

# Fundamentals of Computer Systems

## Transistors, Gates, and ICs

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# Semiconductor

sem·i·con·duc·tor

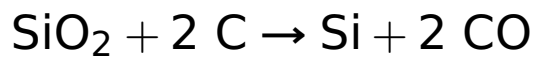
noun

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

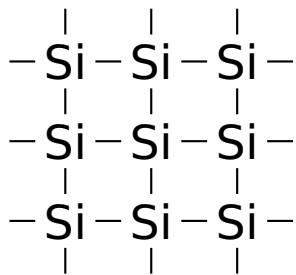


Elemental, amorphous silicon



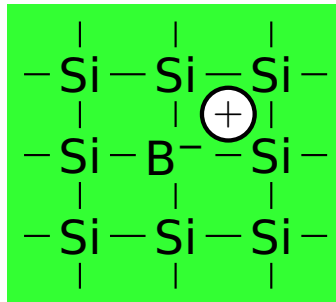
Monocrystalline  
Silicon Ingot

## Doping Silicon Makes It a Better Conductor

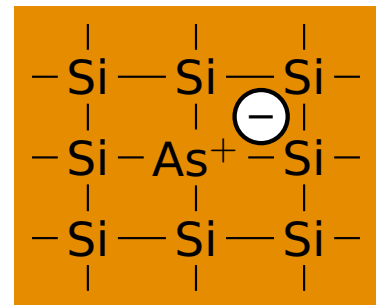


Undoped (pure)  
silicon crystal

Not a good  
conductor

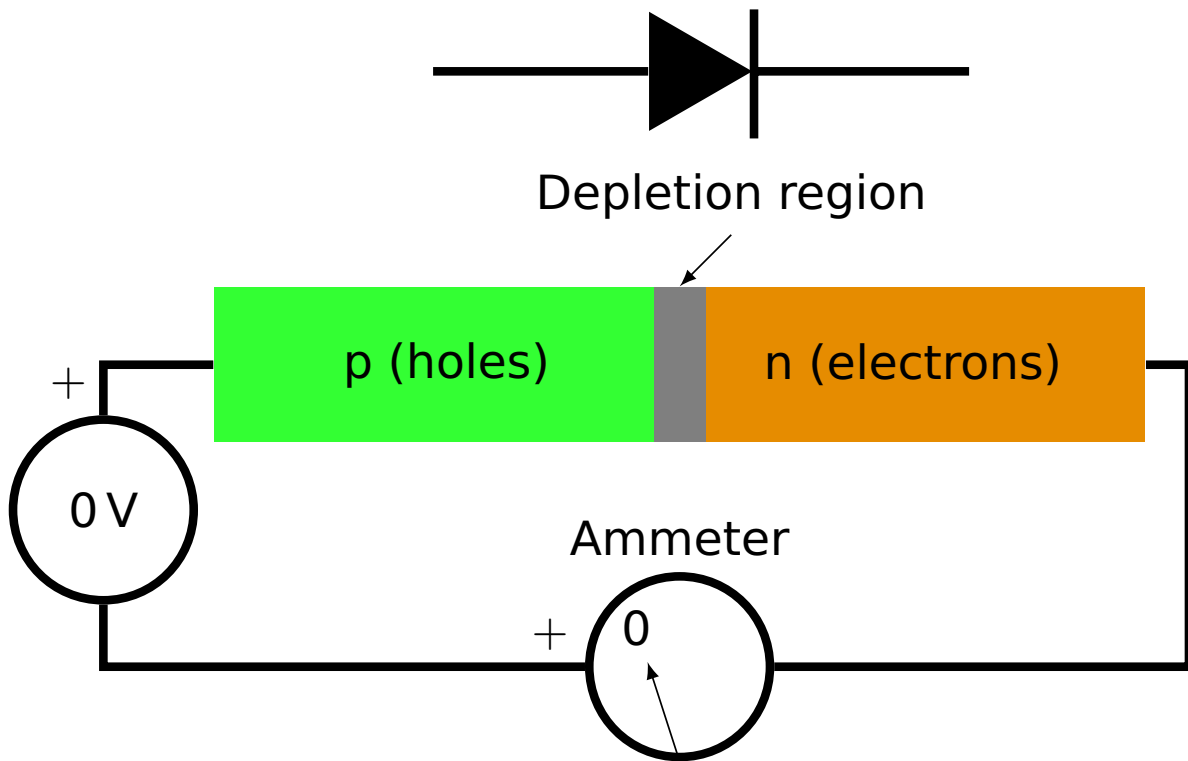


p-type (doped)  
silicon  
boron atom  
steals a nearby  
electron

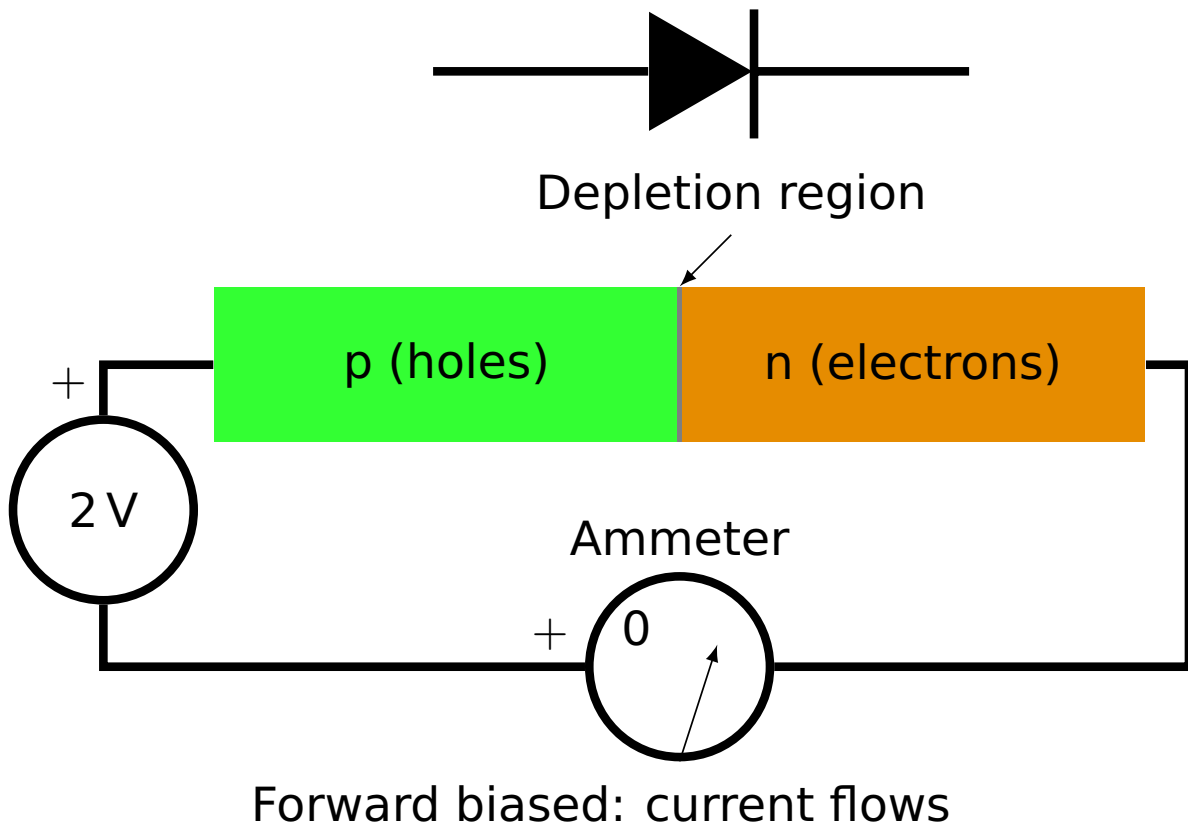


n-type (doped)  
silicon:  
extra electron on  
arsenic atom  
jump loose

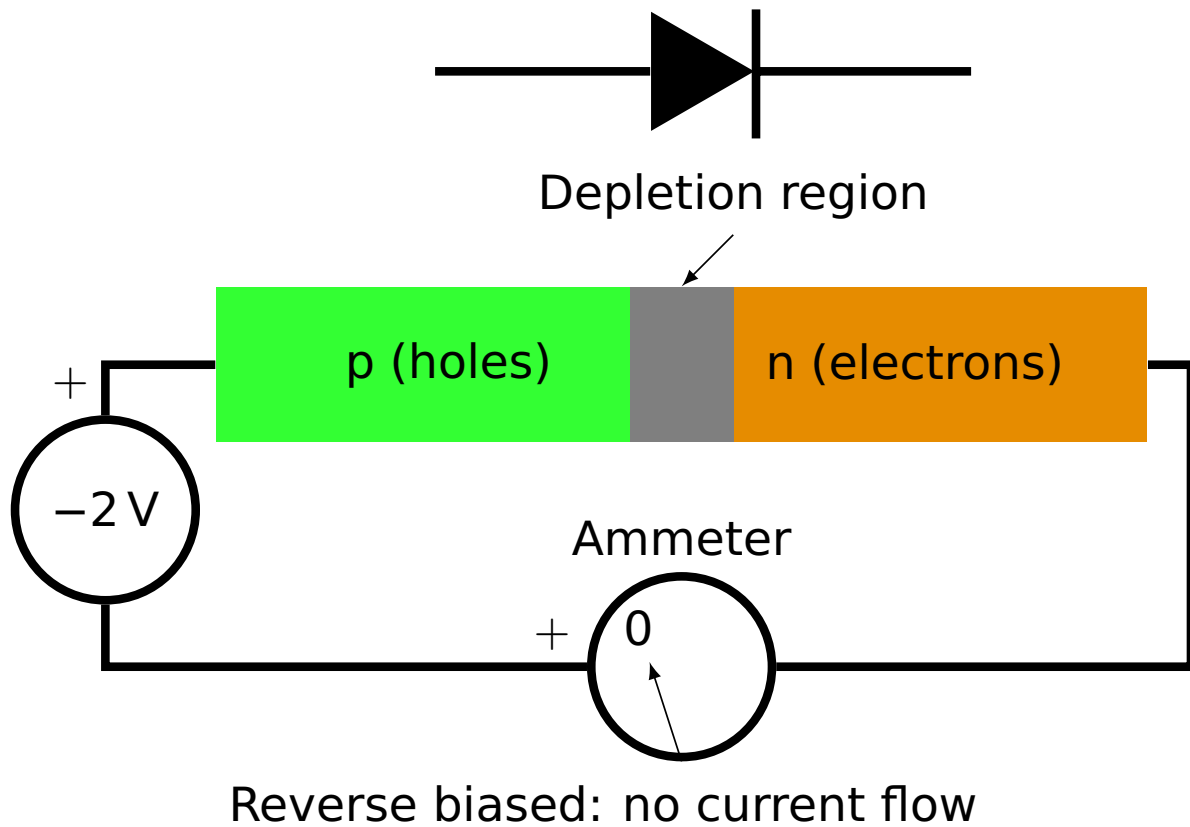
