

PSI-3552 Fabricação e Caracterização de Dispositivos Nanoeletrônicos

Dopagem Implantação Iônica

Laboratório de
Microeletrônica
Escola Politécnica
Universidade de São Paulo

Prof. Roberto K. Onmori sala C2-70 (tel. 3091-5251)

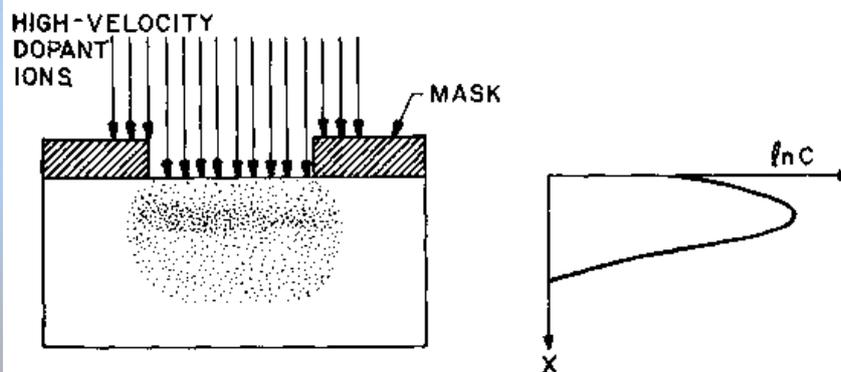
email: RKONMORI@LME.USP.BR

