Combinatorial Logic

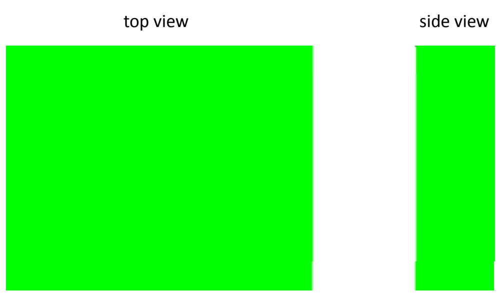
COMP370

Intro to Computer Architecture

VLSI Production Steps

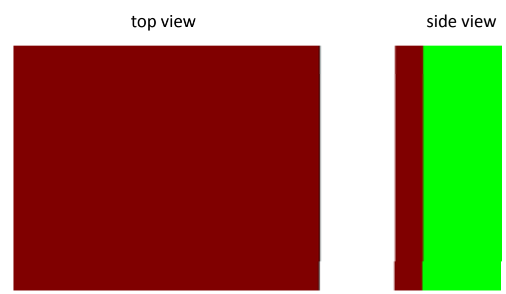
- Cover the chip with photoresist
- Expose a pattern by shining light through a mask
- Dissolve the exposed photoresist
- Expose the exposed chip to a chemical
- Wash off the photoresist

Creation of a Transistor



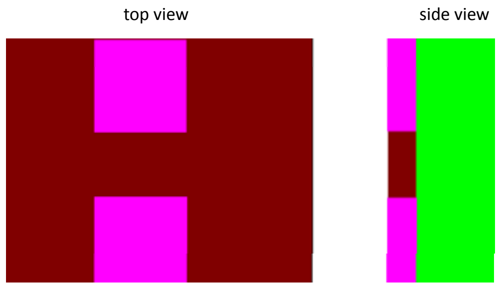
Start with lightly P doped silicon

Creation of a Transistor



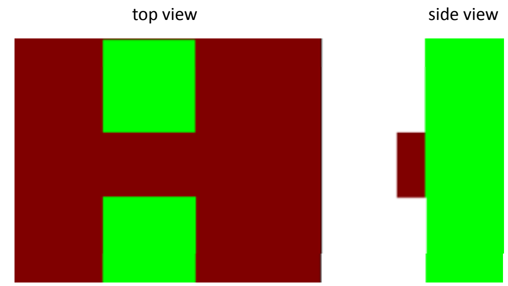
Cover the silicon with photoresist

Creation of a Transistor



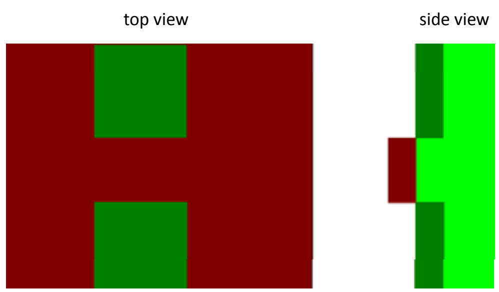
Expose portions of the photoresist to light by projecting an image onto the chip.

Creation of a Transistor



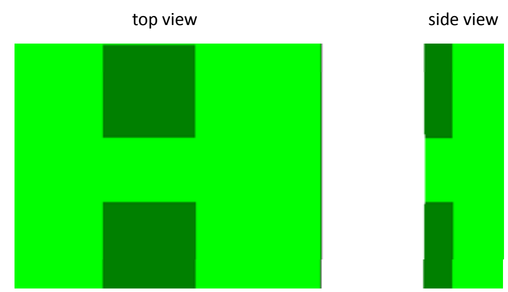
Wash away the exposed photoresist

Creation of a Transistor



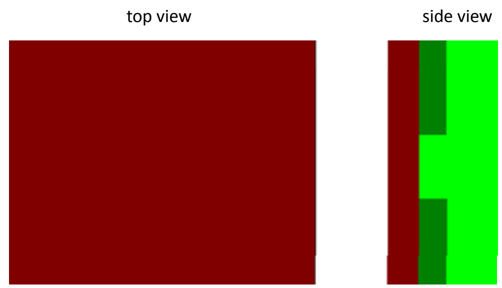
Embed lots of N dopant in the exposed silicon