# A PN Junction aka A Diode



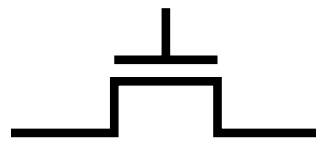
## A PN Junction aka A Diode



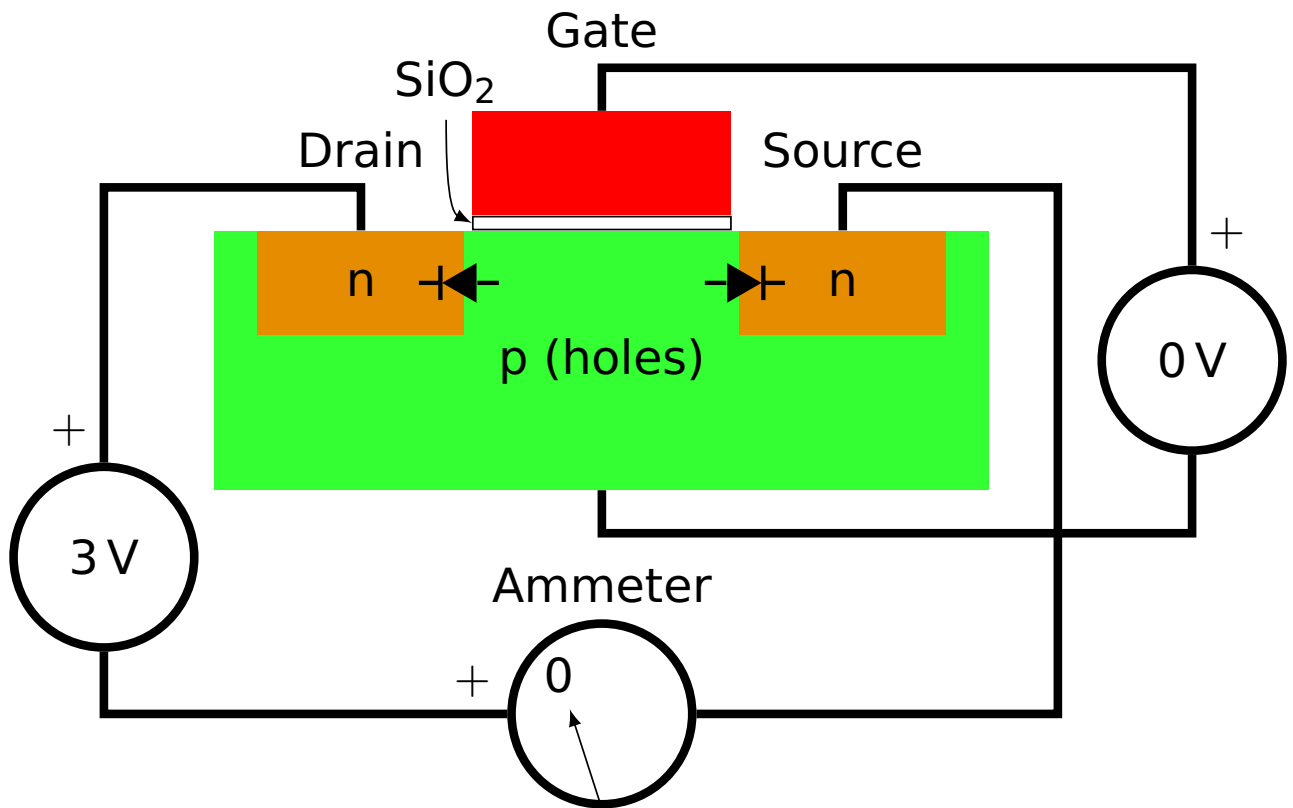
## A PN Junction aka A Diode



# An N-Channel MOS Transistor

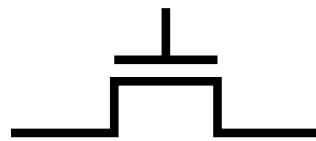


Gate at 0V: Off

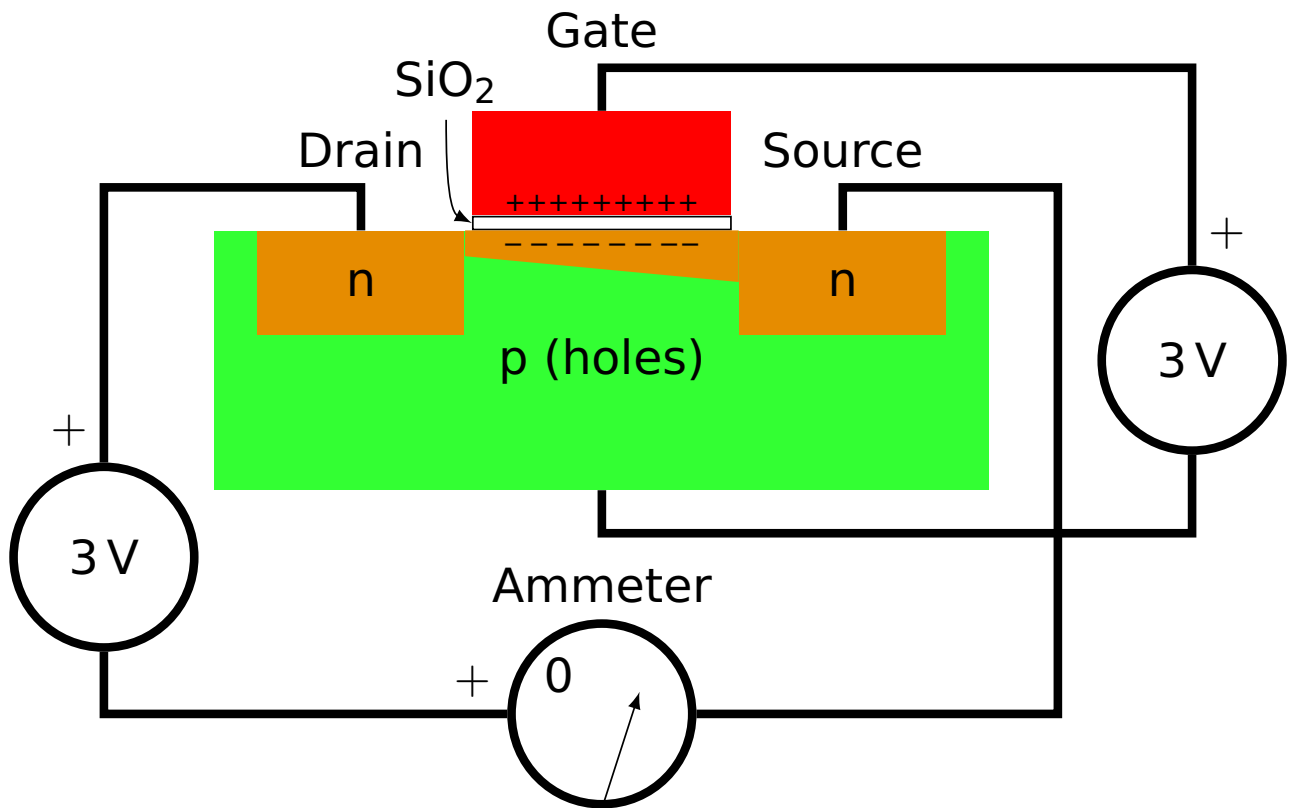




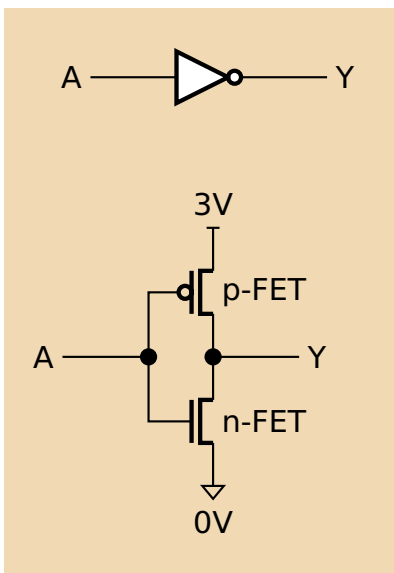
# An N-Channel MOS Transistor



Gate positive: On



# The CMOS Inverter

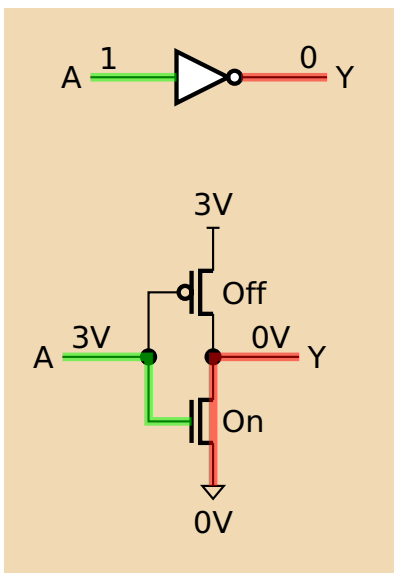


