

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 SA							
1 H Hydrogen 1.008	2 He Helium 4.003																	10 Ne Neon 20.180							
3 Li Lithium 6.941	4 Be Beryllium 9.012																	11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 B Boron 10.811	14 C Carbon 12.011	15 N Nitrogen 14.007	16 O Oxygen 15.999	17 F Fluorine 18.998	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 72.630	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 102.905	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	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	57-71 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 195.084	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 Fr Francium 223	88 Ra Radium 226	89-103 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 270	115 Uup Ununpentium 271	116 Lv Livermorium 272	117 Uus Ununseptium 273	118 Uuo Ununoctium 274								
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 168.930	102 Yb Ytterbium 173.054	103 Lu Lutetium 174.967											
94 Ac Actinium 227	95 Th Thorium 232.038	96 Pa Protactinium 231.036	97 U Uranium 238.029	98 Np Neptunium 237.048	99 Pu Plutonium 244.064	100 Am Americium 243.061	101 Cm Curium 247.070	102 Bk Berkelium 247.070	103 Cf Californium 251.08	104 Es Einsteinium 252.083	105 Fm Fermium 257.10	106 Md Mendelevium 258.10	107 No Nobelium 259.10	108 Lr Lawrencium 260.10											

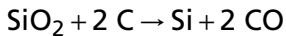
Legend:

- 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

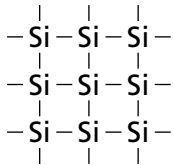


Elemental, amorphous silicon



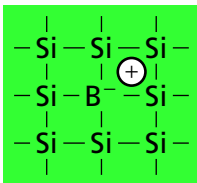
Monocrystalline
Silicon Ingot

Doping Silicon Makes It a Better Conductor



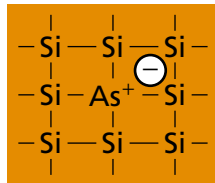
Undoped (pure)
silicon crystal

Not a good
conductor



p-type (doped)
silicon:

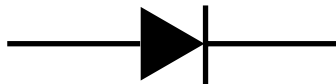
boron atom steals
a nearby electron



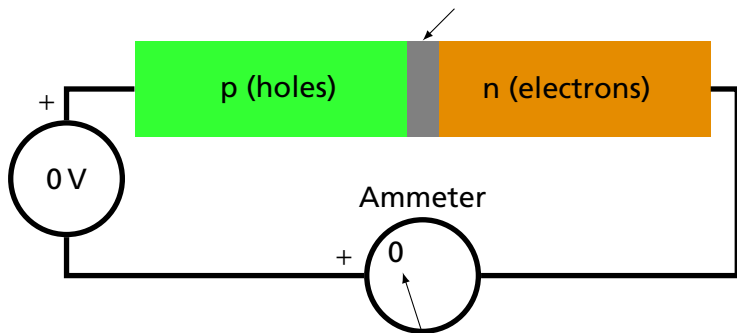
n-type (doped)
silicon:

arsenic's extra
electron jumps loose

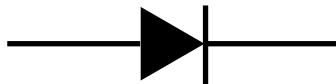
A PN Junction aka A Diode



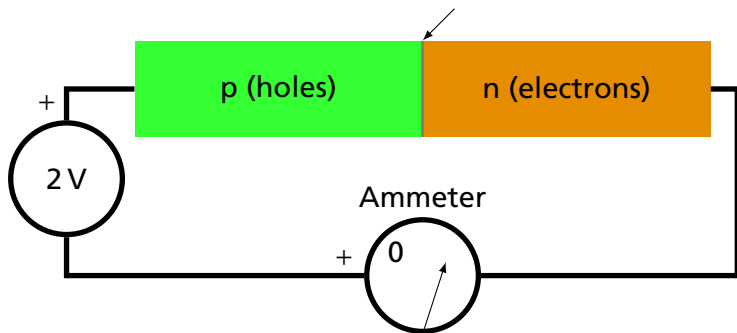
Depletion region



A PN Junction aka A Diode

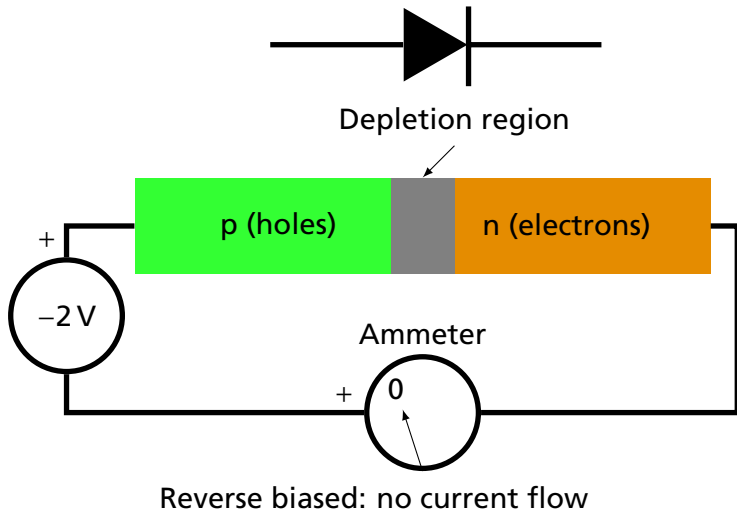


Depletion region

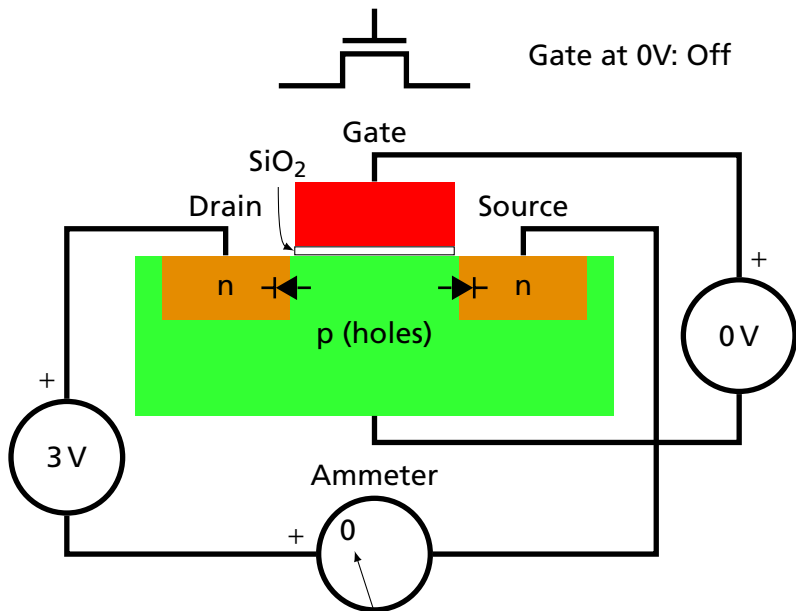


Forward biased: current flows

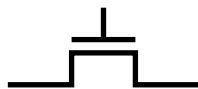
A PN Junction aka A Diode



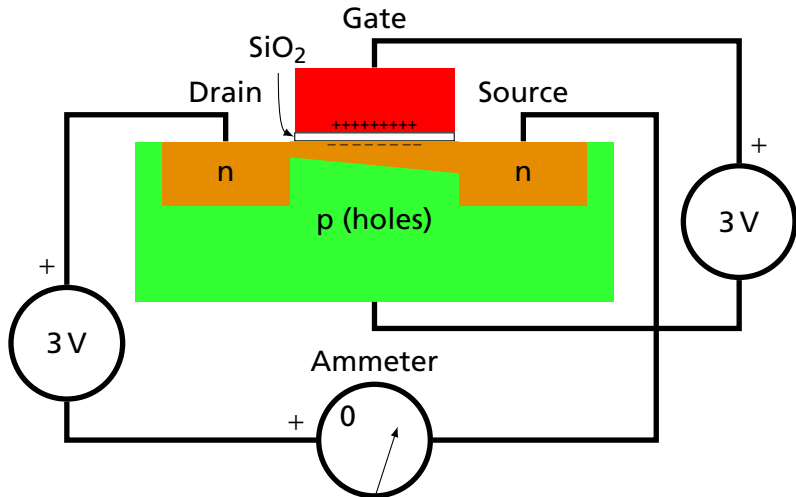
An N-Channel MOS Transistor



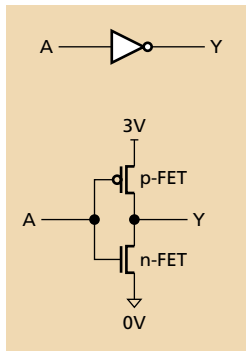
An N-Channel MOS Transistor



Gate positive: On



The CMOS Inverter

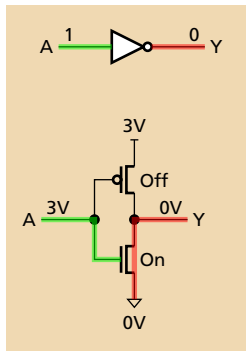


An inverter is built from two MOSFETs:

An n-FET connected to ground

A p-FET connected to the power supply

The CMOS Inverter



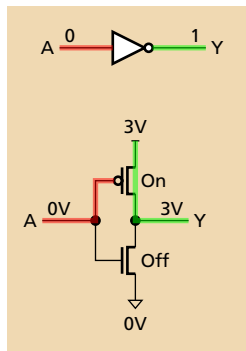
When the input is near the power supply voltage ("1"),

