UNIVERSITÀ DEGLI STUDI DI TRIESTE

dipartimento di ingegneria e architettura

L'ingegneria elettronica, informatica e biomedica nella rivoluzione digitale

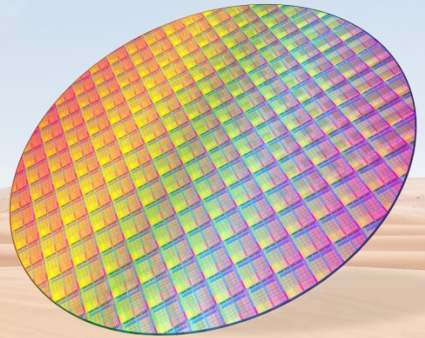
– parte II

Prof. Alberto Carini

Docente di Elettronica

UNIVERSITÀ DEGLI STUDI DI TRIESTE

dipartimento di ingegneria e architettura



Dalla Sabbia ai Circuiti Integrati

Indice

- Il silicio
- Diodi e Transistori
- Il processo di fabbricazione dei circuiti integrati.

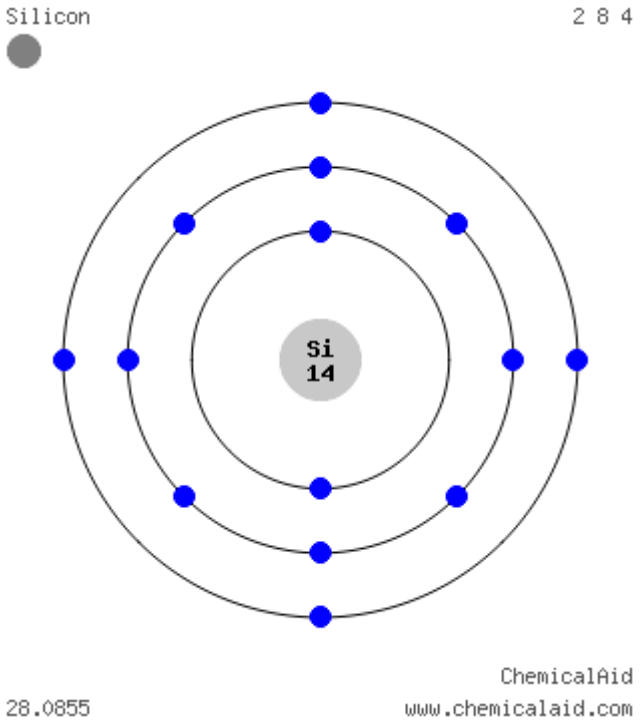
Il Silicio

- E’ il semiconduttore più usato nell'elettronica.
- Il secondo elemento per abbondanza nella crosta terreste, dopo l'ossigeno.
- Usato in elettronica in forma di cristallo.
- I *chip* (i processori, le memorie) sono costituiti da un singolo cristallo di silicio opportunamente trattato.

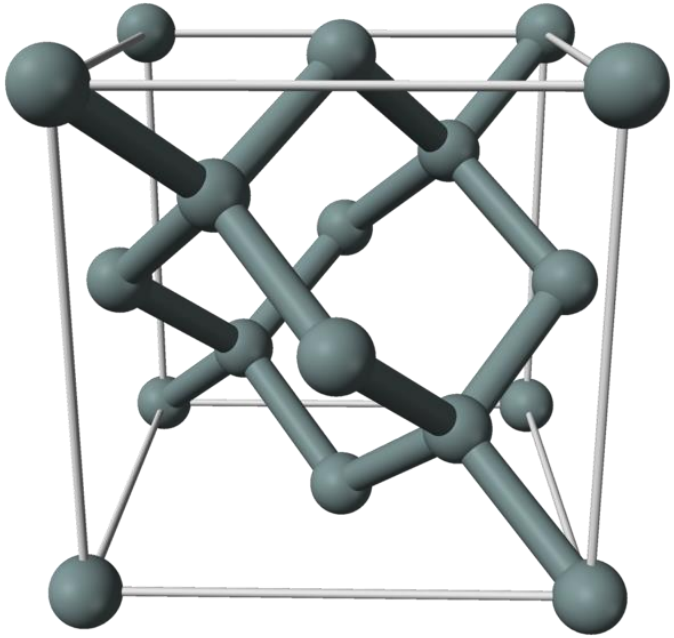
- I materiali si dividono in **amorfi**, **policristallini**, o **cristallini** a seconda della disposizione dei loro atomi.
- Nei materiali *amorfi* gli atomi hanno una distribuzione totalmente disordinata.
- Nei *cristalli* abbiamo una disposizione regolare
- I materiali *policristallini* sono formati da tanti grani di cristallo.

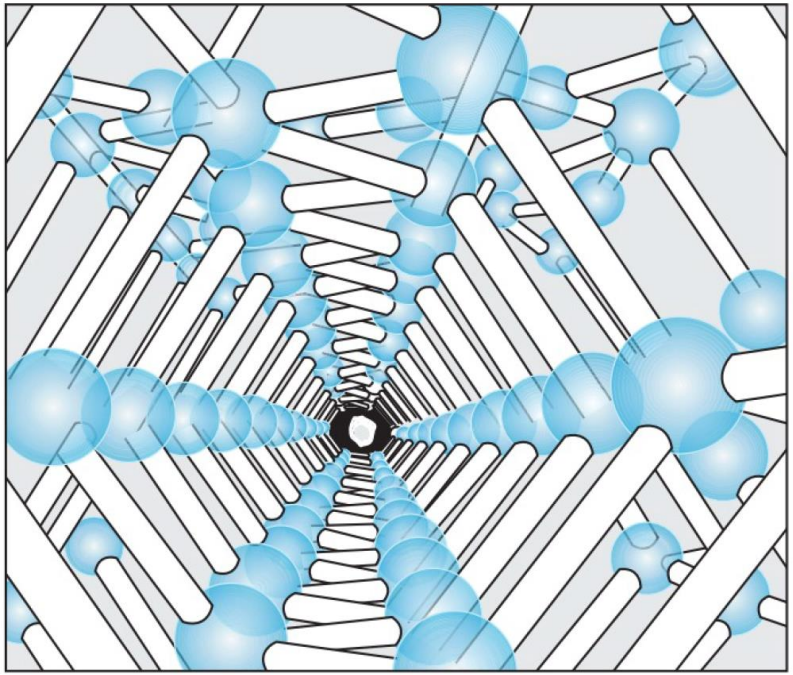
Il Silicio

	IIIA	IVA	VA	VIA
	5 10.811 **B** Boron	6 12.01115 **C** Carbon	7 14.0067 **N** Nitrogen	8 15.9994 **O** Oxygen
	13 26.9815 **Al** Aluminum	14 28.086 **Si** Silicon	15 30.9738 **P** Phosphorus	16 32.064 **S** Sulfur
IIB				
30 65.37 **Zn** Zinc	31 69.72 **Ga** Gallium	32 72.59 **Ge** Germanium	33 74.922 **As** Arsenic	34 78.96 **Se** Selenium
48 112.40 **Cd** Cadmium	49 114.82 **In** Indium	50 118.69 **Sn** Tin	51 121.75 **Sb** Antimony	52 127.60 **Te** Tellurium
80 200.59 **Hg** Mercury	81 204.37 **Tl** Thallium	82 207.19 **Pb** Lead	83 208.980 **Bi** Bismuth	84 (210) **Po** Polonium

