

# Fundamentals of Computer Systems

## Transistors, Gates, and ICs

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# Semiconductor

sem·i·con·duc·tor

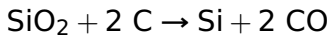
noun

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

# Sand into Silicon



Silica a.k.a.  $\text{SiO}_2$  a.k.a. Quartz

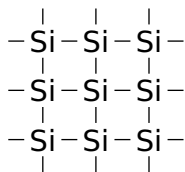


Elemental, amorphous silicon



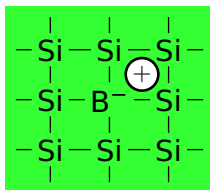
Monocrystalline  
Silicon Ingot

# Doping Silicon Makes It a Better Conductor

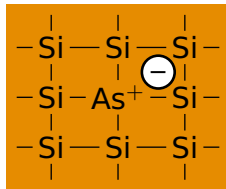


Undoped (pure)  
silicon crystal

Not a good  
conductor

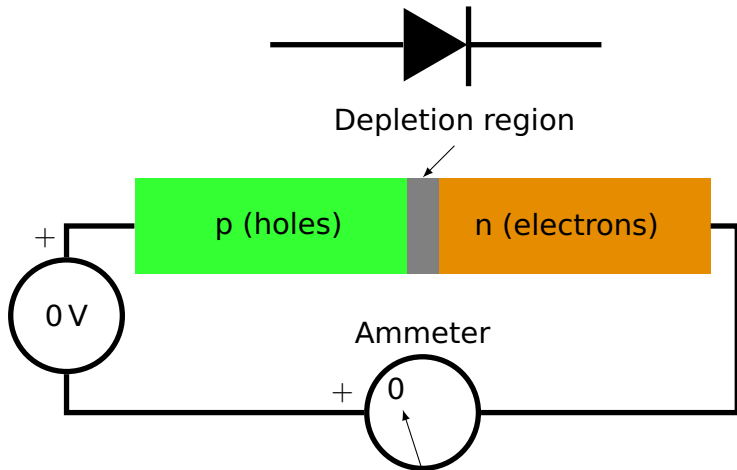


p-type (doped)  
silicon  
boron atom  
steals a nearby  
electron

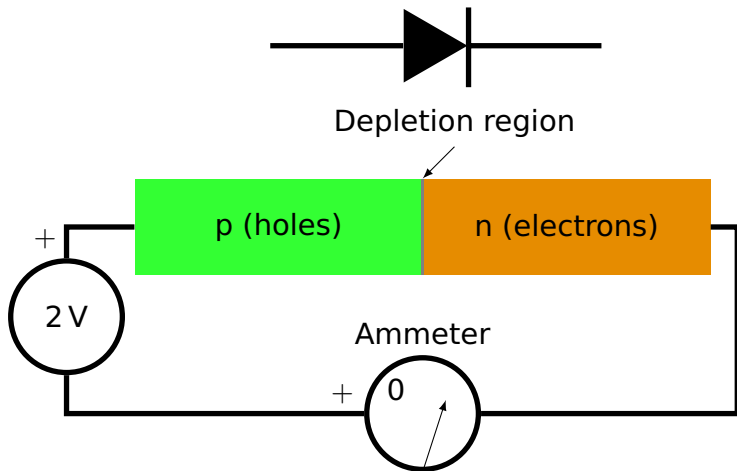


n-type (doped)  
silicon:  
extra electron on  
arsenic atom  
jump loose

# A PN Junction aka A Diode

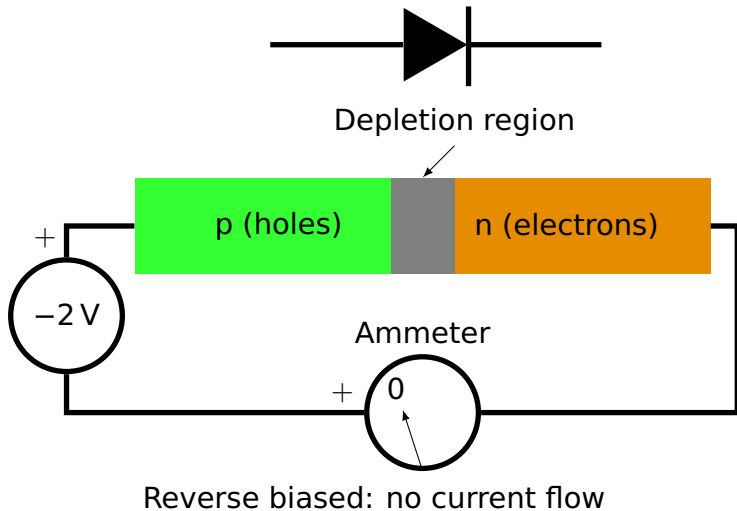