Prof. Fernando J. Fonseca sala C2-65 (tel. 3091-0730)

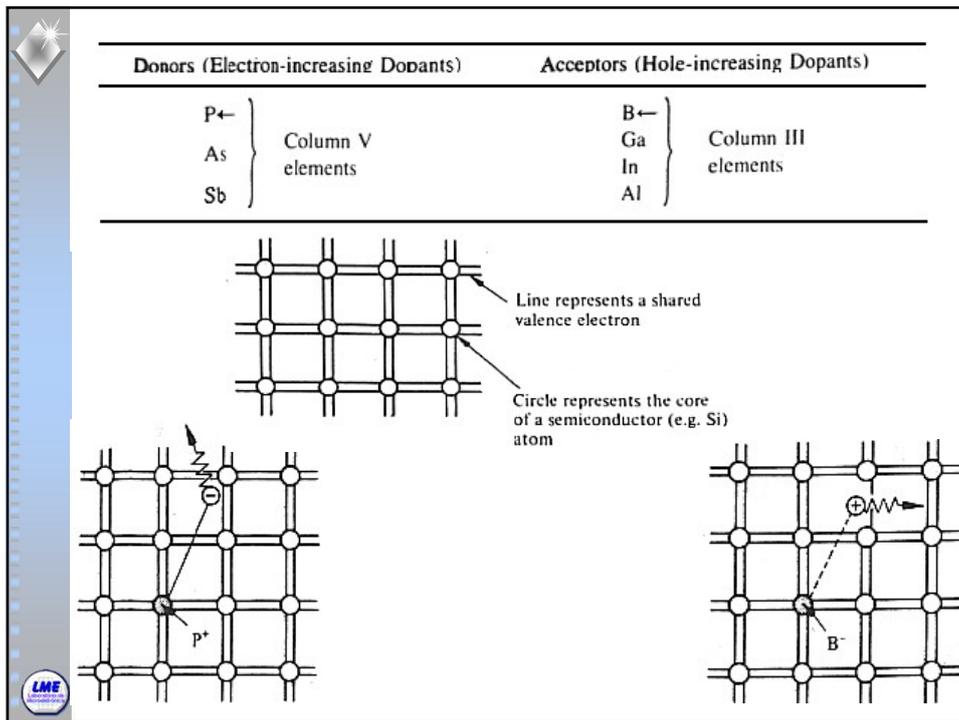
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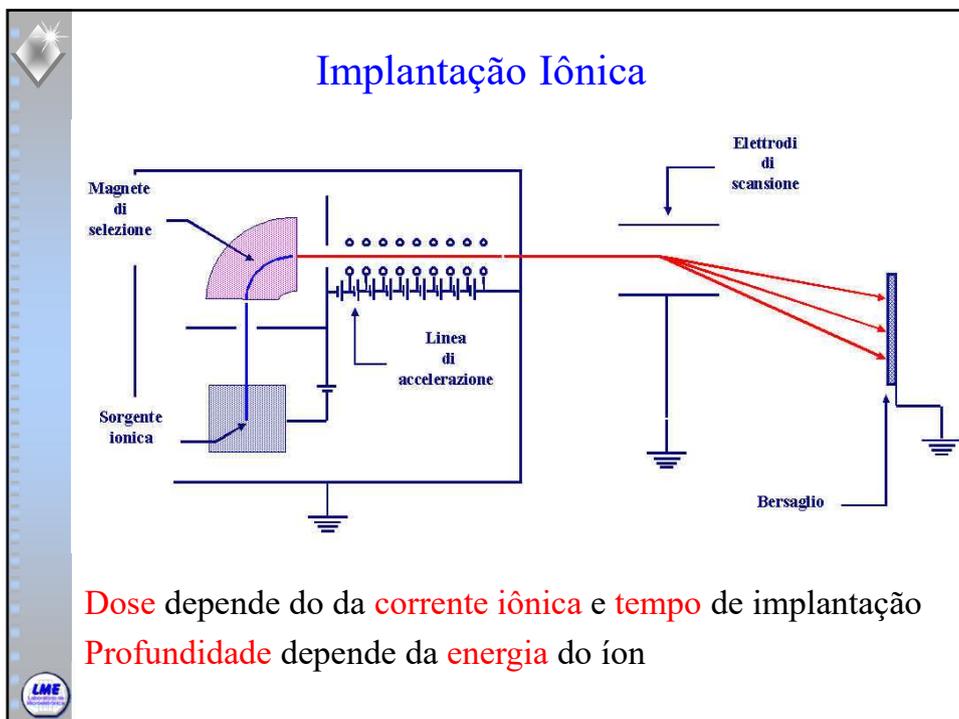
- A partir de 1970, o processo de dopagem passou a ser via implantação iônica com o seguinte aspecto:



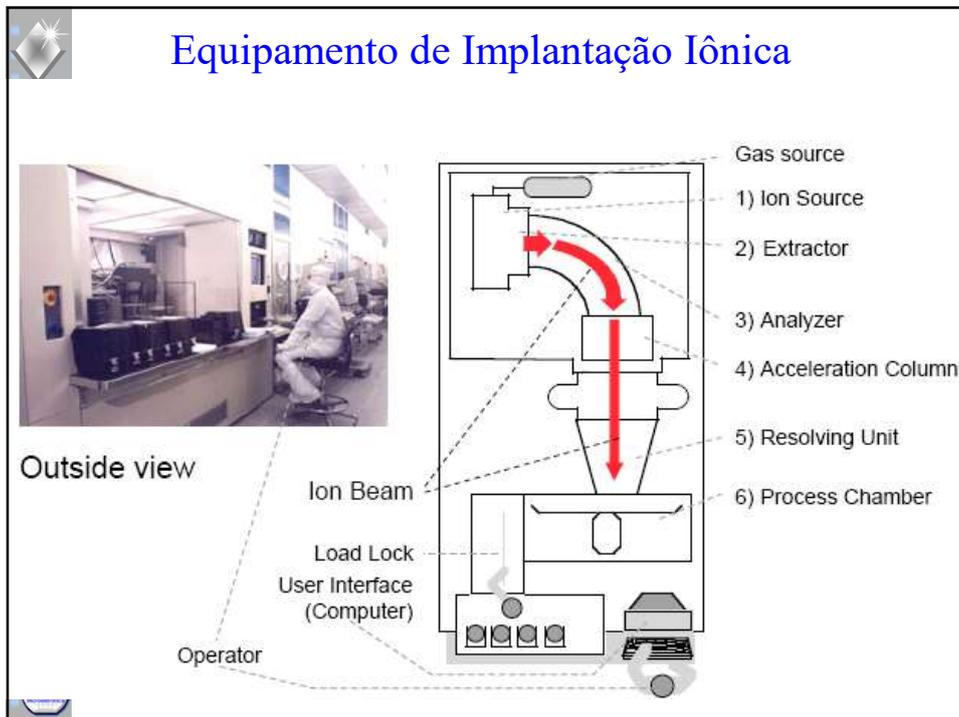
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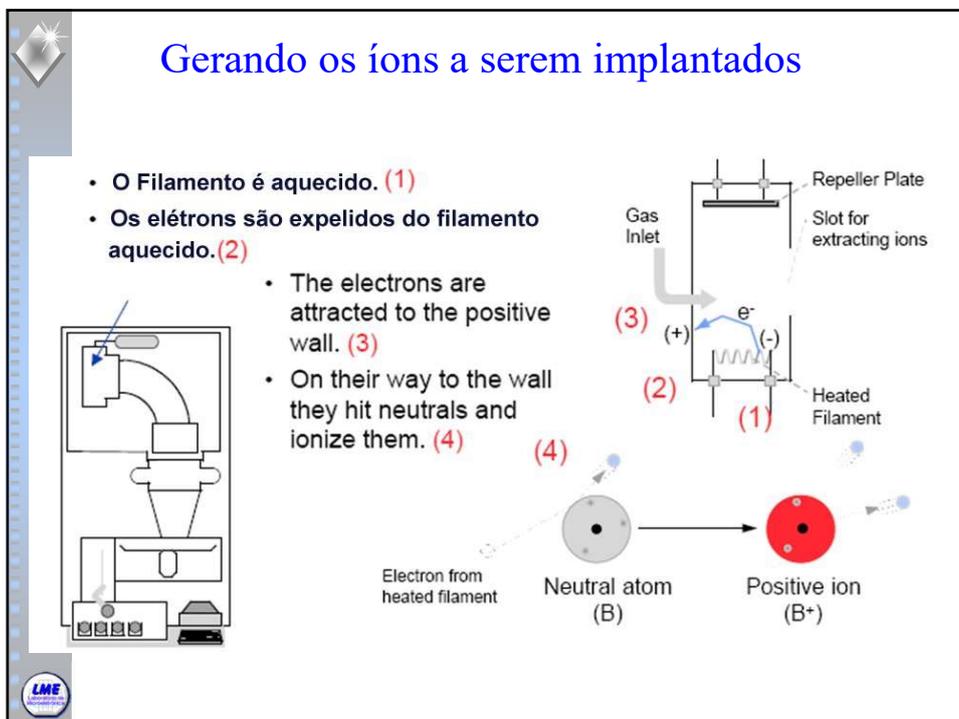
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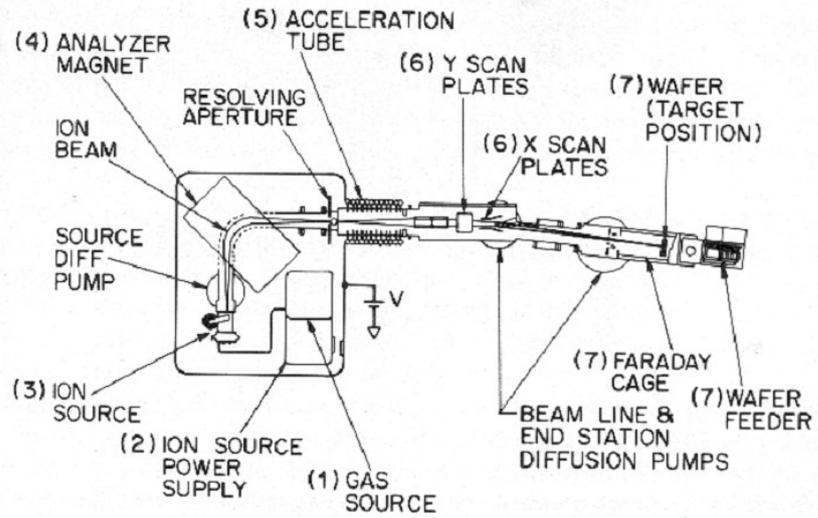