An inverter is built from two MOSFETs:

An n-FET connected to ground

A p-FET connected to the power supply

## The CMOS Inverter



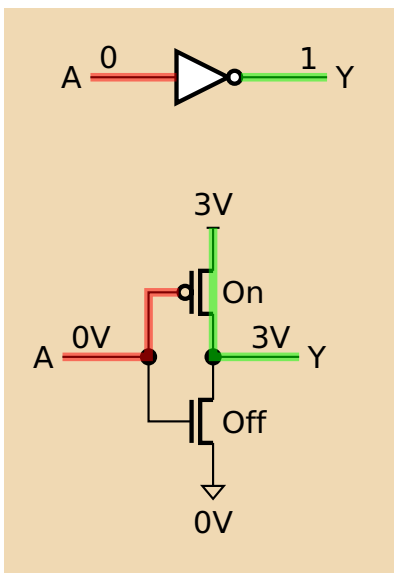
When the input is near the power supply voltage (“1”),

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

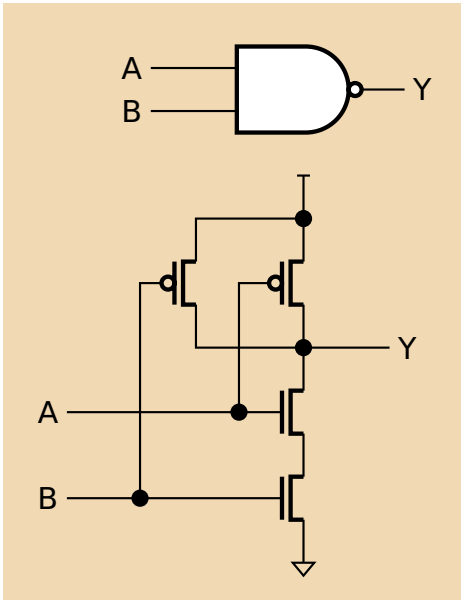
## The CMOS Inverter



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.