# A PN Junction aka A Diode

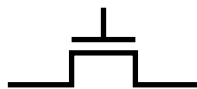


Forward biased: current flows

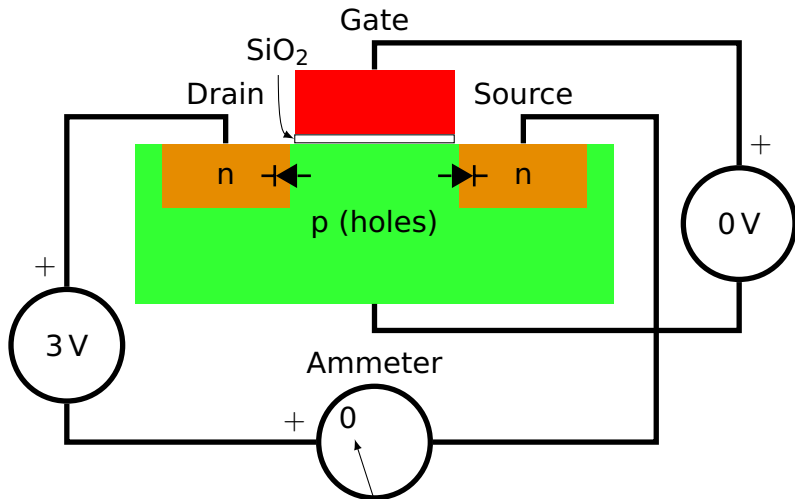
# A PN Junction aka A Diode



# An N-Channel MOS Transistor

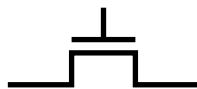


Gate at 0V: Off

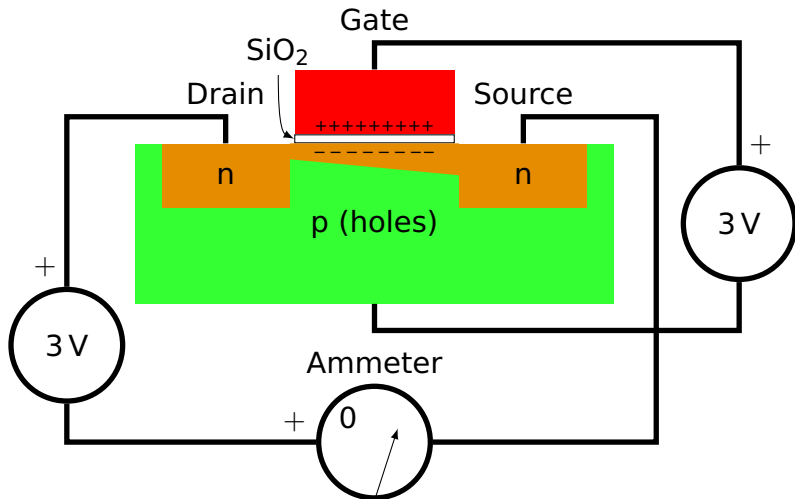




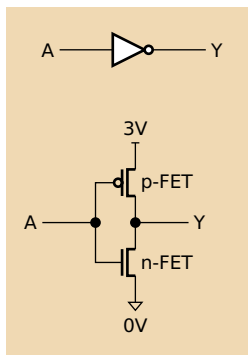
# An N-Channel MOS Transistor



Gate positive: On



# The CMOS Inverter

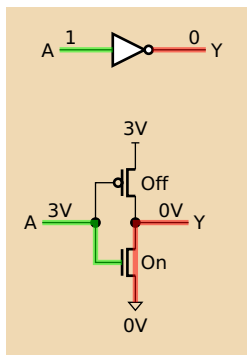


An inverter is built from two MOSFETs:

An n-FET connected to ground

A p-FET connected to the power supply

# The CMOS Inverter



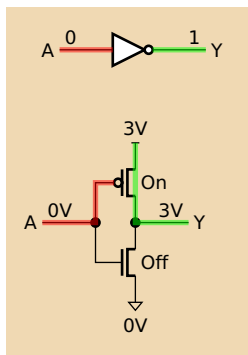
When the input is near the power supply voltage ("1"),

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

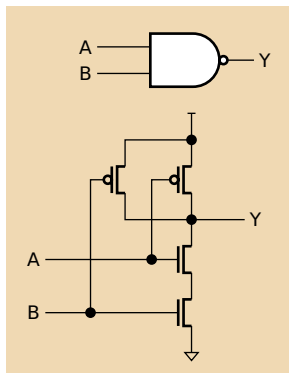
# The CMOS Inverter



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.