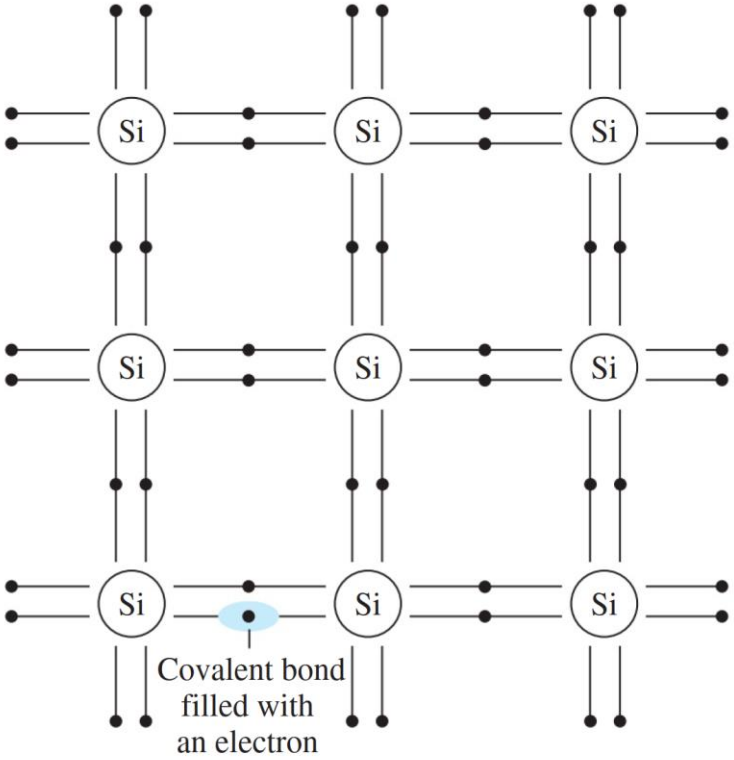


Il Silicio

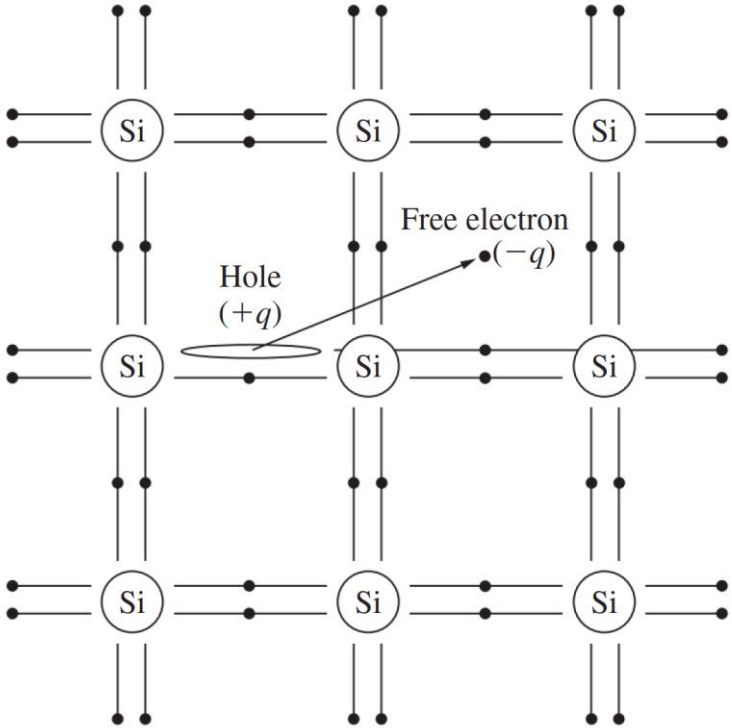




Il Silicio


Si
Si
Si
Si
Si
Si
Si
Si
Si
Covalent bond
filled with
an electron

Il Silicio



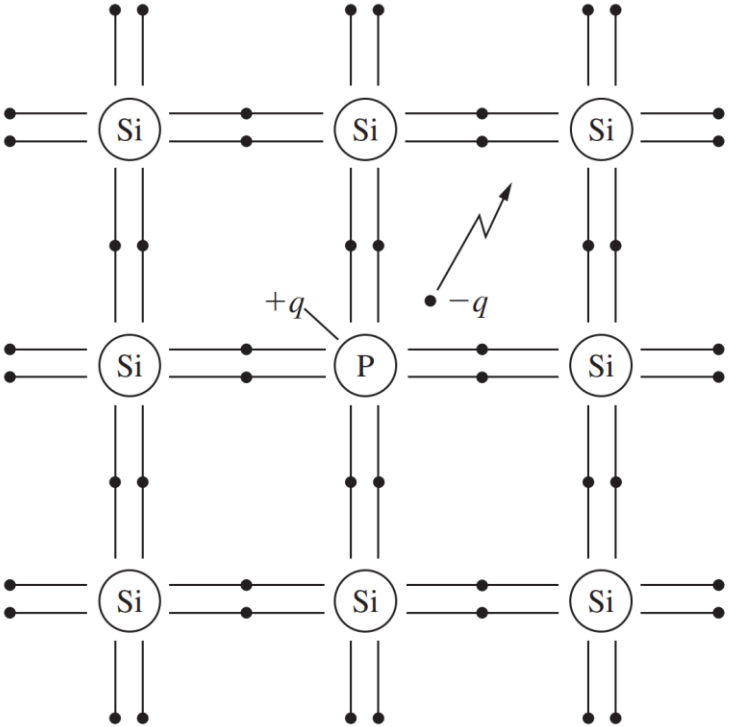
Silicio intrinseco e drogato

- A temperatura ambiente (23°C = 300K):
  - concentrazione intrinseca di elettroni e lacune: 7 10^{9} el./ cm^{3}=7,000,000,000 el./cm^{3}
  - concentrazione degli atomi di Si: 5 10^{22} atomi/ cm^{3}=500,000,000,000,000,000,000,000 atomi/cm^{3}
- Il silicio puro è quasi un **isolante …**
- … ma possiamo modificarne la conducibilità **drogandolo** con
  - **atomi accettori** (III colonna, e.g., Boro)
  - **atomi donatori** (V colonna, e.g. Fosforo, Arsenico, Antimonio)

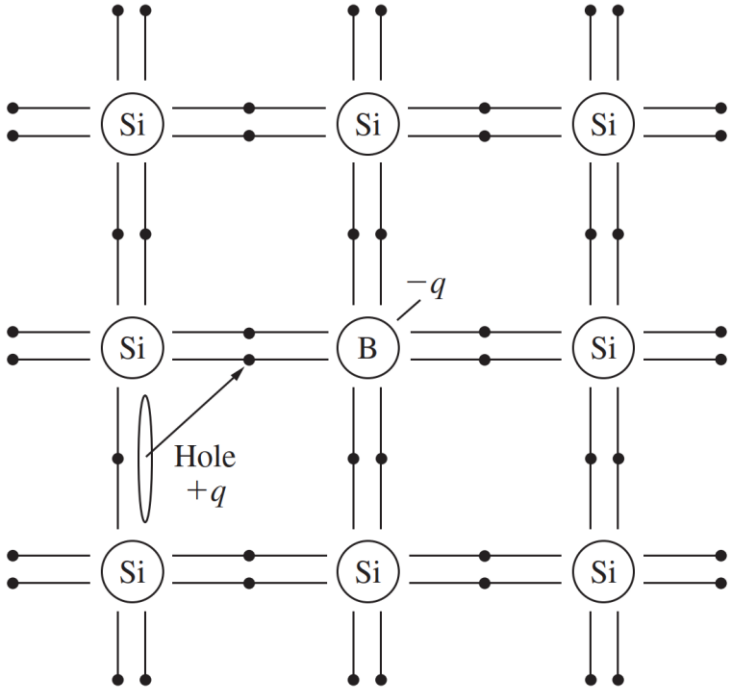
Il Silicio

		IIIA	IVA	VA	VIA
		5 10.811 **B** Boron	6 12.01115 **C** Carbon	7 14.0067 **N** Nitrogen	8 15.9994 **O** Oxygen
		13 26.9815 **Al** Aluminum	14 28.086 **Si** Silicon	15 30.9738 **P** Phosphorus	16 32.064 **S** Sulfur
IIB					
30 65.37 **Zn** Zinc	31 69.72 **Ga** Gallium	32 72.59 **Ge** Germanium	33 74.922 **As** Arsenic	34 78.96 **Se** Selenium	
48 112.40 **Cd** Cadmium	49 114.82 **In** Indium	50 118.69 **Sn** Tin	51 121.75 **Sb** Antimony	52 127.60 **Te** Tellurium	
80 200.59 **Hg** Mercury	81 204.37 **Tl** Thallium	82 207.19 **Pb** Lead	83 208.980 **Bi** Bismuth	84 (210) **Po** Polonium	

