

# PSI-3552 Fabricação e Caracterização de Dispositivos Nanoeletrônicos

## Aula 02 - Oxidação Térmica

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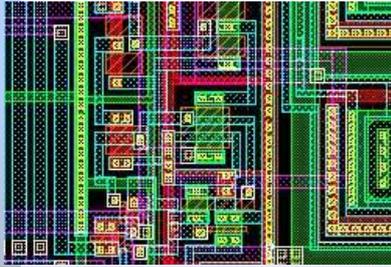
## Introdução

- Uso de diferentes tipos de filmes - 4 grupos:
  - Óxidos térmicos
  - Camadas dielétricas
  - Silício Policristalino e
  - Metais.

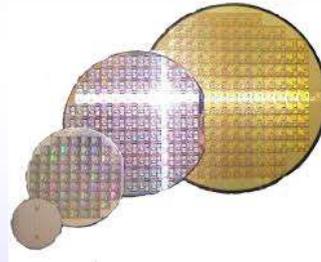
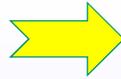


## Na fabricação dos CIs:

O projetista de Circuitos Integrados **gera um desenho** com regiões com condutividades diferentes a serem gravadas sobre a lâmina de Silício!



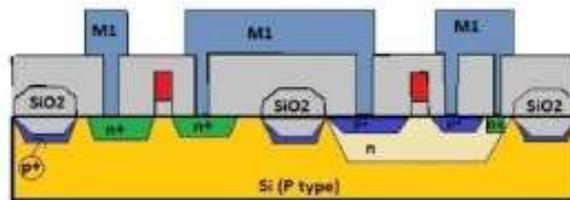
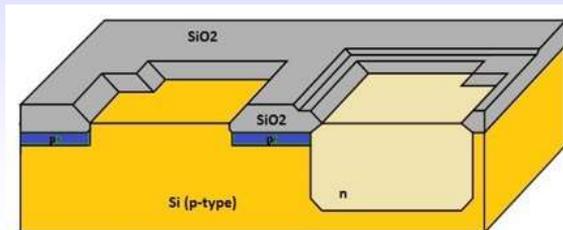
Projeto de CI