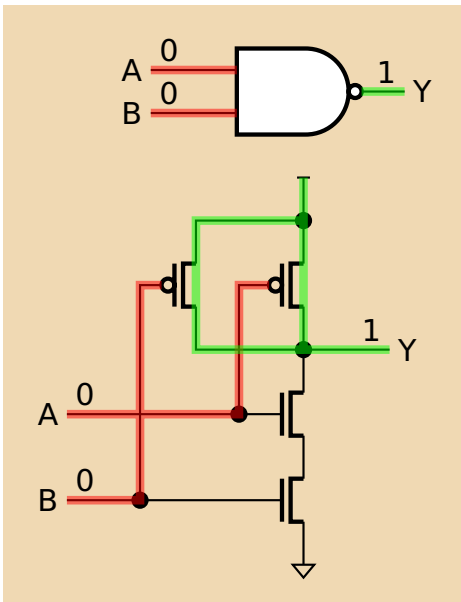
p-FETs are only good at passing 1’s

## The CMOS NAND Gate



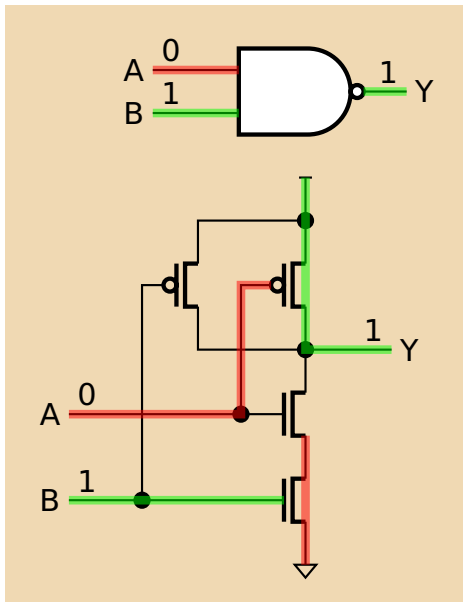
Two-input NAND gate:  
two n-FETs in series;  
two p-FETs in parallel

## The CMOS NAND Gate



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

## The CMOS NAND Gate



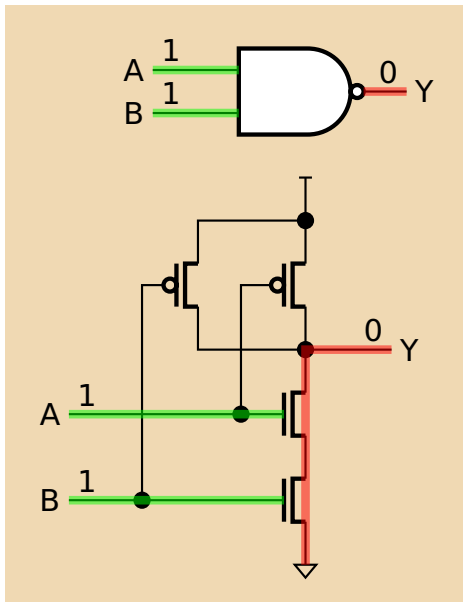
One input 1, the other 0:

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:

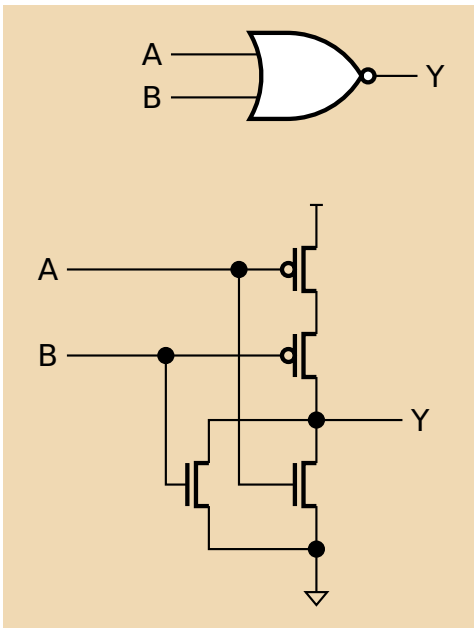
Both n-FETs turned on

Output pulled low

Both p-FETs turned off



## The CMOS NOR Gate



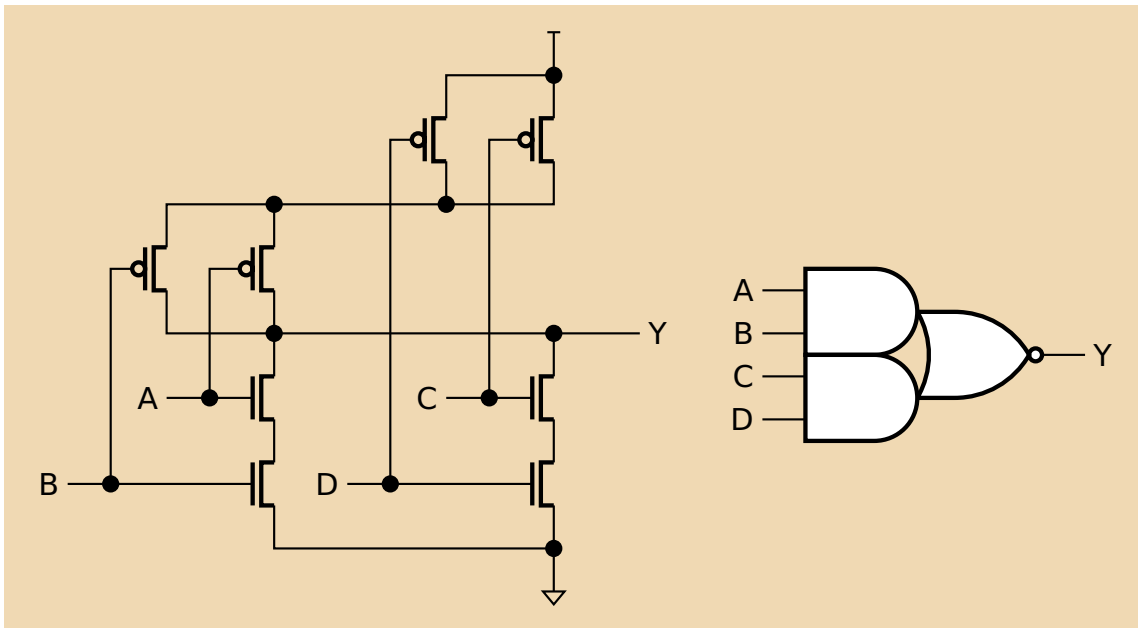
Two-input NOR gate:

two n-FETs in parallel;

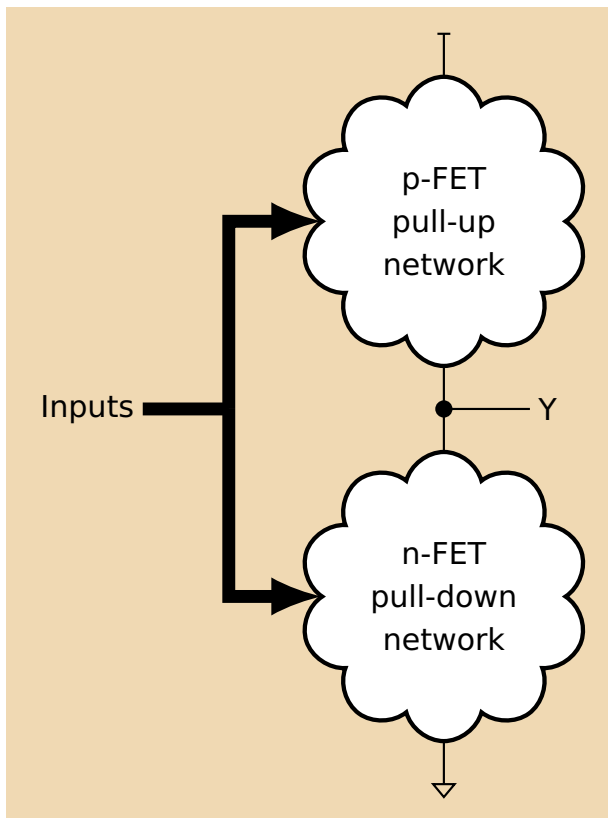
two p-FETs in series.

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

## A CMOS AND-OR-INVERT Gate



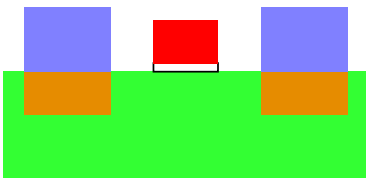
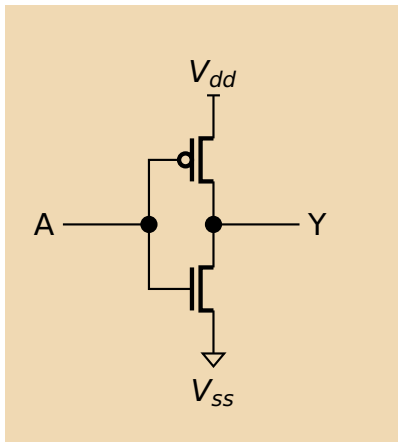
## Static CMOS Gate Structure



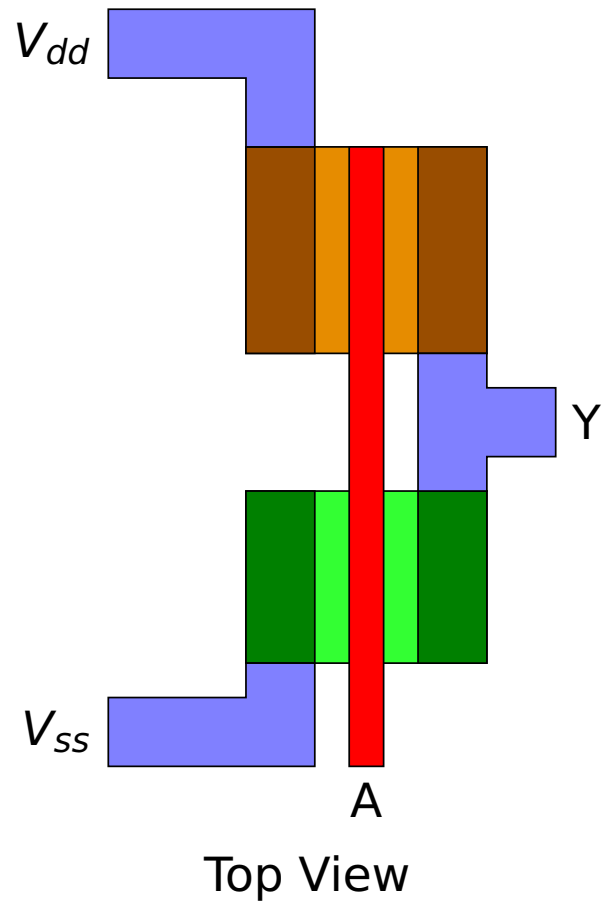
Pull-up and Pull-down networks must be complementary; exactly one should be connected for each input combination.