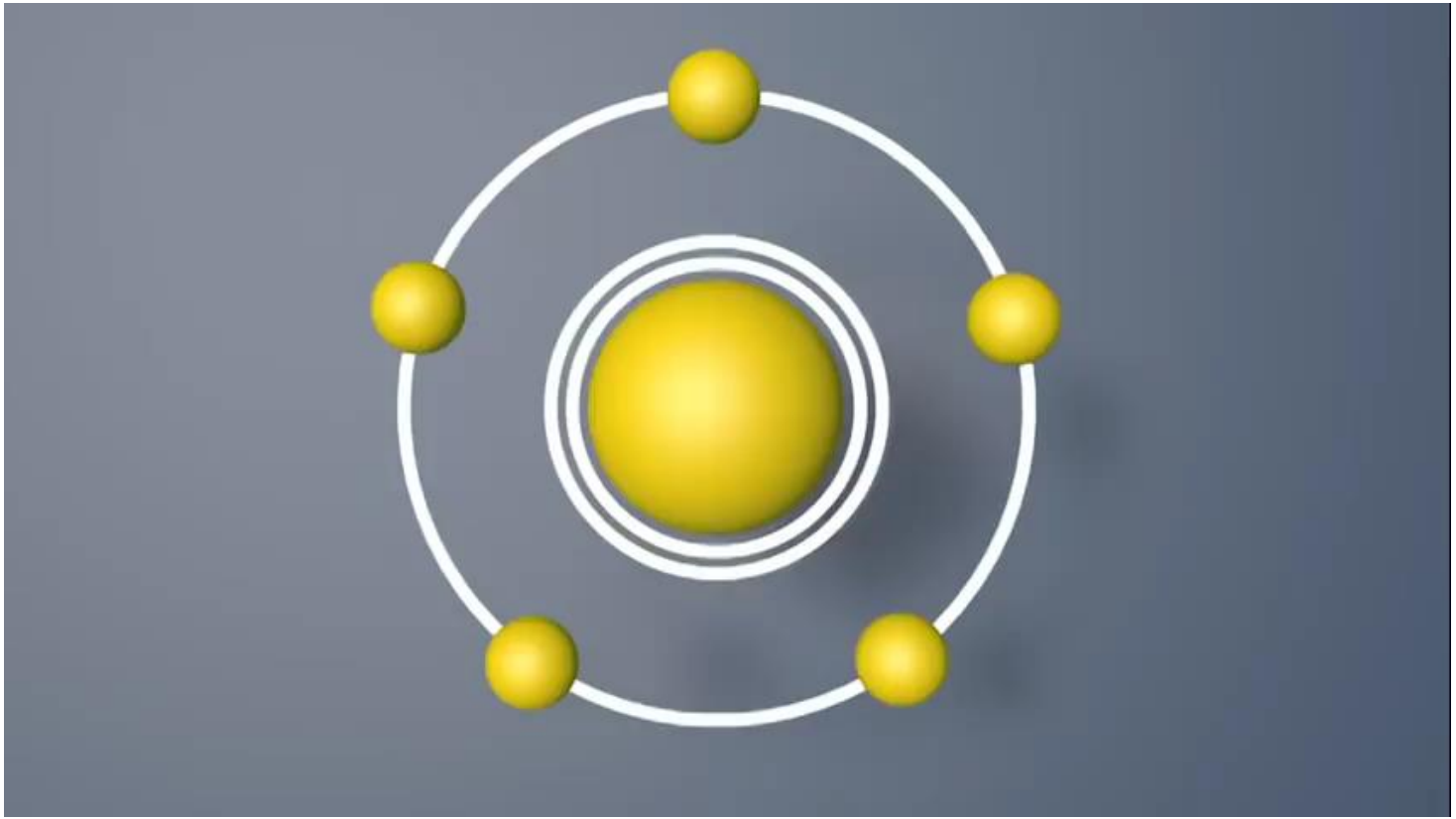
Il Silicio drogato n



Il Silicio drogato p

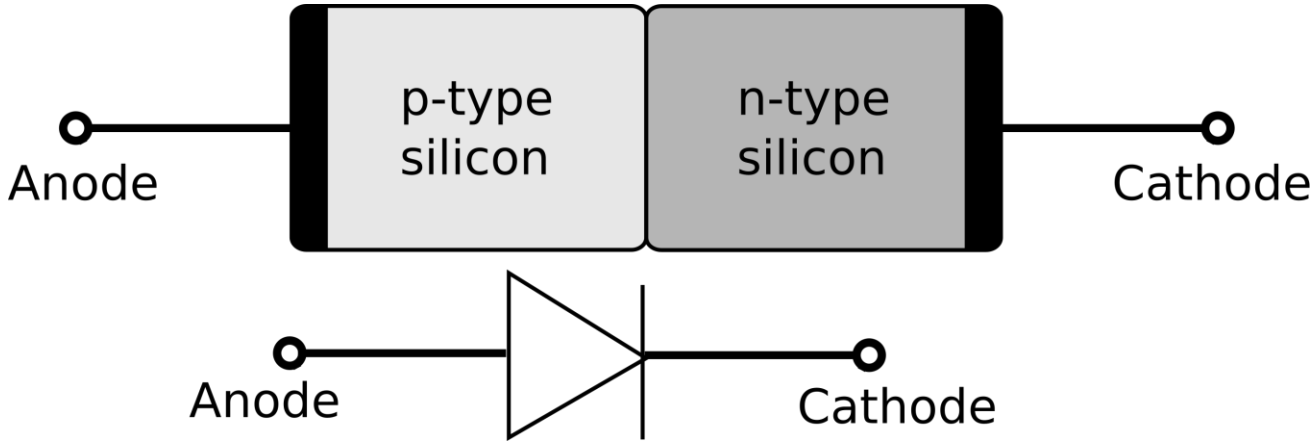


Il Silicio drogato n e p

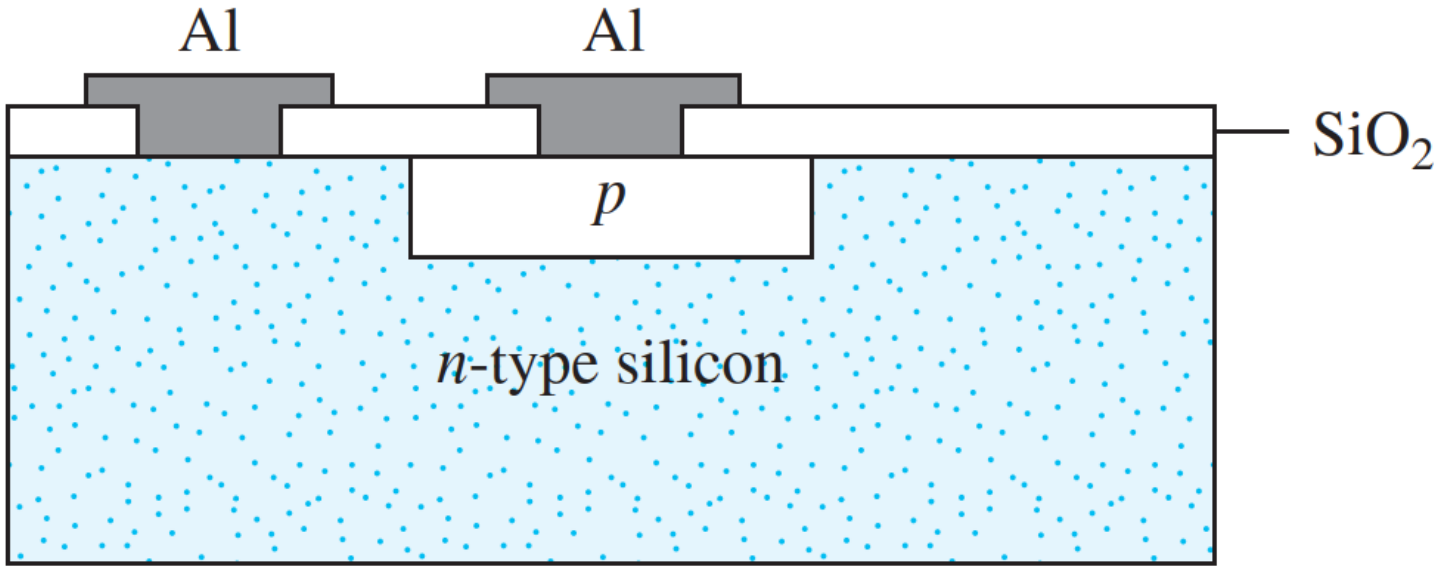


Tratto da: https://www.youtube.com/watch?v=bor0qLifjz4

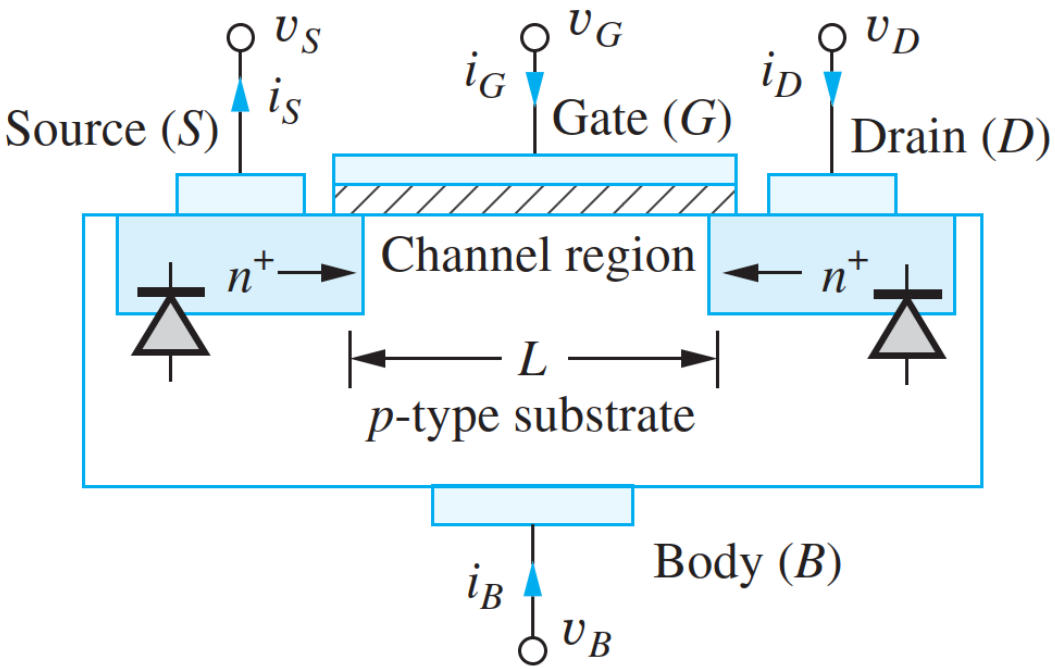
Giunzione pn - Diodo

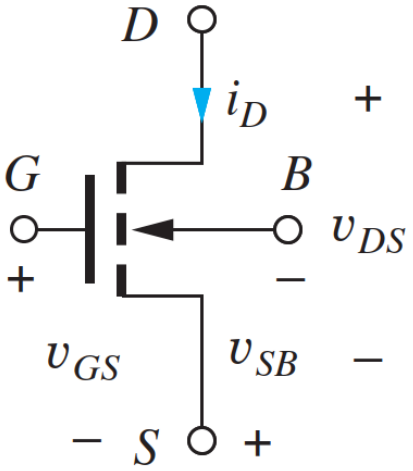


Giunzione pn - Diodo

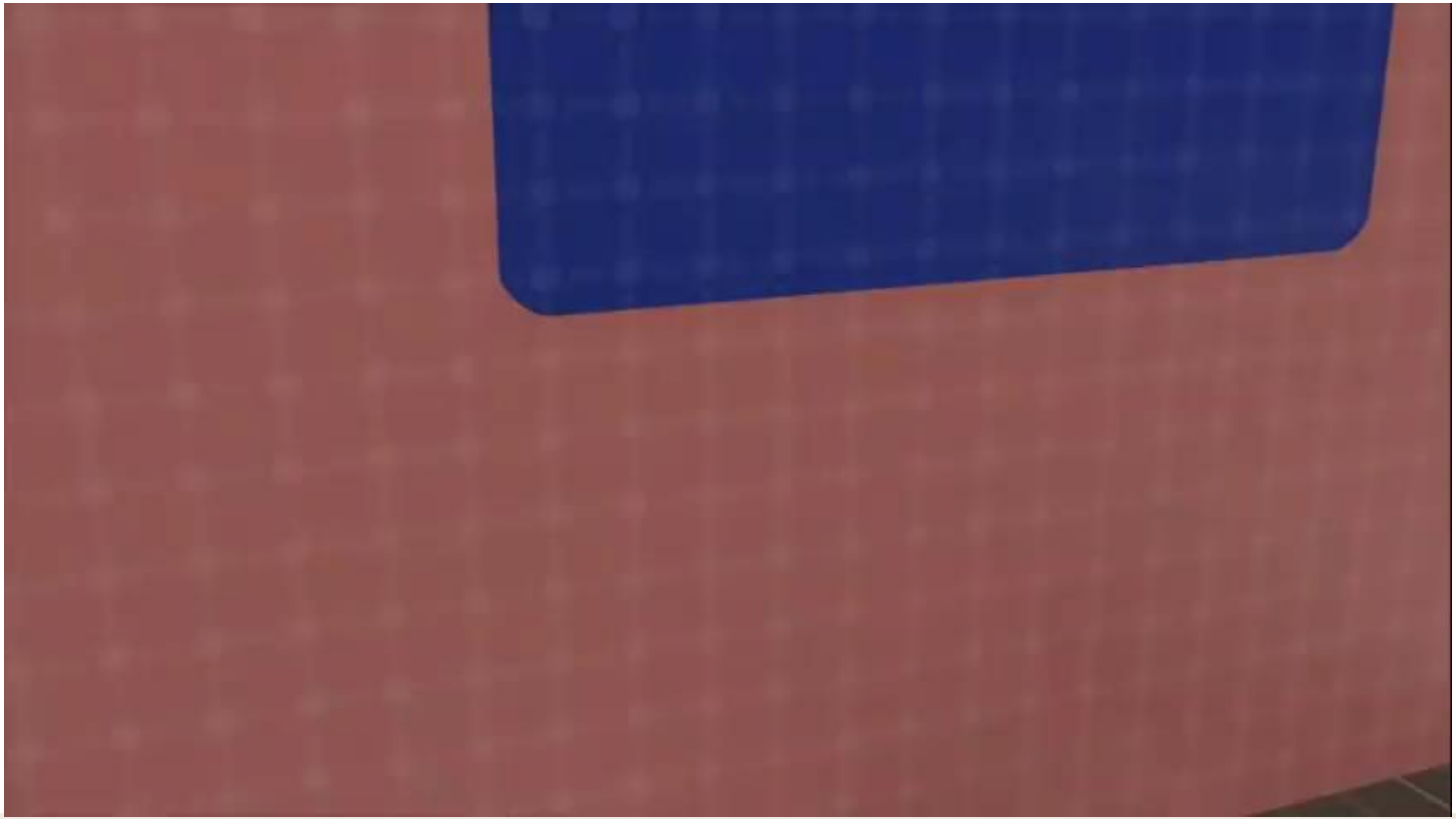