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



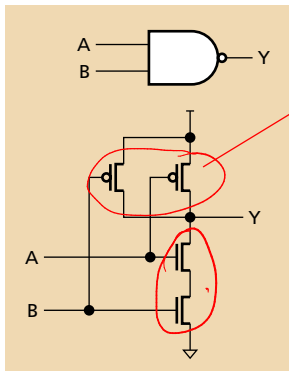
When the input is near ground ("0"),
the p-FET is turned on, connecting the
output to the power supply ("1");
the n-FET is turned off.
p-FETs are only good at passing 1's

The CMOS NAND Gate

Enhancement-mode MOSFETS

Pull-up

depletion



Two-input NAND gate:

two n-FETs in series;

two p-FETs in parallel

FET

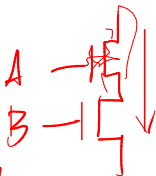
;

$$Y = \overline{A B}$$

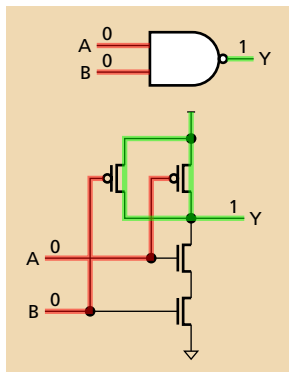
pull-down network

$$Y = \overline{A B}$$

= 0 when $A=1$ and $B=1$



The CMOS NAND Gate

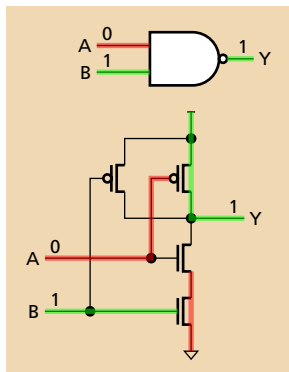


Both inputs 0:

Both p-FETs turned on

Output pulled high

The CMOS NAND Gate



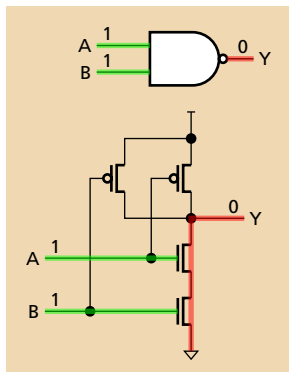
One input 1, the other 0:

One p-FET turned on

Output pulled high

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

The CMOS NAND Gate



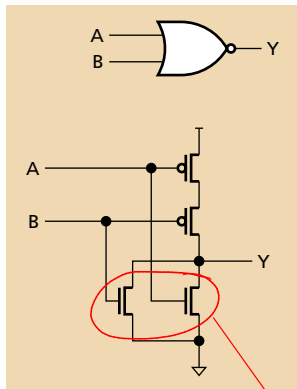
Both inputs 1:

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;

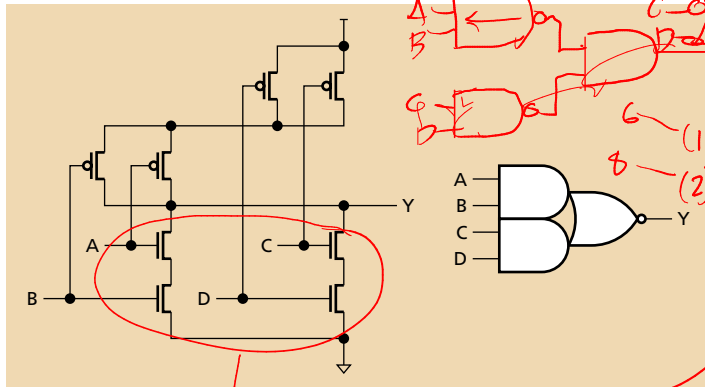
two p-FETs in series.

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

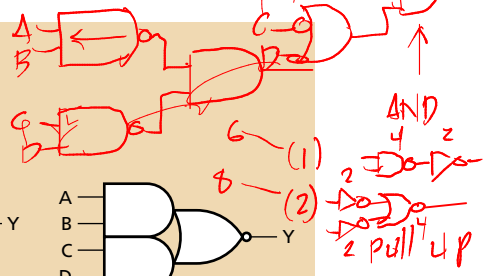
$$Y = \overline{A+B}$$

when
 $A=1$ or
 $B=1$

A CMOS AND-OR-INVERT Gate



$(\overline{AB})(\overline{CD})$



AND 4 2
~~2~~ ~~2~~
 2 pull up

pull down network

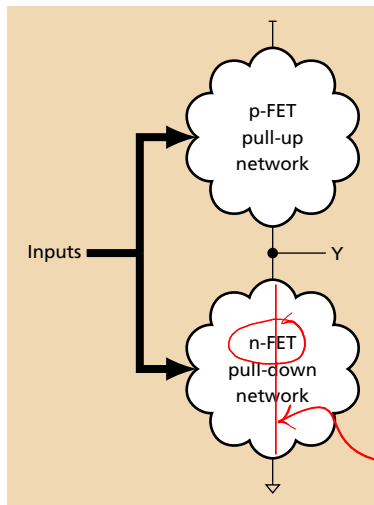
structure of pull-down

$\overline{AB + CD}$
 series

positive literals



Static CMOS Gate Structure

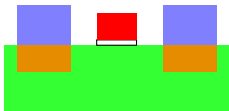
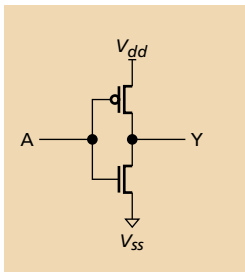


Pull-up and Pull-down networks must be complementary; exactly one should be connected for each input combination.

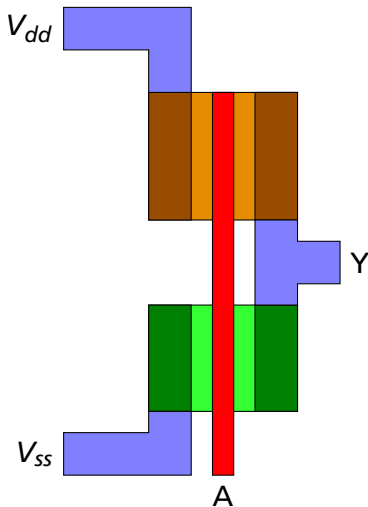
Series connection in one should be parallel in the other

