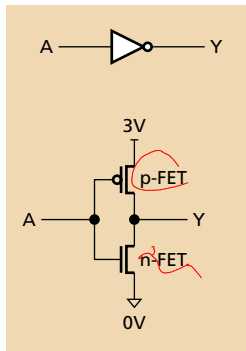
An N-Channel MOS Transistor



Gate positive: On



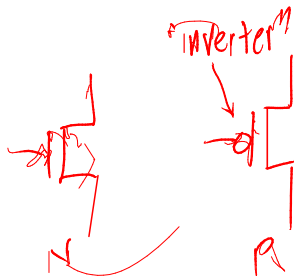
The CMOS Inverter



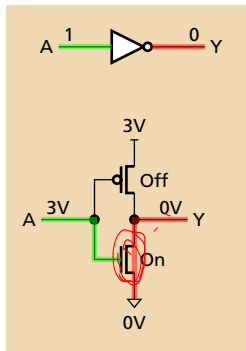
An inverter is built from two MOSFETs:

An n-FET connected to ground

A p-FET connected to the power supply



The CMOS Inverter



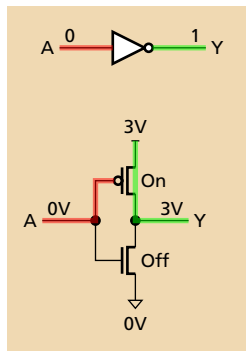
When the input is near the power supply voltage ("1"),

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

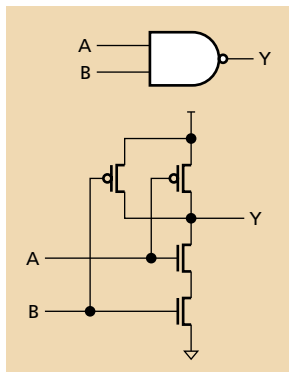
The CMOS Inverter



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.

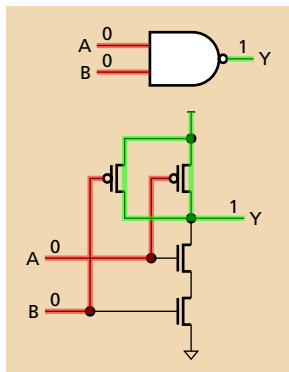
p-FETs are only good at passing 1's

The CMOS NAND Gate



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

The CMOS NAND Gate

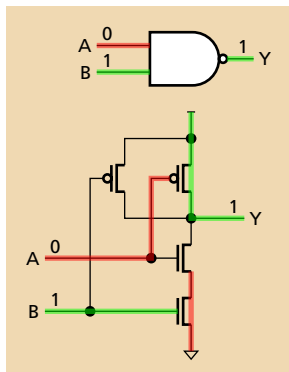


Both inputs 0:

Both p-FETs turned on

Output pulled high

The CMOS NAND Gate



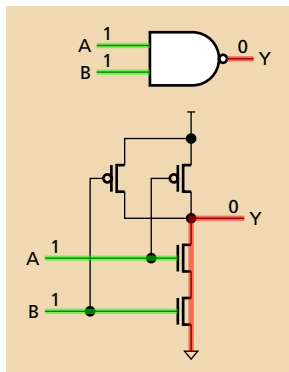
One input 1, the other 0:

One p-FET turned on

Output pulled high

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

The CMOS NAND Gate



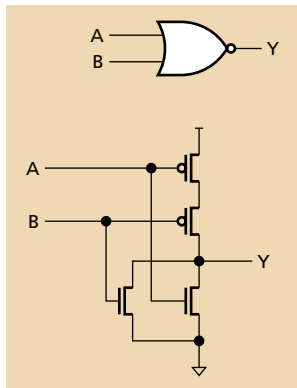
Both inputs 1:

Both n-FETs turned on

Output pulled low

Both p-FETs turned off

The CMOS NOR Gate



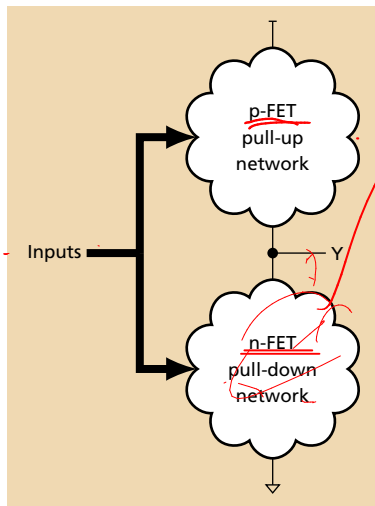
Two-input NOR gate:

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

Static CMOS Gate Structure



~~ANDS & ORS & VARIABLES~~

not inverted

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

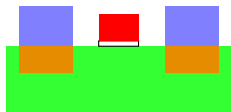
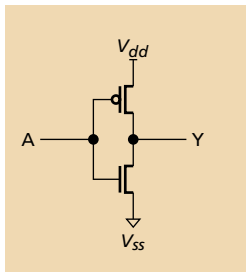
exch. →

ser.
par.