Il transistore MOS – Metallo Ossido Semiconduttore



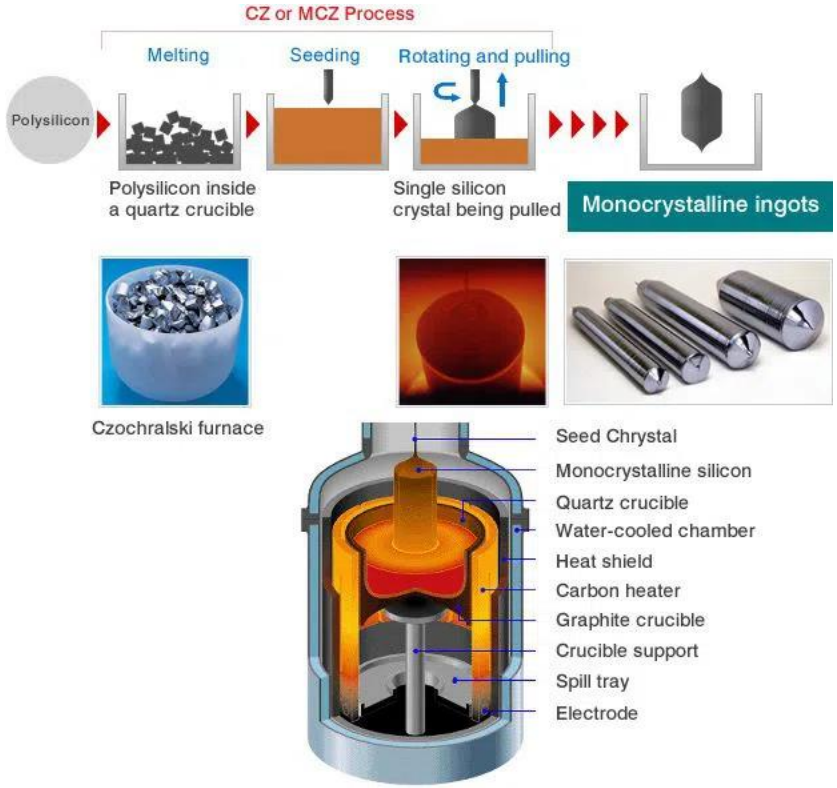


Il transistore MOS – Metallo Ossido Semiconduttore



Tratto da: https://www.youtube.com/watch?v=bor0qLifjz4

Dal silicio a un lingotto monocristallino



Tratto da: https://www.youtube.com/watch?v=xo-ir73TA_U

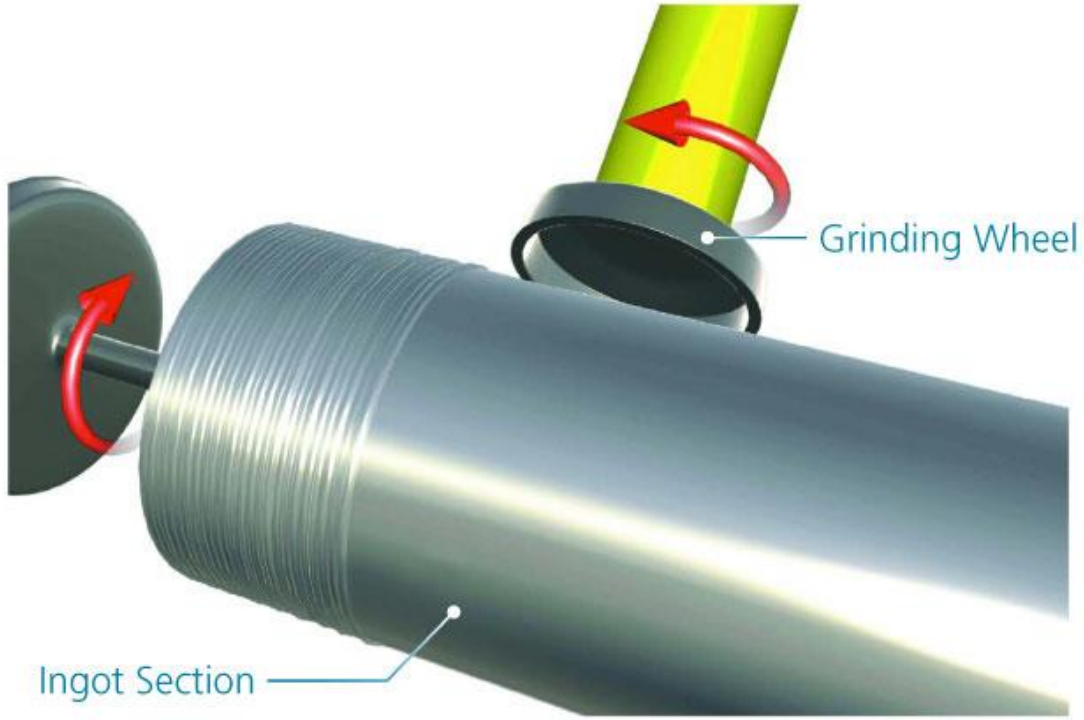
Dal silicio a un lingotto monocristallino