make this connection when we want $y=0$

CMOS Inverter Layout



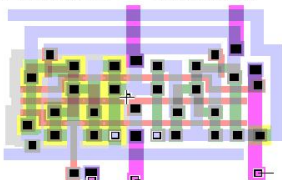
Cross Section Through
N-channel FET



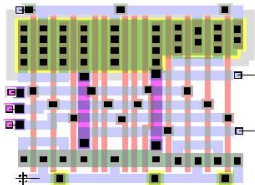
Top View

Full Adder Layouts

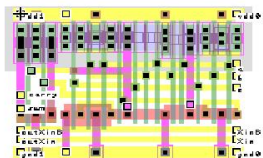
fa_ly_mini_jk size: 60 · 40μm (1.2μmCMOS)



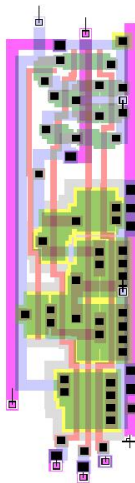
fa_ly_opt1 size: 63 · 50μm (1.2μmCMOS)



Fulladd L size: 37 · 26 μm (0.5μmCMOS)



fa_ly_itt size: 117 · 31 μm (1.2μmCMOS)



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 4-bit parallel adder, subtractor, 4-bit registers, an accumulator and a read-only memory on one chip. 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 few as five dual in-line packages.

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 random access or shift register storage. When you require rapid turn-around or need only a few systems, Intel's erasable and re-programmable ROM, Type 4002, may be substituted for the Type 4001 mask-programmed ROM.

Intel's 4003 provides a ready-to-use shift register, bus controller, display, multiplexers, counters, decoders, 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 02/539-4131. In Japan, contact Intel Japan, Ltd., Parkside Plaza Bldg., 8th F., 2-2-1 Shinjyogasaki, Shinjyogasaki, Tokyo 162, Japan. Phone 03-433-4131. Intel Corporation now produces micro-computers, microprocessors and microperipherals at 3065 Avenida de las Americas, San Jose, Costa Rica. Phone 0222-226-7000.

intel
delivers.

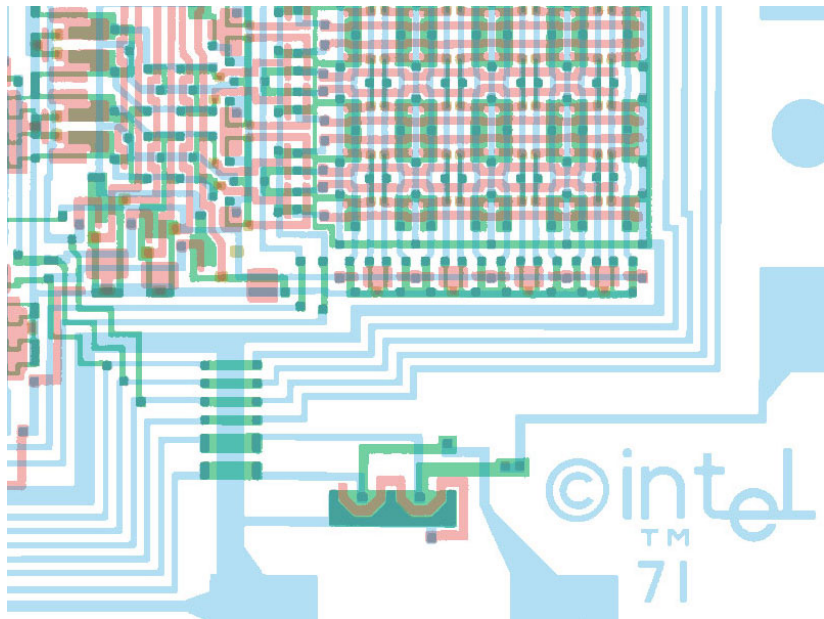
4001: 256-byte ROM + 4-bit IO port

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