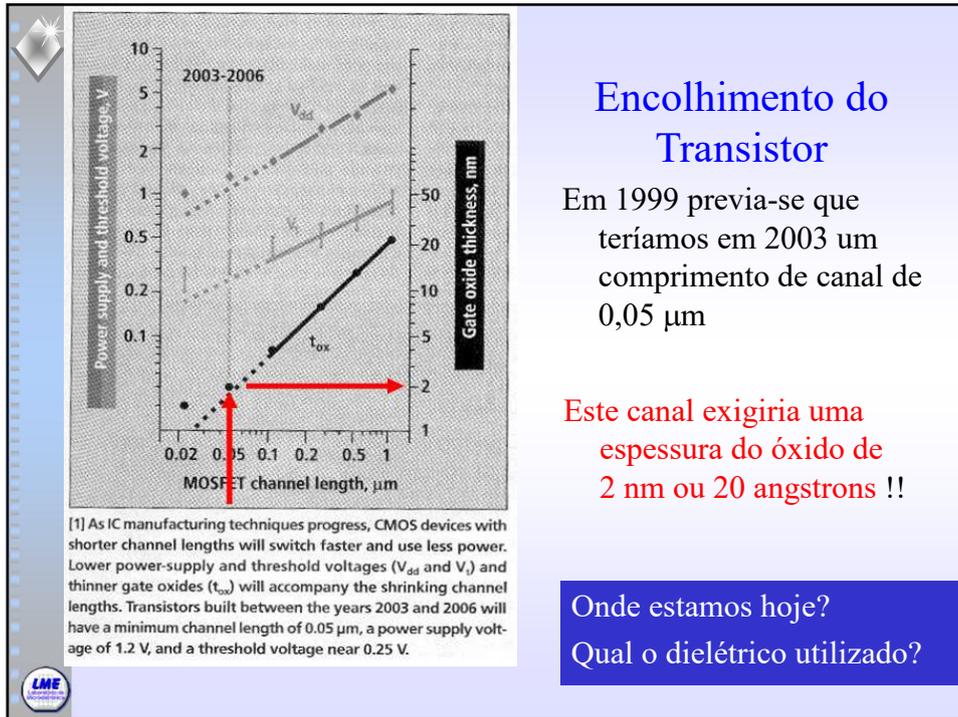


CI sobre o Silício



O projeto do CI exige a definição de regiões N e P



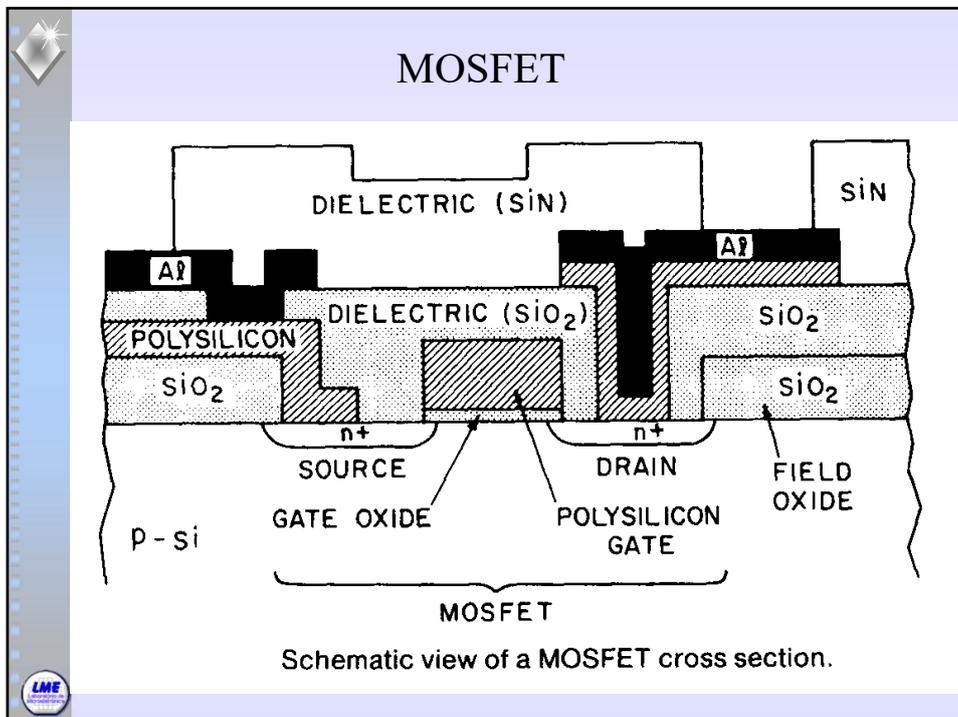


## Encolhimento do Transistor

Em 1999 previa-se que teríamos em 2003 um comprimento de canal de 0,05 μm

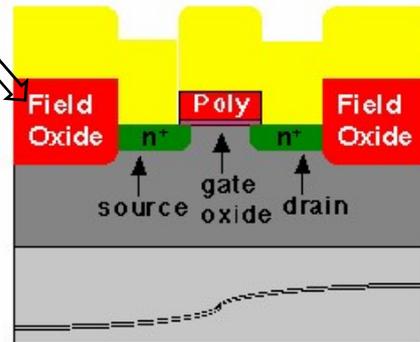
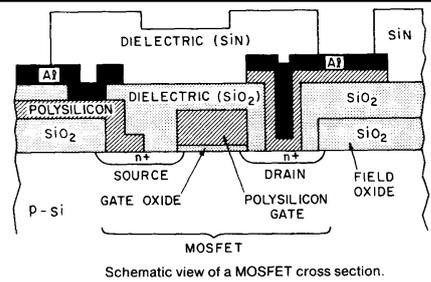
Este canal exigiria uma espessura do óxido de 2 nm ou 20 angstroms !!

Onde estamos hoje?  
Qual o dielétrico utilizado?



## Oxidação

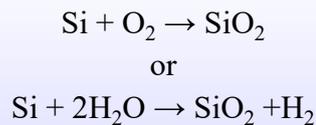
- Various oxides are grown or deposited to insulate or protect the formed transistors
- Deep Field Oxides are grown to isolate each transistor from its adjacent partners
- Dielectric isolation oxides are deposited to insulate the transistors from the interconnecting layers which will be built above
- Passivation oxides are later deposited on top of completed wafers to protect the surface



## Tipos de Oxidação

- Vários tipos de oxidação:
  - Térmica
  - Anodização eletroquímica
  - Deposição e
  - Reação por plasma