Tratto da: https://www.youtube.com/watch?v=xo-ir73TA_U

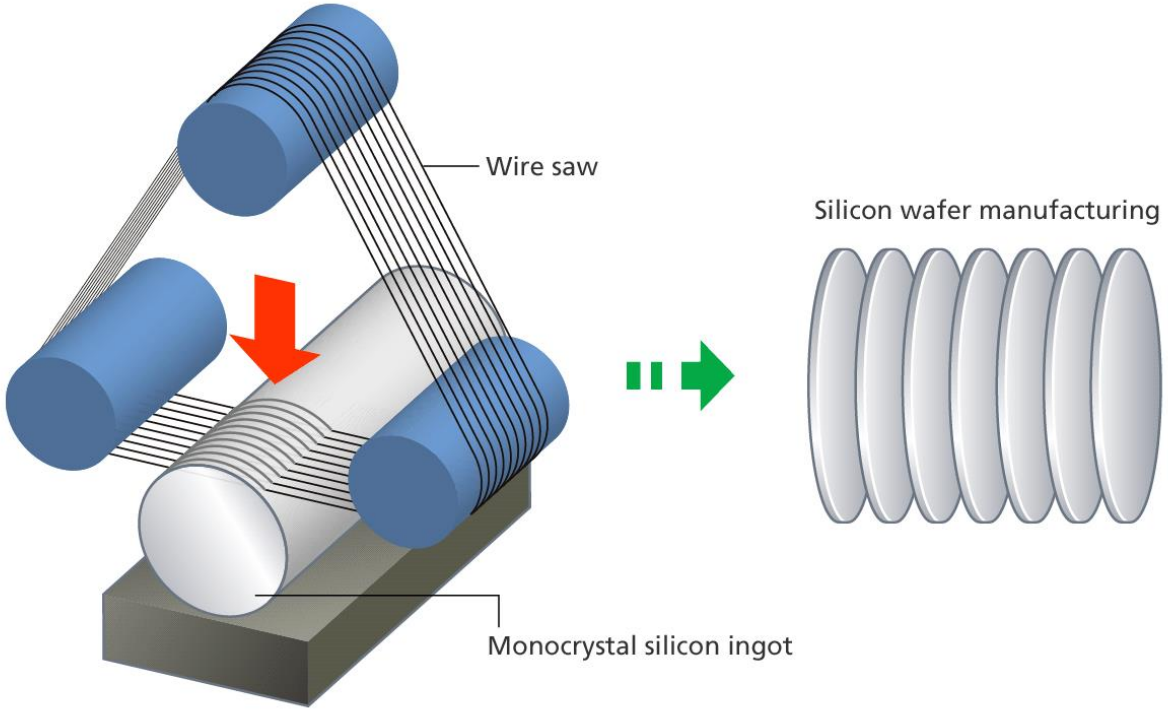
Il lingotto di silicio

Tratto da: https://www.youtube.com/watch?v=O2jrjiRe8cE

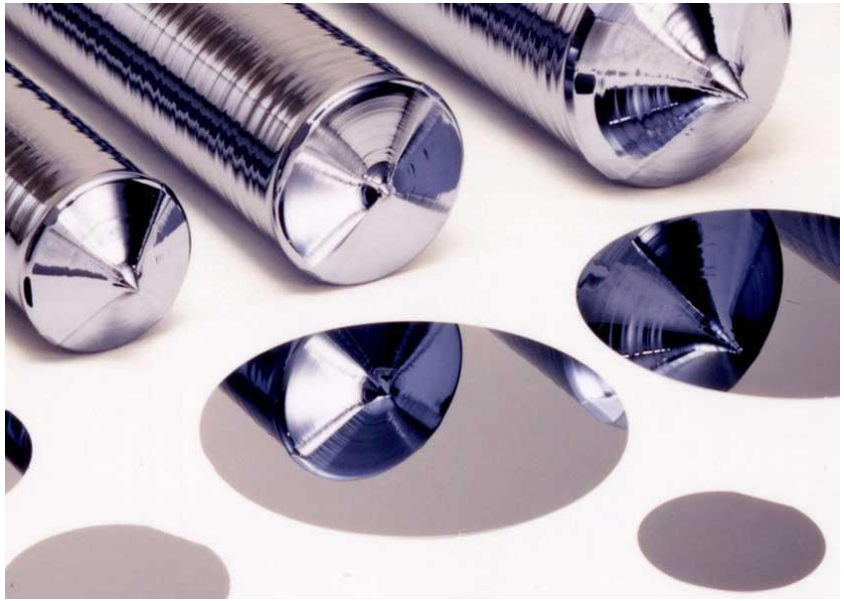
Il lingotto viene levigato



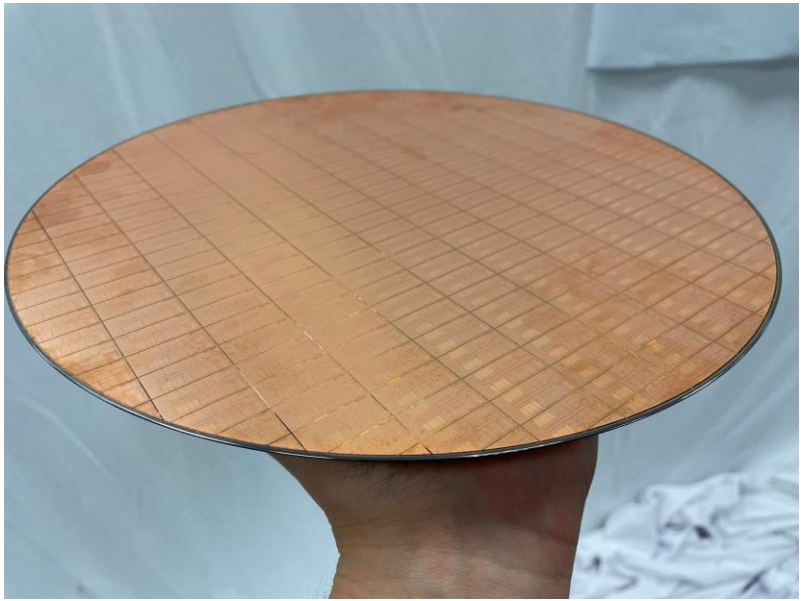
Il lingotto viene affettato



Produzione del wafer



Prima

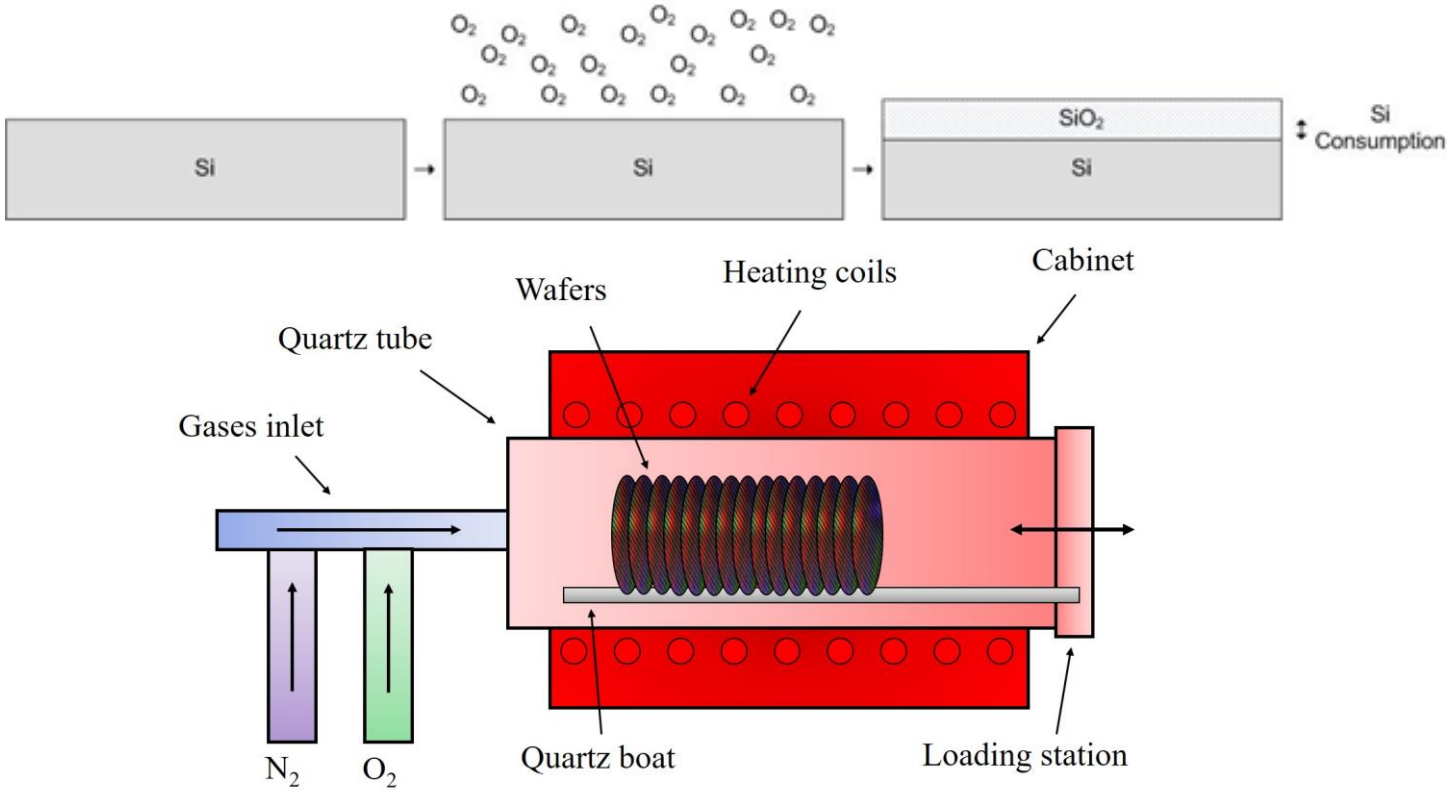


Dopo

Principali processi

- Ossidazione
- Fotolitografia
- Incisione (Etching)
- Deposizione
- Impiantazione ionica
- Ricottura (Annealing)

Ossidazione



Fotolitografia

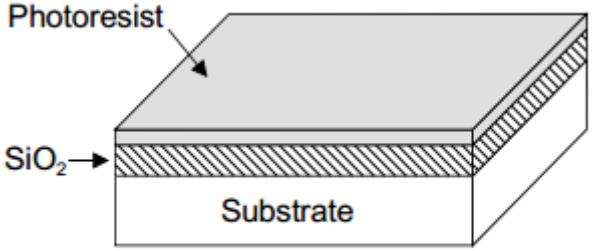
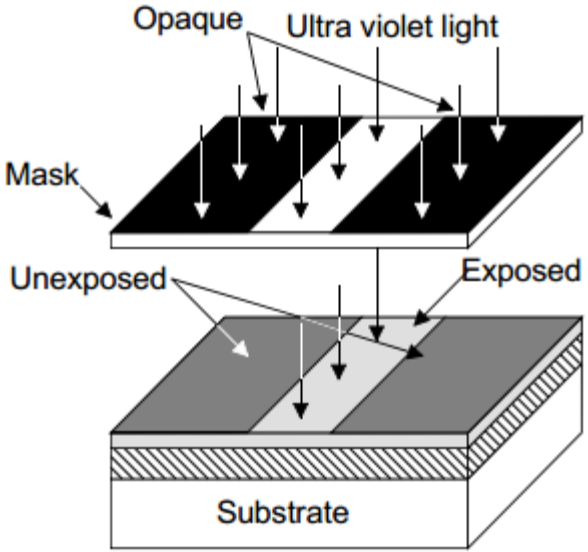
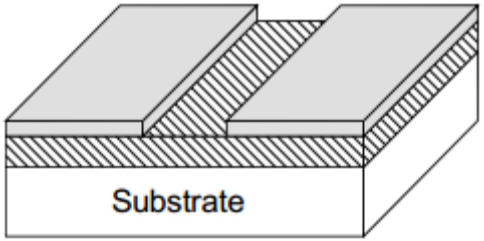