Series connection in one should be parallel in the other

# CMOS Inverter Layout



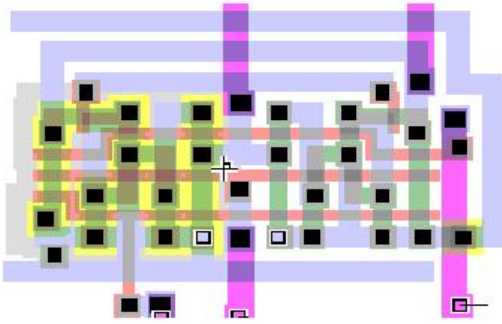
Cross Section Through  
N-channel FET



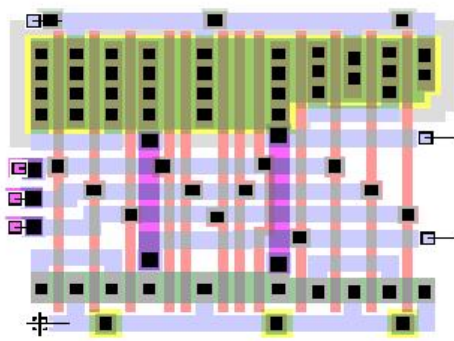
Top View

# Full Adder Layouts

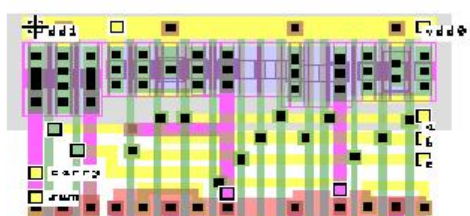
fa\_ly\_mini\_jk size: 60 · 40 $\mu$ m (1.2 $\mu$ mCMOS)



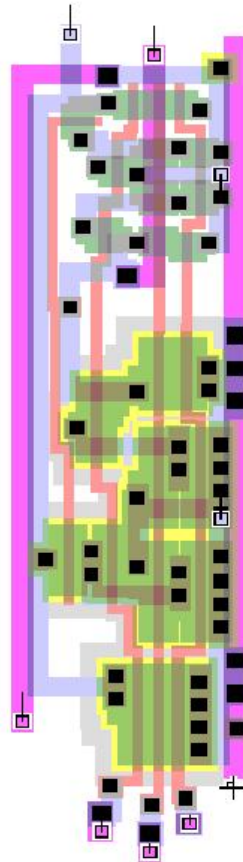
fa\_ly\_opt1 size: 63 · 50 $\mu$ m (1.2 $\mu$ mCMOS)



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



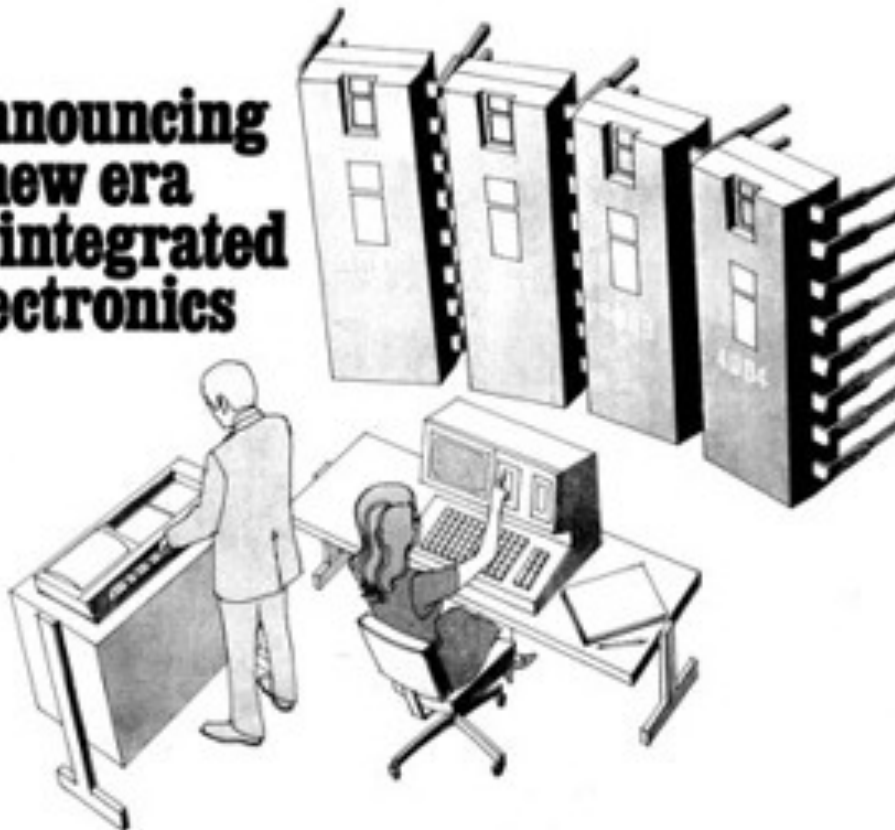
fa\_ly\_itt size: 117 · 31 $\mu$ m (1.2 $\mu$ mCMOS)



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 CPU complete with a 4-bit parallel adder, subtractor, 4-bit registers, an accumulator and a built-in timer clock on one chip. It's one of a family of four new ICs which comprise the MCS-4 micro-computer system - the first system to bring you the power and flexibility of a dedicated general-purpose computer at one cost or as few as two chips in one package.