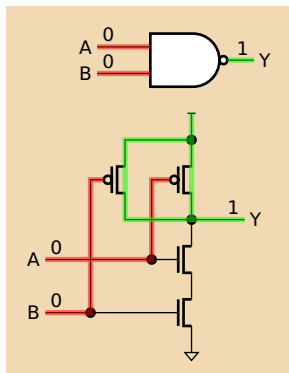
p-FETs are only good at passing 1’s

# The CMOS NAND Gate



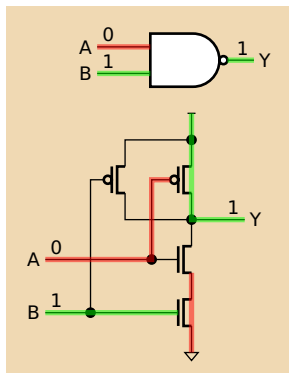
Two-input NAND gate:  
two n-FETs in series;  
two p-FETs in parallel

# The CMOS NAND Gate



Both inputs 0:  
Both p-FETs turned on  
Output pulled high

# The CMOS NAND Gate



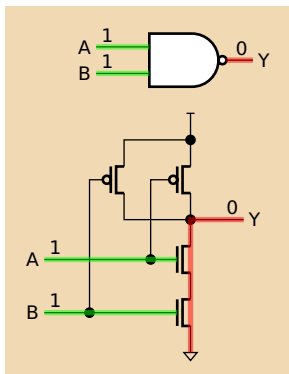
One input 1, the other 0:

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:

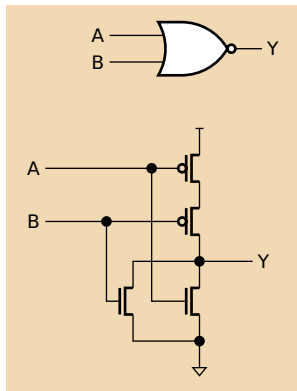
Both n-FETs turned on

Output pulled low

Both p-FETs turned off



# The CMOS NOR Gate



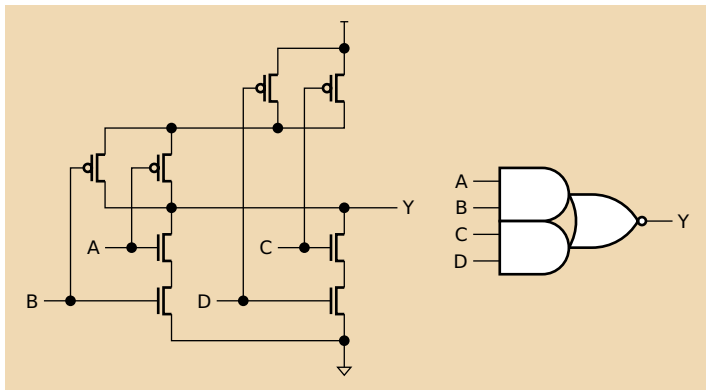
Two-input NOR gate:

two n-FETs in parallel;

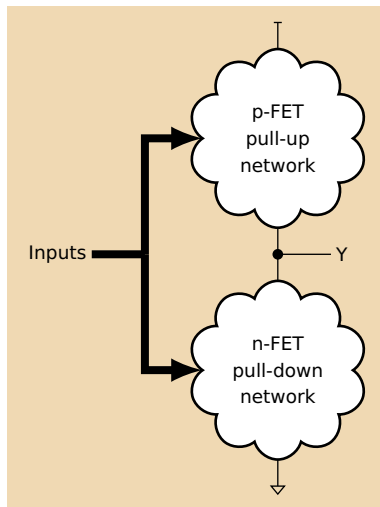
two p-FETs in series.

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

# A CMOS AND-OR-INVERT Gate



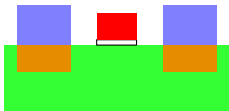
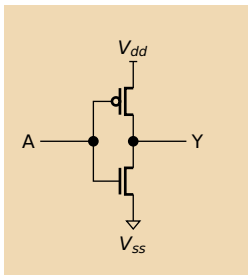
# Static CMOS Gate Structure



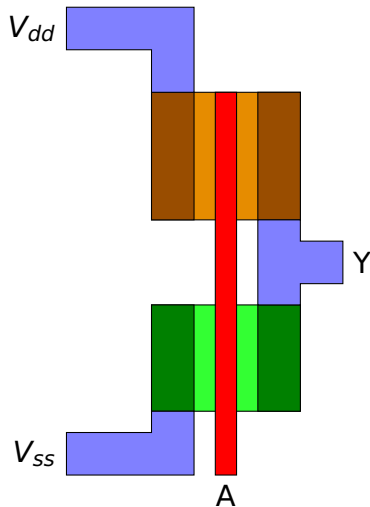
Pull-up and Pull-down networks must be complementary; exactly one should be connected for each input combination.