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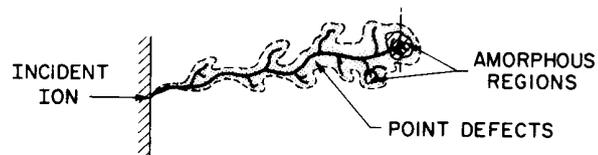
Implantação Iônica



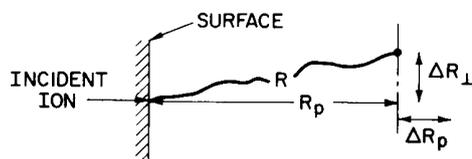
Schematic diagram of a typical commercial ion implant system.

7

Alcance do íon implantado

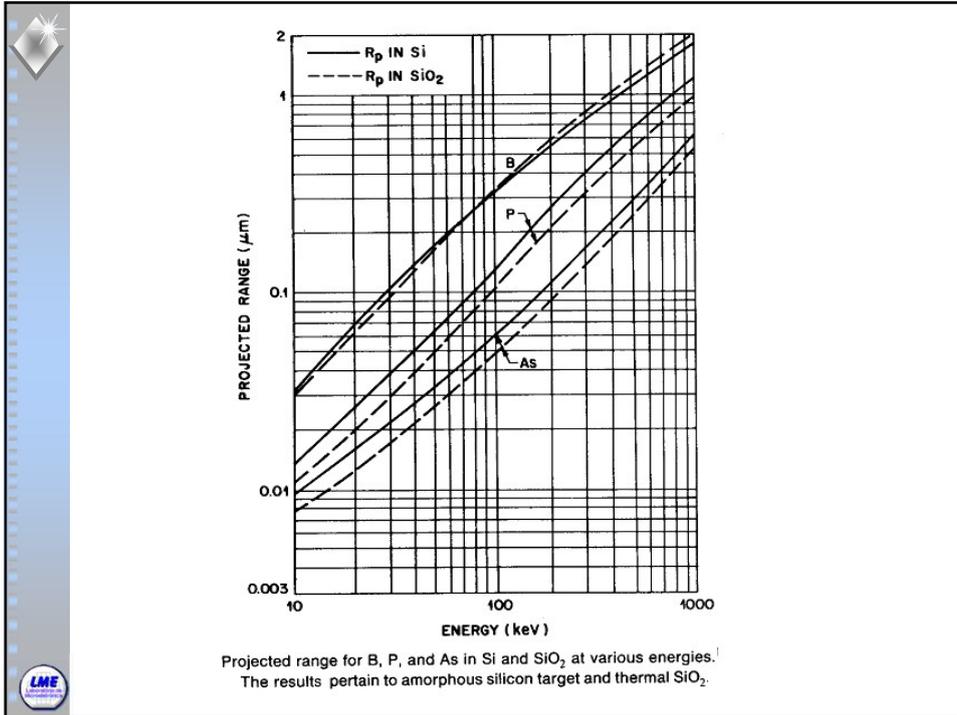


(a)