Photo Resist coating

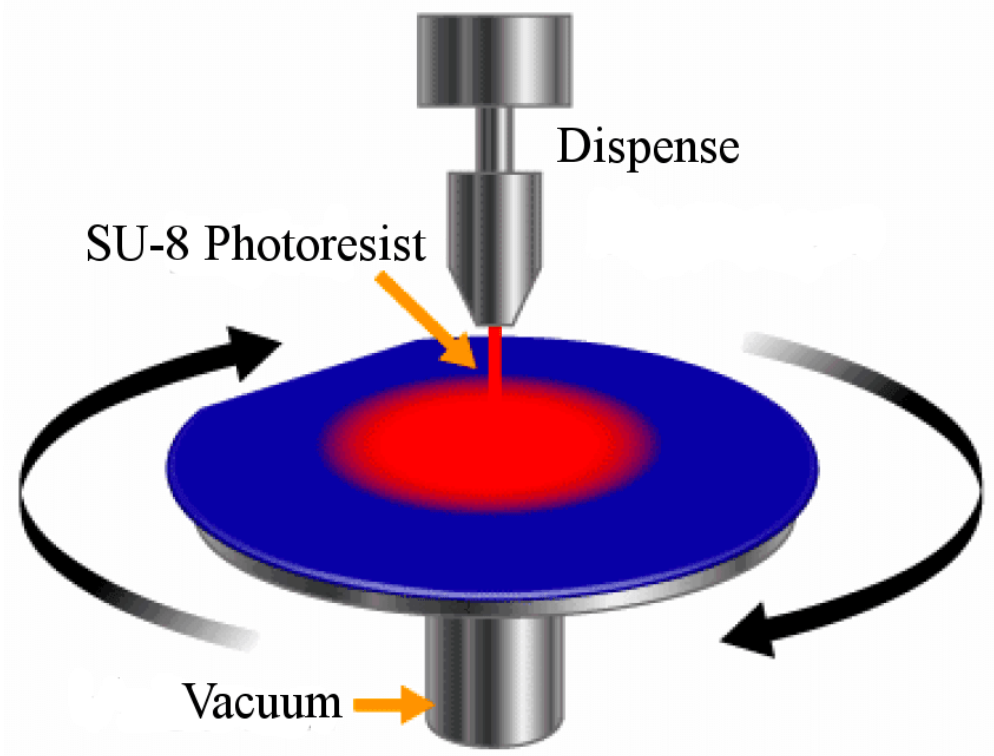


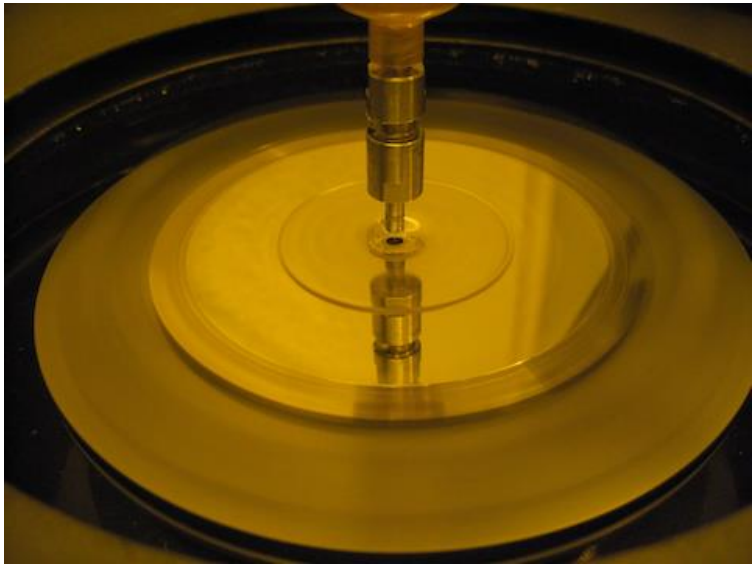
Exposure



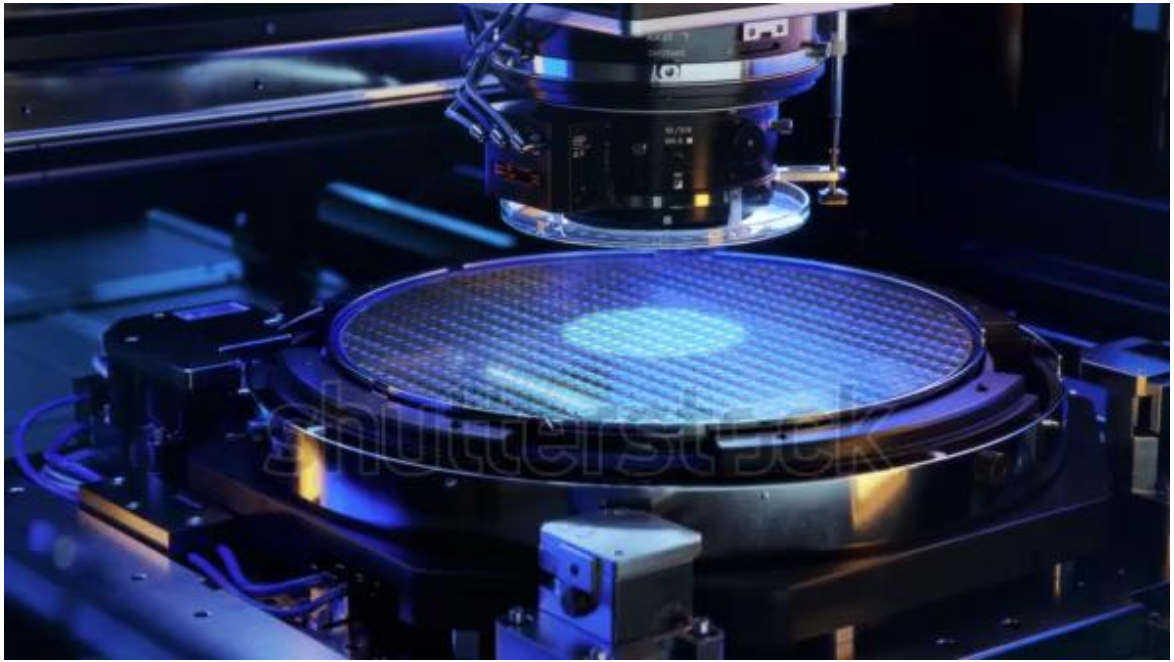
Development

Fotolitografia: deposizione del photoresist



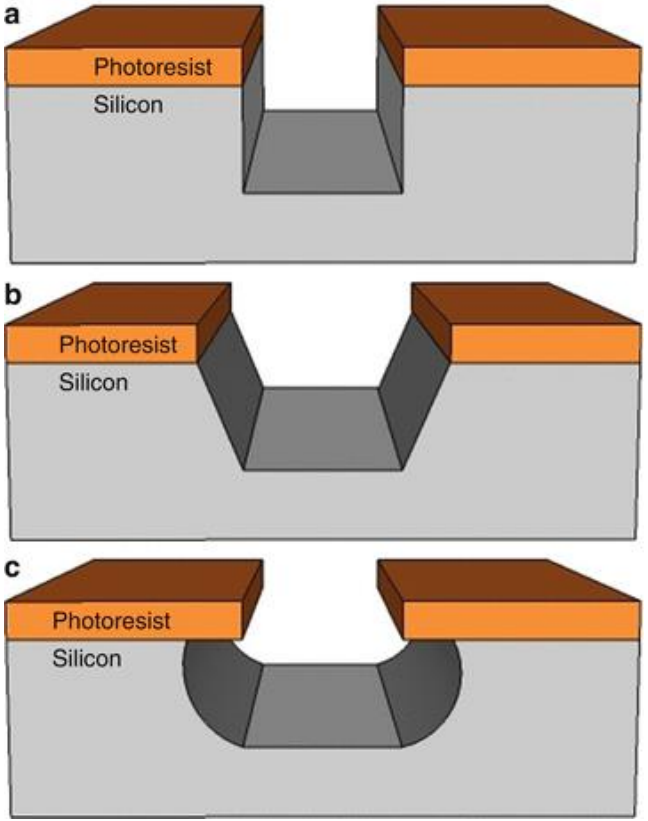


Litografia

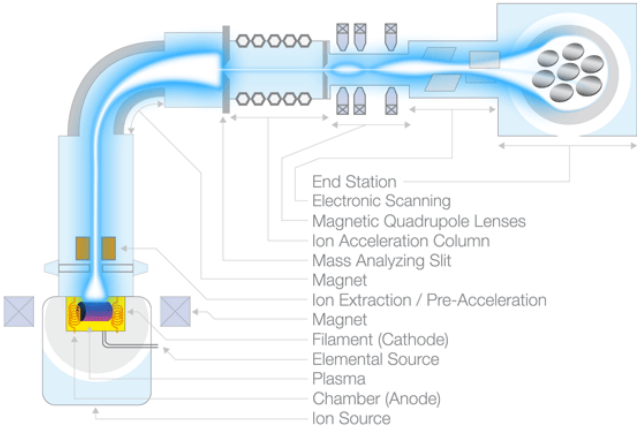


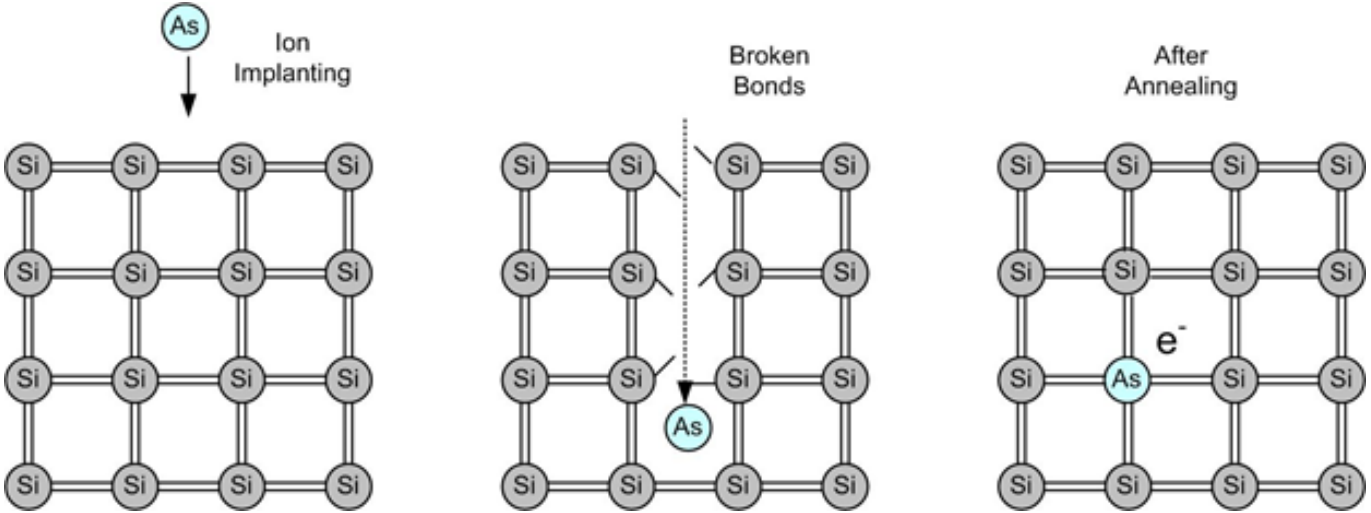
Litografia EUV – macchina ASLM (laser UV a 13,5 nm)