Series connection in one should be parallel in the other

# CMOS Inverter Layout



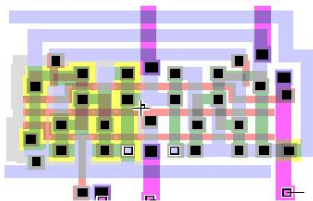
Cross Section Through  
N-channel FET



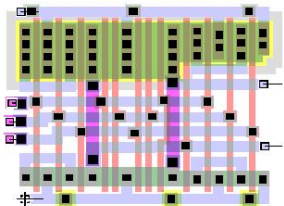
Top View

# Full Adder Layouts

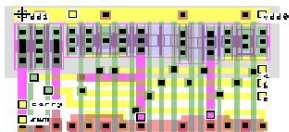
fa\_ly\_mini\_jk size: 60     · 40 $\mu$ m (1.2 $\mu$ mCMOS)



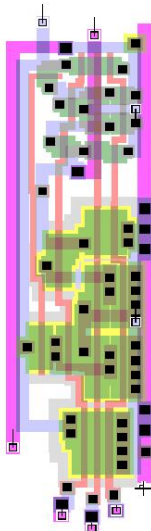
fa\_ly\_opt1 size: 63     · 50 $\mu$ m (1.2 $\mu$ mCMOS)



Fulladd.L size: 37     · 26  $\mu$ m (0.5 $\mu$ mCMOS)



fa\_ly\_itt size: 117     · 31  $\mu$ m (1.2 $\mu$ mCMOS)



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 microprocessor with a ROM for address, instruction, and control, and a 4-bit register, an accumulator, and a 4-bit shift register. It is the first of a family of four chips that comprise the MCS-4 microcomputer 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 software provides complete computing and control functions for data acquisition, data handling, utility functions, monitoring systems, controls control systems, and process 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 stack Type 4001 ROM, an 8-bit shift register, and data buffer plus a fully functioning microprogrammable computer. To this you may add Type 4002 ROMs for local on-chip memory and Type 4003 registers to expand the output ports.

Using its flexible software you have the flexibility of a microprogrammable computer with the benefits of ROM storage and on-chip on-board storage. When you require rapid local memory or need only a few gates, Intel's on-chip on-chip programmable ROM, Type 4004, may be substituted for the Type 4001 microprogrammable 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(0)2 537 4211. In Japan, contact Intel Japan, Ltd., Parkside Plaza Bldg., 8th Fl., 2-2-1 Sendagaya, Shibuya-Ku, Tokyo 100. Phone 81(0)3 409-4141.

Intel Corporation also produces microcomputers, microprocessors and peripheral systems at 3065 Avenida Arroyo, San Jose, Costa Rica. Phone 506(2) 226-7000.

intel  
delivers.

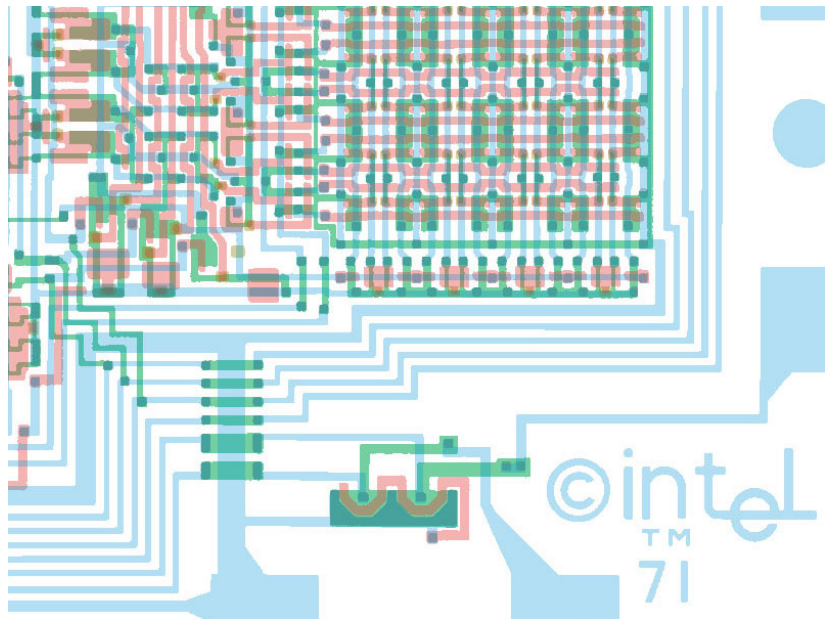
4001: 256-byte ROM + 4-bit IO port

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