$$n(x) = n(R_p) \exp \left[\frac{-(x - R_p)^2}{2\Delta R_p^2} \right]$$

8



9

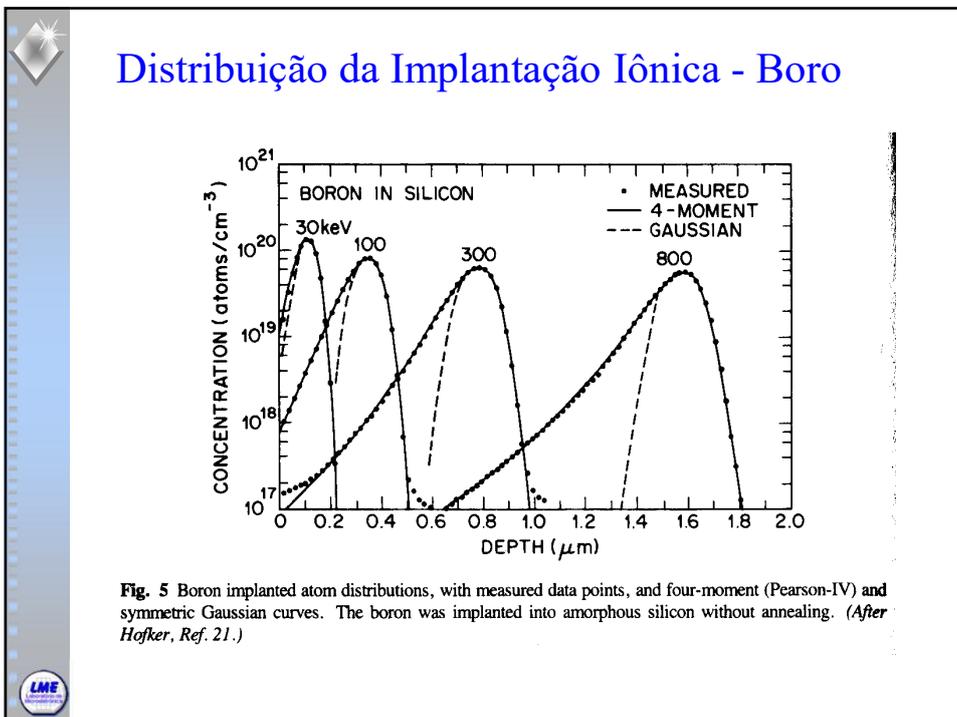


Fig. 5 Boron implanted atom distributions, with measured data points, and four-moment (Pearson-IV) and symmetric Gaussian curves. The boron was implanted into amorphous silicon without annealing. (After Hofker, Ref. 21.)

10

Destruição da rede cristalina

Some possible ions from BF_3 are shown here.

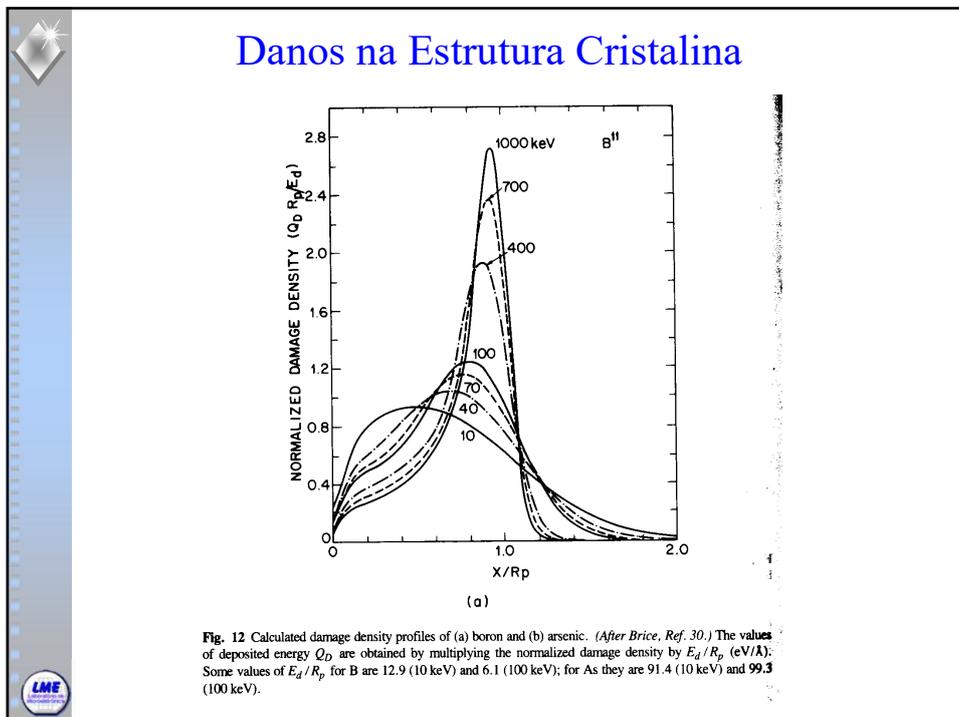
Electron from filament
Neutral Molecule BF_3

Beam of ions

Si Wafer

- Silicon is doped with boron, phosphorous and arsenic by ion implantation
- Ions from the ion beam damage the lattice.