Etching

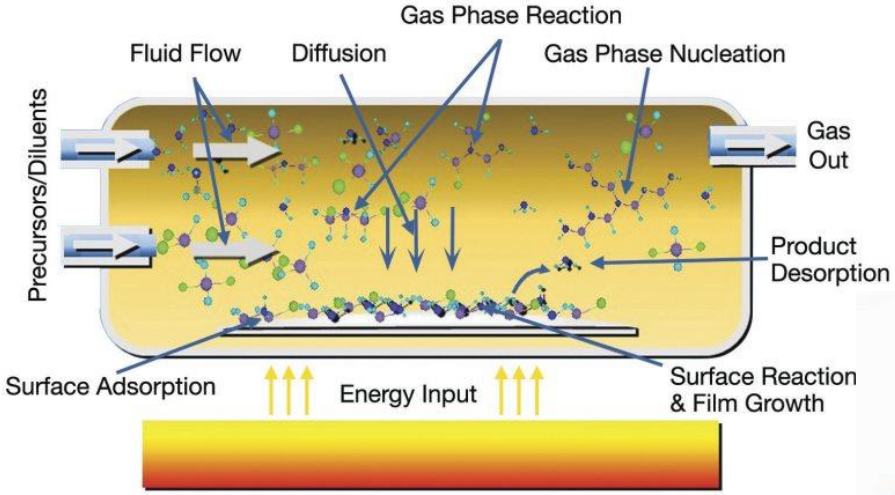

a
Photoresist
Silicon
b
Photoresist
Silicon
c
Photoresist
Silicon

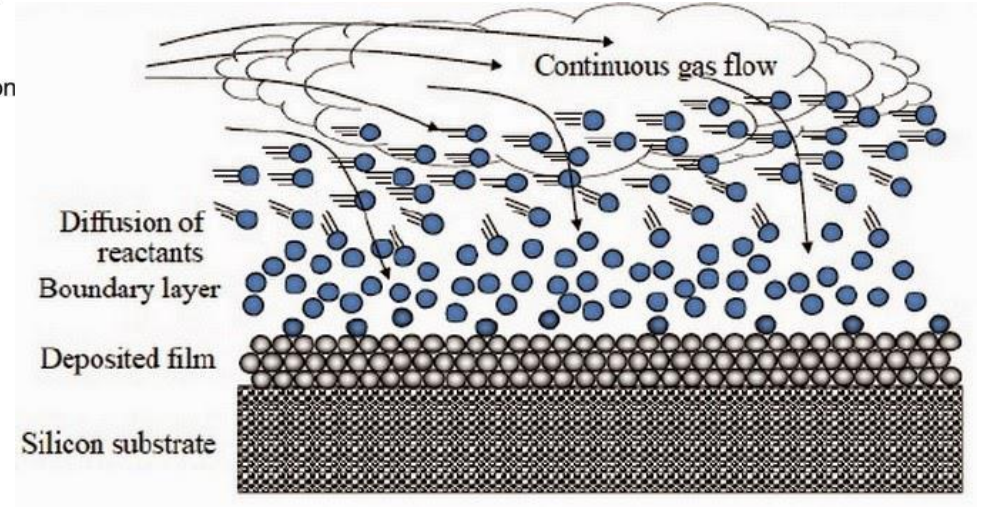
Impiantazione ionica



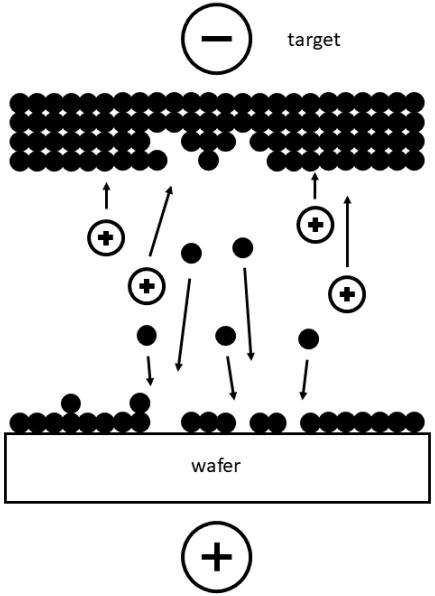


Deposizione mediante CVD

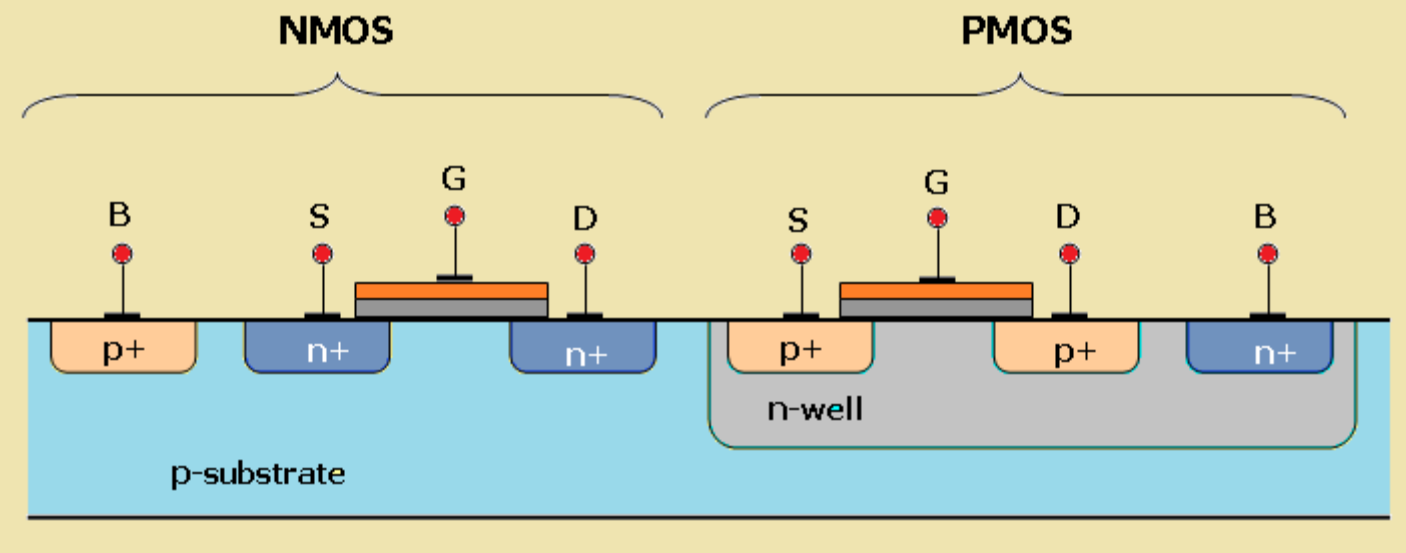




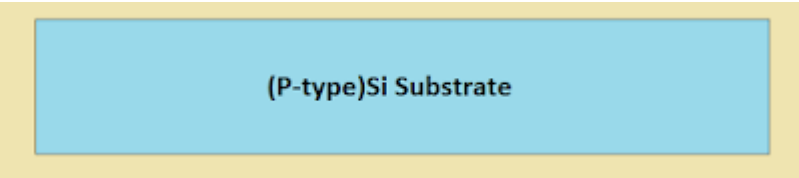
Metalizzazione - sputtering



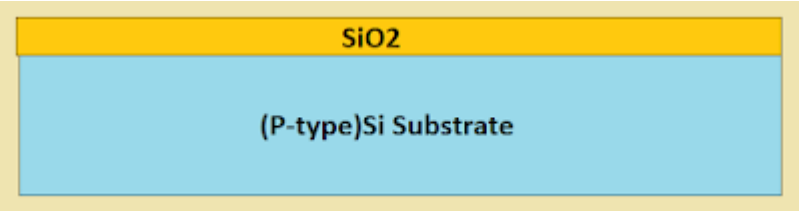
Il processo di fabbricazione CMOS



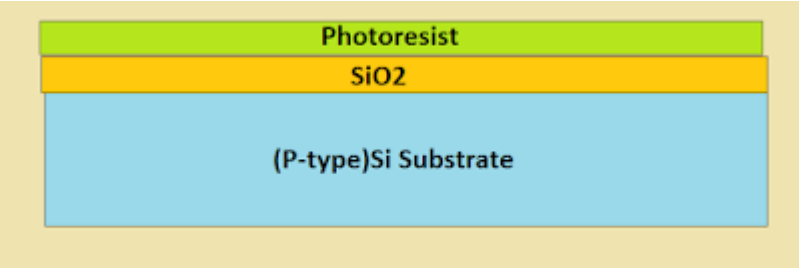
Il processo di fabbricazione CMOS



Il substrato

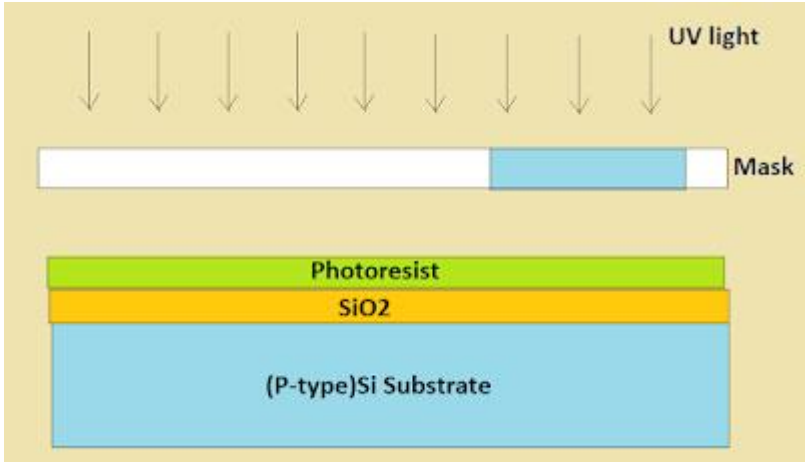


L'ossidazione

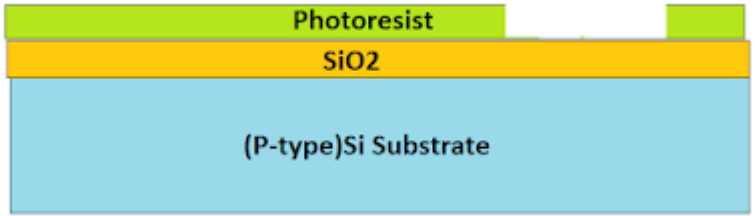


Il fotoresist

Il processo di fabbricazione CMOS

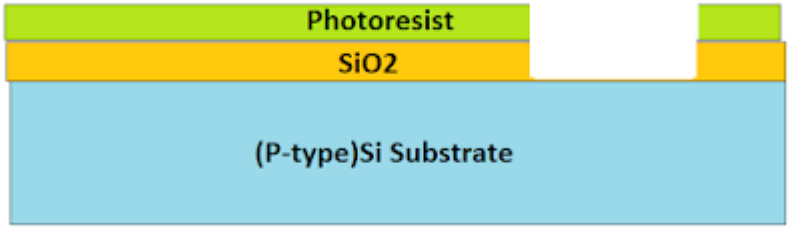


Maschera e
Irragiamento UV