Creation of a Transistor



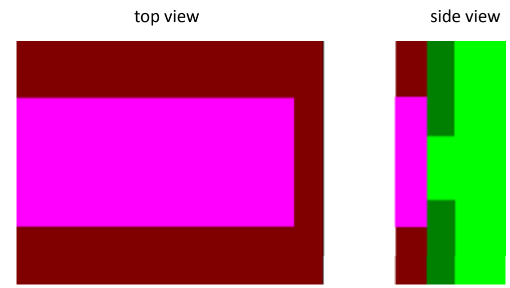
Wash away the photoresist

Creation of a Transistor



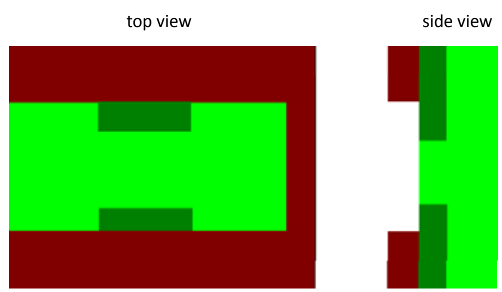
Cover the chip with photoresist

Creation of a Transistor



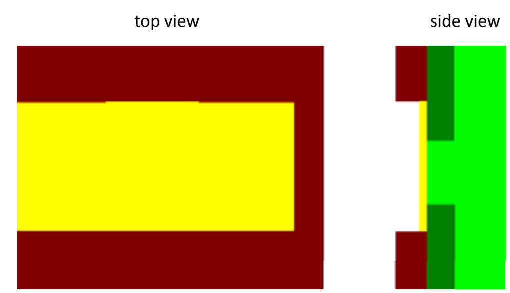
Expose portions of the photoresist to light

Creation of a Transistor



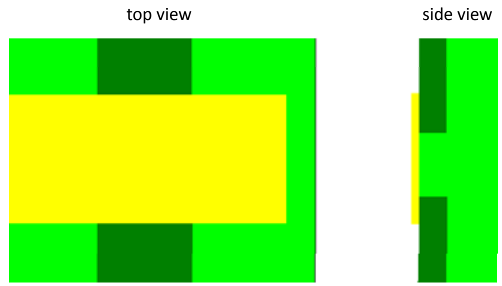
Wash away the exposed photoresist

Creation of a Transistor



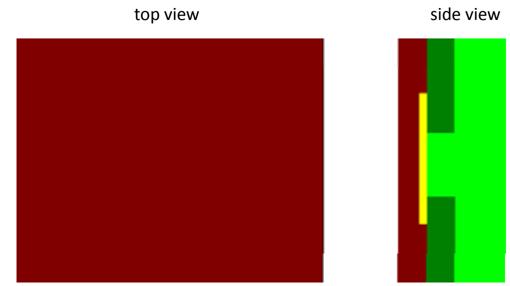
Grow silicon dioxide in the exposed areas

Creation of a Transistor



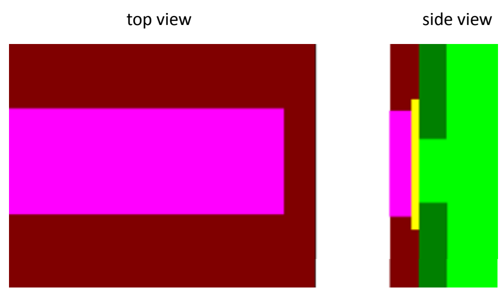
Wash off the photoresist

Creation of a Transistor



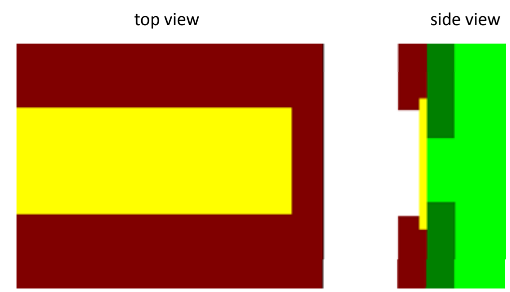
Cover the chip with photoresist

Creation of a Transistor



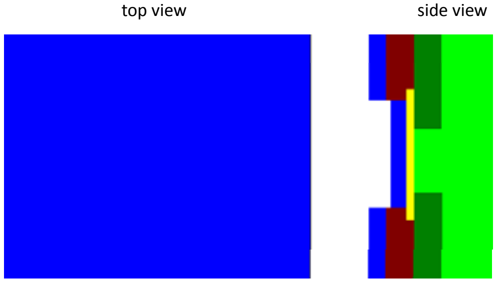
Expose portions of the photoresist to light