11

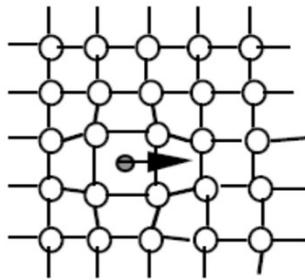


12

Ativação elétrica dos íons implantados

Intersticial

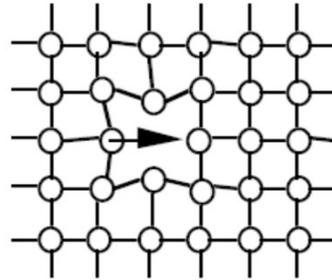
O, Cu, Au, Fe, Ni



$E_A \approx 0.5 - 1 \text{ eV}$

Substitucional

P, B, As, Al, Ge, In



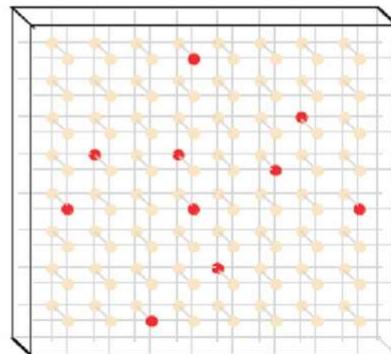
$E_A \approx 3 - 4 \text{ eV}$

13

Annealing (Tratamento térmico)

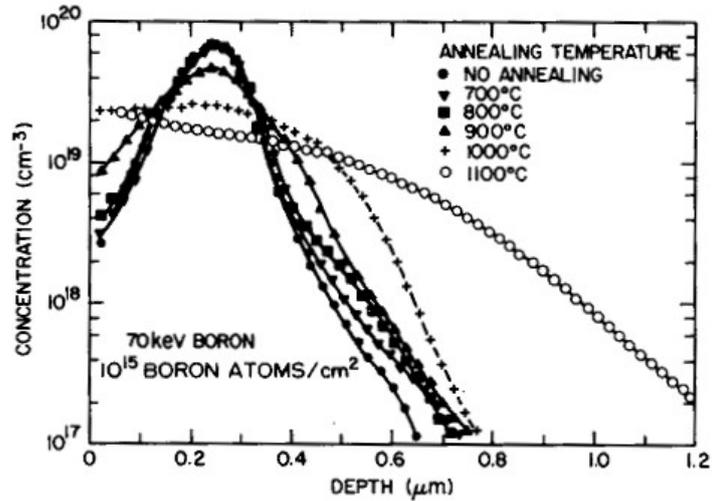


- Annealing is a process where the wafer is heated to repair the damage to the lattice
- The dopant ions become part of the crystal lattice (Activation)
- The ions also spread out during anneal (Diffusion)



14

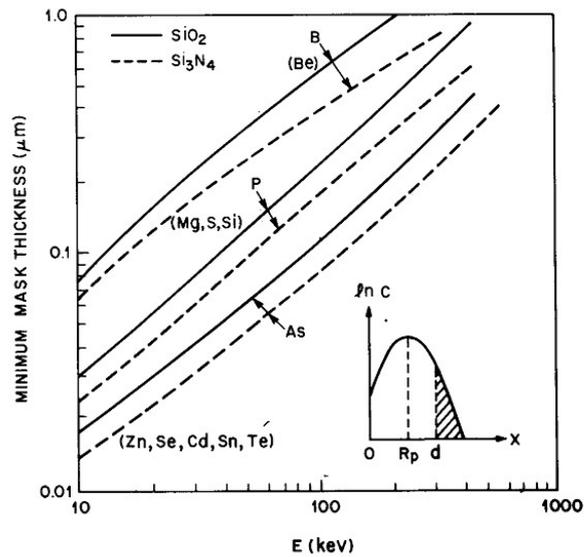
Annealing



Boron atom concentrations as a function of annealing at various temperatures. The anneal time is 35 minutes. (After Hofker, Ref. 21.)

15

Proteção contra a Implantação Iônica

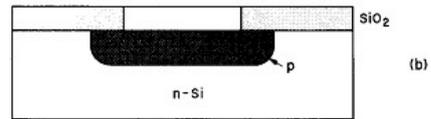
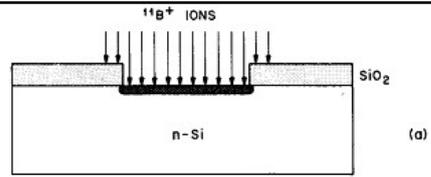


Minimum thickness of SiO_2 and Si_3N_4 for a masking effectiveness of 99.99%.
Insert shows ion penetration beyond a depth d .