With its general-purpose computing and control functions for data systems, data acquisition, testing, 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 powerful set of 45 instructions, adding one or more Type 4001 ROMs for program storage and data tables gives you a fully functioning micro-programmed computer. To this you may add Type 4002 RAMs for read-write memory and Type 4003 registers to expand the output ports.

Using no more than 200 ICs from this family of four, you can create a system with 4096 bits of user storage and 16 bits of on-chip storage. With an optional input/output port, you can interface with systems, input devices and an programmable ROM. Type 4004 may be substituted for the Type 4001 mask-programmed ROM.

MCS-4 systems interface easily with switches, key boards, displays, magnetic tape, printers, modems, A/D converters and other popular peripherals.

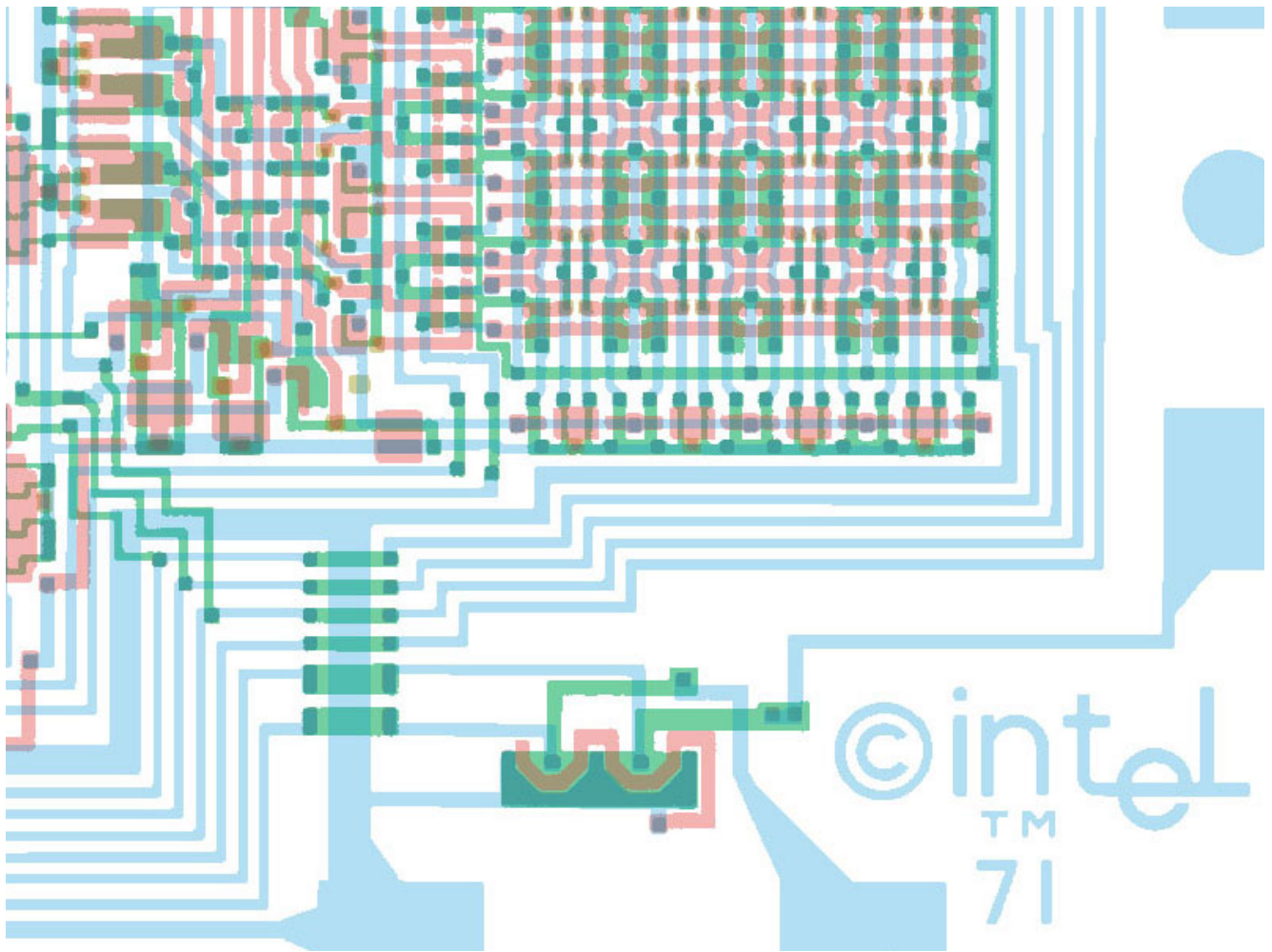
The MCS-4 family is now in stock at Intel's Santa Clara Headquarters and at our marketing headquarters in Europe and Japan. In the U.S., contact your local Intel representative for technical information and literature. In Europe, contact Intel at Avenue Louise 210, B-1050 Brussels, Belgium. Phone 2229000. In Japan, contact Intel Japan, Ltd., Postoffice Box 5965, Seto 5, 5-2-2, Seto-ku, Mie-ken 514, Japan. Phone 0448-4161.

Intel Corporation now produces micro-computers, microprocessors and memory systems in both Santa Clara, California, and Fremont, California. Please contact Intel.

**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