Creation of a Transistor



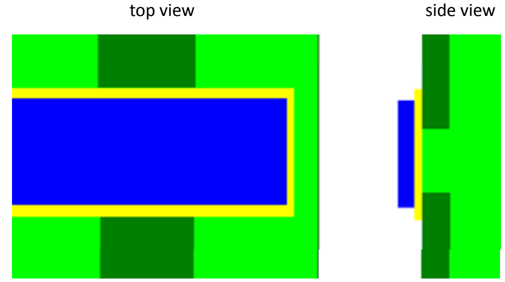
Wash off the exposed photoresist

Creation of a Transistor



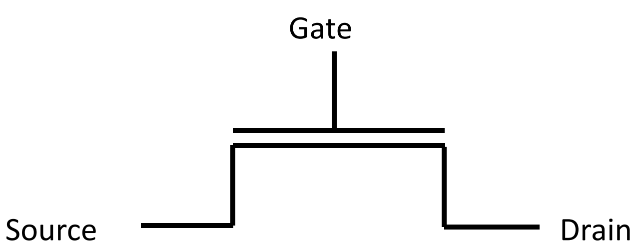
Cover the chip with conductive polysilicon

Creation of a Transistor



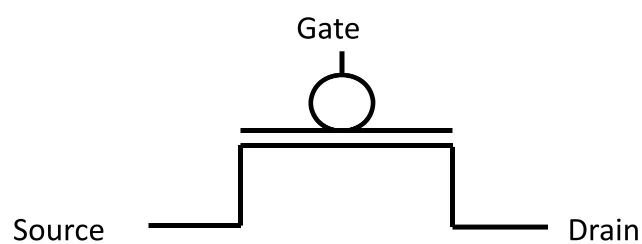
Wash off the photoresist. The polysilicon on top of the photoresist is also removed.

NPN Transistor Stick Diagram



Conducts when the gate has current.

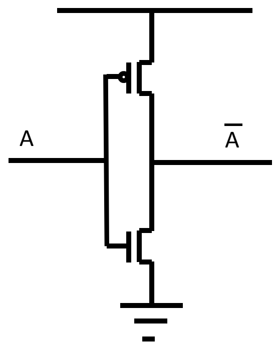
PNP Transistor Stick Diagram



Conducts when the gate does not have current.

Not Gate

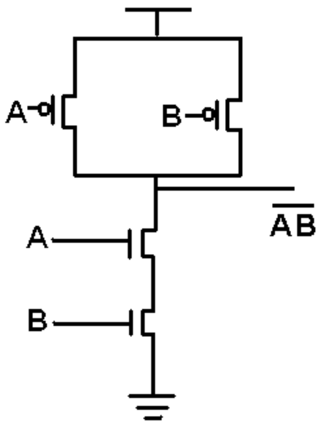
- When the input is 1 (current) the upper PNP transistor does not conduct. Power cannot flow to the output
- The lower NPN transistor does conduct. The output is connected to ground.
- When the input is 0 (no current) the upper PNP transistor can conduct power to the output.
- The lower NPN transistor does not connect the output to ground.



NAND Gate

- When either A or B is 0, the output is connected to power.
- When both A and B are one, the output is connected to ground.

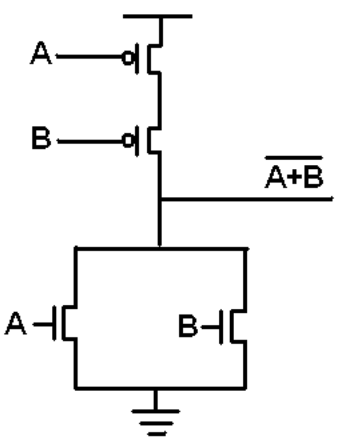
A	B	output
0	0	1
0	1	1
1	0	1
1	1	0



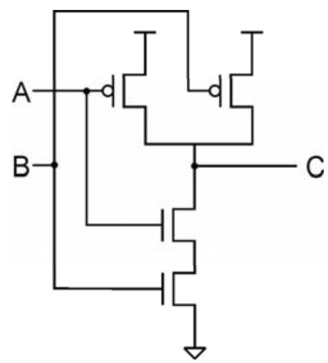
NOR Gate

- When A & B are 0, the output is connected to power.
- When either A or B are one, the output is connected to ground.