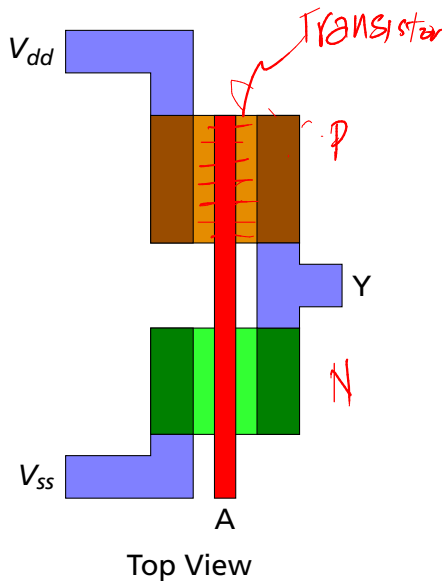
$$F = \dots e \dots$$



CMOS Inverter Layout

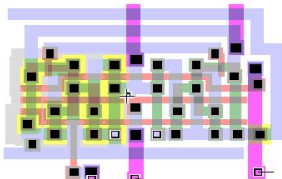


Cross Section Through
N-channel FET

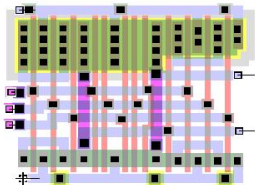


Full Adder Layouts

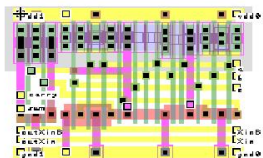
fa_ly_mini_jk size: 60 · 40 μ m (1.2 μ mCMOS)



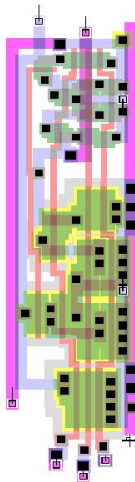
fa_ly_opt1 size: 63 · 50 μ m (1.2 μ mCMOS)



Fulladd L size: 37 · 26 μ m (0.5 μ mCMOS)



fa_ly_itt size: 117 · 31 μ m (1.2 μ mCMOS)



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

Intel 4004: The First Single-Chip Microprocessor

1971

Announcing a new era of integrated electronics



A micro- programmable computer on a chip!

Intel introduces an integrated CMOS complete with a 4-bit parallel adder, subtractor, 4-bit register, an accumulator and a stack pointer capable of one cycle. It's one of a family of four that do which 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 ten days in the marketplace.

MCS-4 is available in complete computing and control functions for use in systems, data handling, utility functions, measuring systems, control 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 or stack Type 4001 ROM, for program storage, and data buffer plus a 4-bit bus for program and program control. To this you may add Type 4002 RAM for local data memory and Type 4003 register to expand the output code.

Using its complete other Type 4004 bus, the family of four, the micro-computer is capable of 4000 bytes of ROM storage and 1000 bytes of RAM storage. When you require rapid turn-around or need only a few systems, Intel's complete on-chip programmable ROM, Type 4004, may be substituted for the Type 4001 mask-programmed ROM.

MCS-4 systems interface easily with satellites, bus boards, display, video, 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 392010. In Japan, contact Intel Japan, Ltd., Parkside Plaza Bldg., 8th Fl., 2-2-1, Shinjuku, Shinjuku-Ku, Tokyo 102. Phone 03-455-4151.

Intel Corporation now produces micro-computers, microprocessors and related systems at 3065 Bowers Avenue, Santa Clara, CA 95051. Phone (408) 298-1000.

intel
delivers.

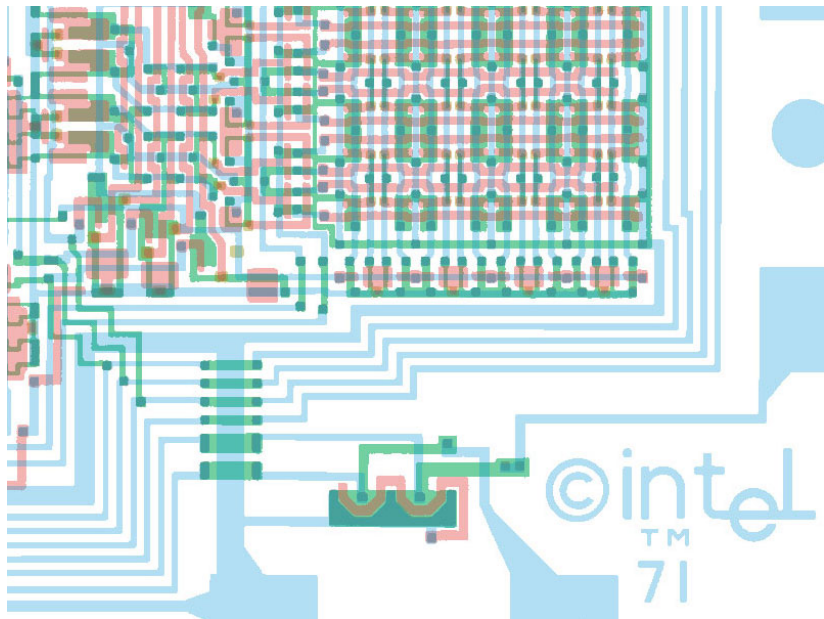
4001: 256-byte ROM + 4-bit IO port

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