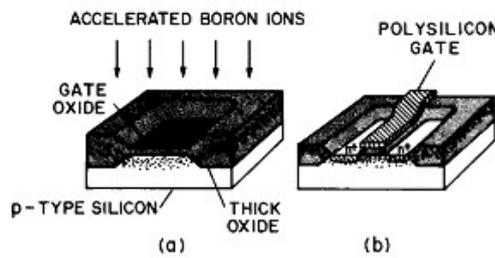
16

Usos

- Ajuste na tensão limiar V_{th} de um transistor MOS
- Dopagem nos contatos de Gate de um MOSFET



(a) Predeposition using ion implantation. (b) After drive-in diffusion.



Threshold voltage adjustment using boron ion implantation.²⁹

17

Parâmetros de Implantação

Equipamento:

Resultado:

tempo
corrente
energia
ângulo

dose
profundidade
uniformidade

18

Channeling (Canalização)

• Ions in beam 3 will hit the atoms or bonds in the lattice and stop early.
Cargas no processo de Implantação

Wafer surface

(100) tilted

(1) (2) (3)

(100)

(110)

(111)

LME

19

Cargas no processo de Implantação

Target
 Electrons from filament (1)
 Filament
 Electrons from target (2)
 (3)
 Positively charged wafer

LME

20

Contaminantes

- Podem vir de:
- • Metálicos – impactos nas paredes....
 - Fe, Cr, Ni.
- • resíduos – várias espécies de dopantes (P, As, B...)
- • Na, Ca, Mg,
- • Óleo da Bomba difusora, carbono, oxigênio, nitrogênio...

21

Modelo para 1 D

$$\frac{\partial C(x,t)}{\partial t} = -\frac{\partial J(x,t)}{\partial x} \quad \& \quad J = -D \frac{\partial C(x,t)}{\partial x}$$

$$G_n = R_n = 0$$

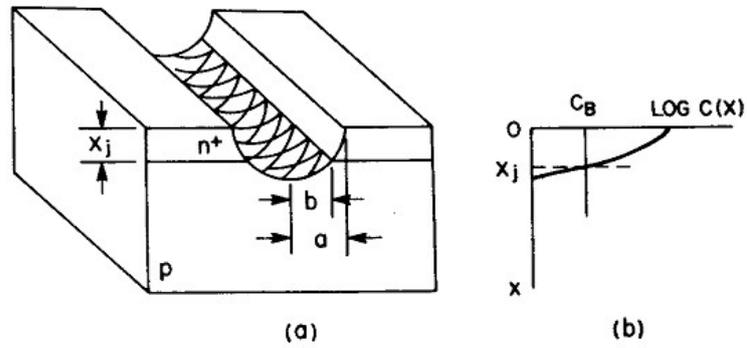
Fick's diffusion equation. $\frac{\partial C(x,t)}{\partial t} = D \frac{\partial^2 C(x,t)}{\partial x^2}$

diffusion coefficients $D = D_o \exp \left[\frac{-E_a}{kT} \right]$

Necessita de 1 condição inicial e 2 condições de contorno

22

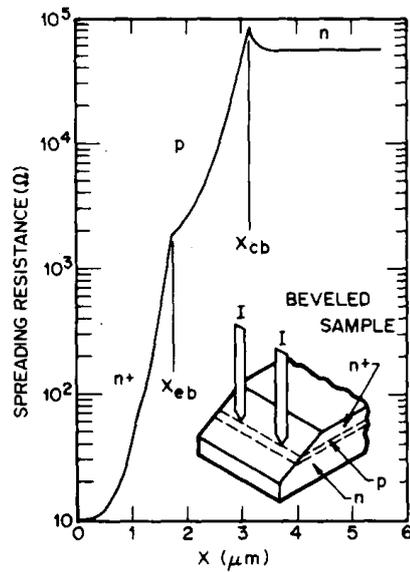
Medida de Profundidade de Junção



Junction depth measurement by grooving and staining.

23

Spread Resistance Probe



The spreading resistance profile of an n-p-n transistor structure.
 x_{eb} = the emitter-base junction depth = 1.7 μm ; x_{cb} = the collector-base junction depth = 3.2 μm .

24