A	B	output
0	0	1
0	1	0
1	0	0
1	1	0



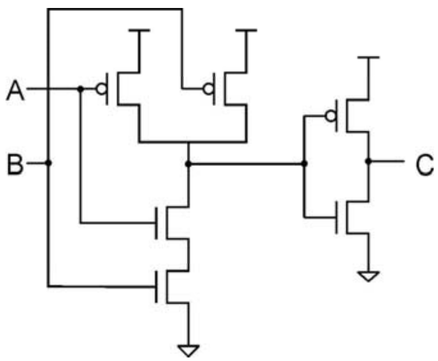
NAND Gate



- Transistors can make a NAND gate.

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

AND Gate

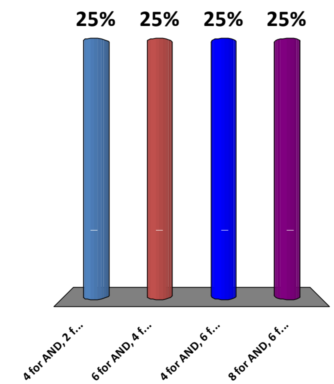


- AND gate is a NAND followed by a NOT gate

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

How many transistors does it take to make AND and NAND gates?

1. 4 for AND, 2 for NAND
2. 6 for AND, 4 for NAND
3. 4 for AND, 6 for NAND
4. 8 for AND, 6 for NAND



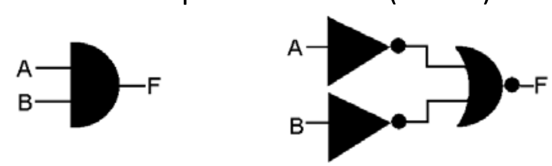
deMorgan's Law

Name	AND version	OR version
de Morgan	(X * Y)' = X' + Y'	(X + Y)' = X' * Y'

- (X * Y)' is a NAND
- (X + Y)' is a NOR
- Frequently logic equations with AND and OR can be converted to NAND and NOR
- F = AB + CD is the same as F = ((AB)' * (CD)')'

AND using NOR

F = AB is equivalent to F = (A' + B')'

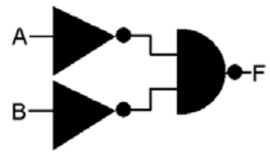


A	B	AND
0	0	0
0	1	0
1	0	0
1	1	1

A	B	A'	B'	OR	NOR
0	0	1	1	1	0
0	1	1	0	1	0
1	0	0	1	1	0
1	1	0	0	0	1

OR using NAND

F = A+B is equivalent to F = (A’ * B’)’

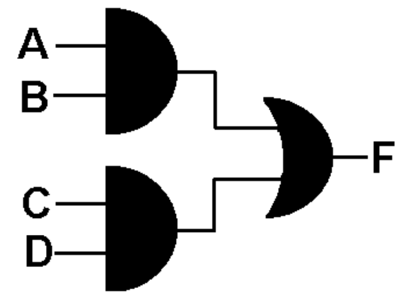


A	B	OR
0	0	0
0	1	1
1	0	1
1	1	1

A	B	A’	B’	AND	NAND
0	0	1	1	1	0
0	1	1	0	0	1
1	0	0	1	0	1
1	1	0	0	0	1

Circuit with AND and OR gates

F = AB + CD

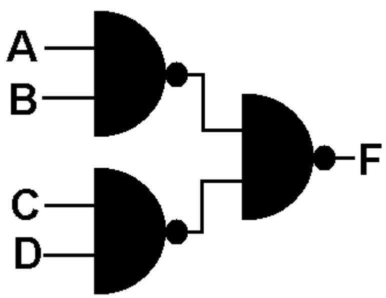


Circuit with NAND gates

$F = \overline{\overline{AB} * \overline{CD}}$

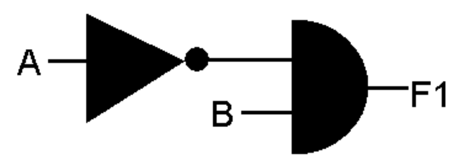
equivalent to

F = AB + CD



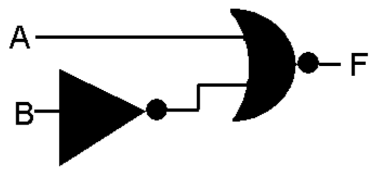
Convert to NAND or NOR gates

- Convert this circuit to use only NOT, NAND or NOR gates.