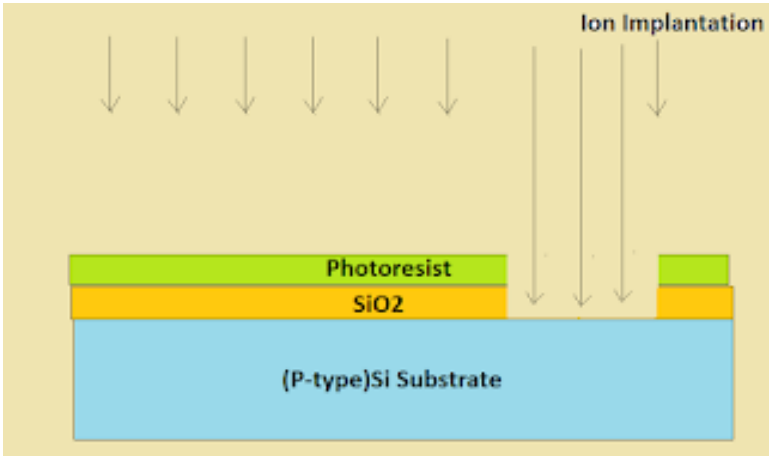


Rimozione del
fotoresist

Il processo di fabbricazione CMOS

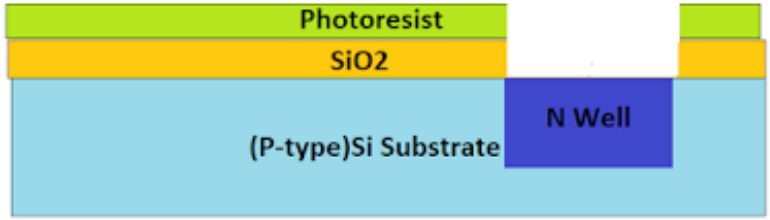


Etching SiO2

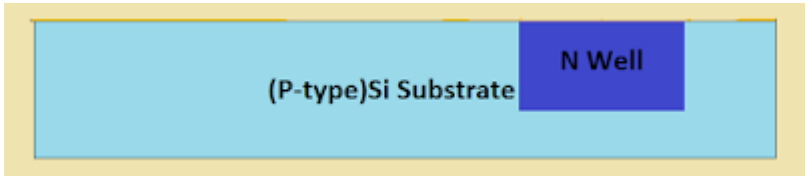


Impiantazione ionica

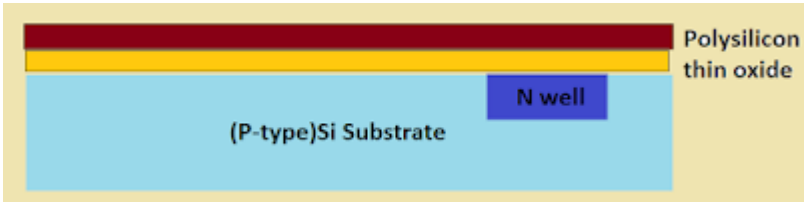
Il processo di fabbricazione CMOS



Formazione del N well

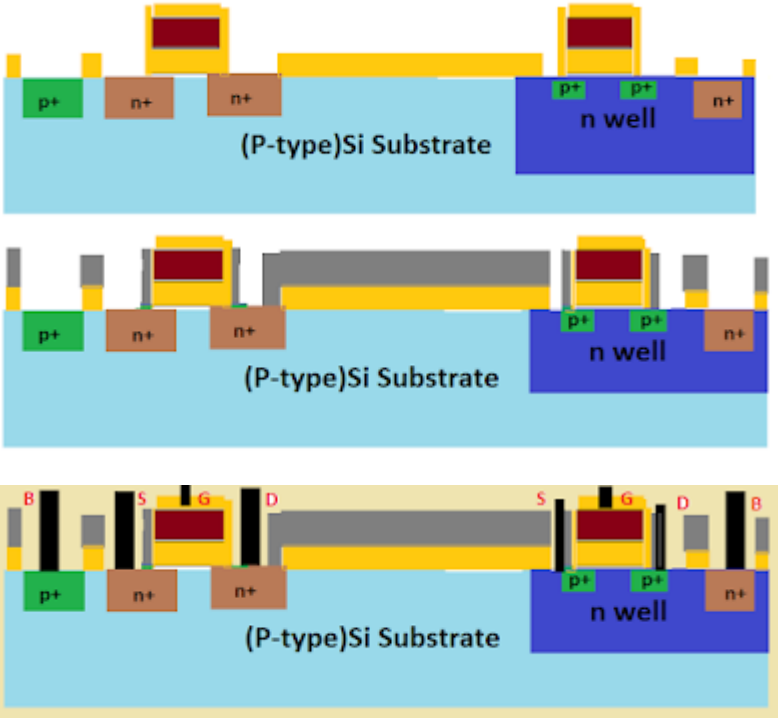


Rimozione del fotoresist e SiO2



Deposizione di uno strato sottile di SiO2 e di uno di polisilicio.

Il processo di fabbricazione CMOS



Impiantazioni N e P

Metalizzazione

Isolamento e contattazione.

UNIVERSITÀ DEGLI STUDI DI TRIESTE

Dipartimento di Ingegneria e Architettura

Grazie per l'attenzione!

Alberto Carini

Università degli Studi di Trieste
Dipartimento di Ingegneria e Architettura

acarini@units.it

dia.units.it