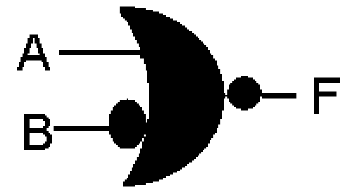


NOR Solution

A	B	F
0	0	0
0	1	1
1	0	0
1	1	0



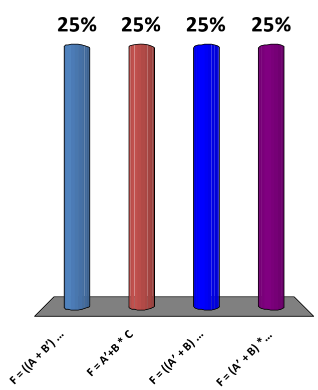
Alternate Notation



- A circle on the input to a gate represents the NOT of the input.

What equation is equivalent to F = A'B + C'

1. F = ((A + B') * C)'
2. F = A'+B * C
3. F = ((A' + B) * C')'
4. F = (A' + B) * C'

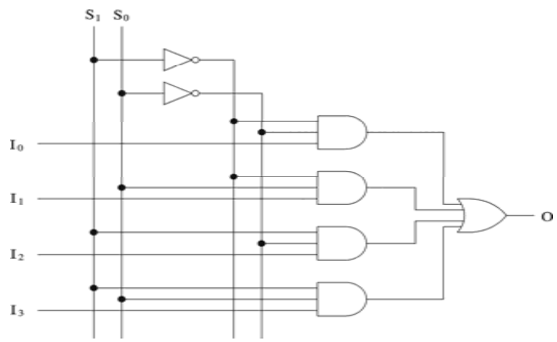


Useful Circuits

- Some circuits are frequently used in creating larger circuits.
- **Multiplexor** (mux) copies one of n inputs to the output based on $\log_2 n$ selector inputs
- **Demultiplexor** (demux) copies input to one of n outputs based on $\log_2 n$ selector inputs

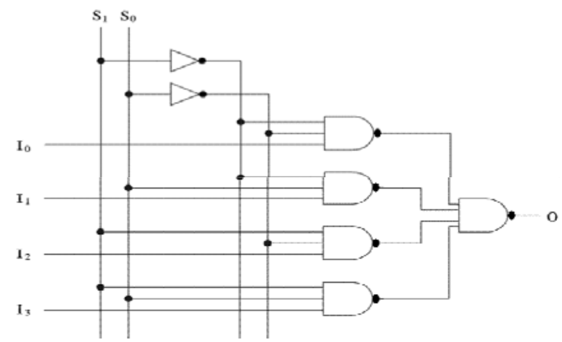
Multiplexor

- One of the four inputs ($I_0 – I_3$) is copied to the output based on the two selectors ($S_0 – S_1$)



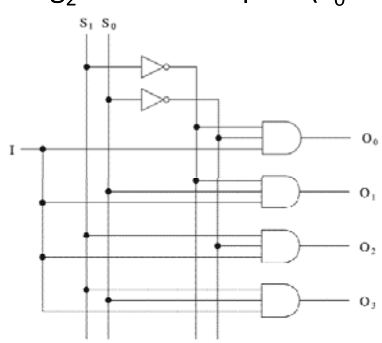
NAND gate Multiplexor

- Multiplexors can be created from NAND gates



Demultiplexor

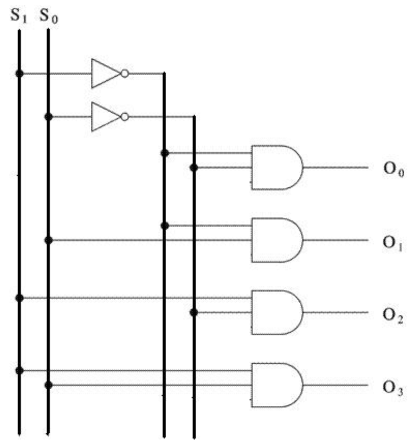
- Copies input to one of n outputs ($O_0 – O_3$) based on $\log_2 n$ selector inputs ($S_0 – S_1$)



Encoders and Decoders

- An encoder is just like a multiplexor with only one inputs being a 1.
- An encoder has n inputs and $\log_2 n$ outputs.
- The encoder output bits contain the binary number of the one input line that is true.
- A decoder is just like a demultiplexor whose input is always a 1.
- A decoder has n outputs and $\log_2 n$ inputs.

Decoder



Using Decoders for Functions

- The decoder implements F = A'B' + AB