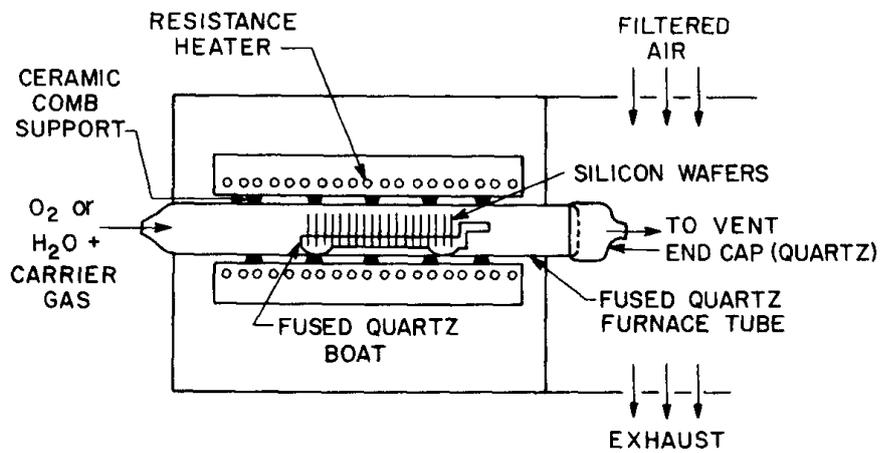
Depois de limpas através da limpeza RCA, as lâminas de silício são colocadas em um forno a alta temperatura ( $900^{\circ}\text{C} < T < 1200^{\circ}\text{C}$ ) na presença de oxigênio ou água, onde ocorre a seguinte reação:



A espessura do óxido pode se prevista através de um controle preciso da temperature e do tempo de oxidação.



## O Forno de Oxidação



Schematic cross section of a resistance-heated oxidation furnace.  
The silicon wafer loading area is shown in a laminar hood.



## O Forno de Oxidação

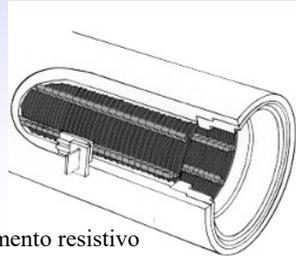


### Fornos de oxidação:

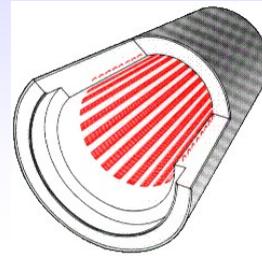
- pressão atmosférica (tubo aberto)
- elevado controle de Temperatura
- automático



## Forno de Oxidação

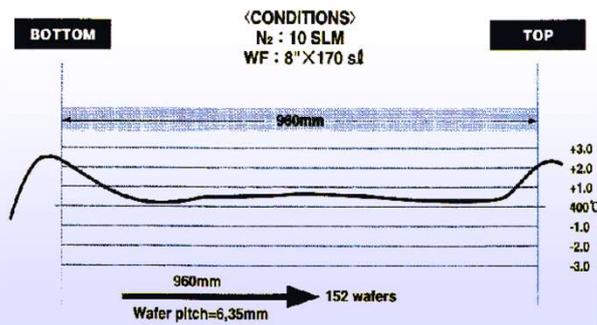


Elemento resistivo

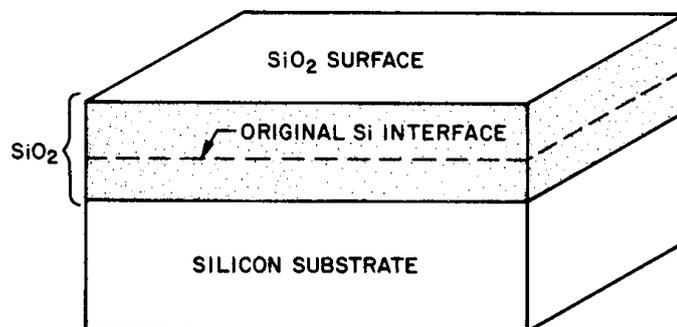
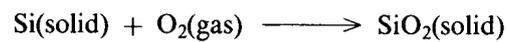


### Fornos de oxidação:

- precisão da temperatura
- Variação < 1°C na região de trabalho



## A Reação química



Growth of silicon dioxide by thermal oxidation.



## Volume e Espessura

$$\frac{\text{Molecular weight of Si}}{\text{Density of Si}} = \frac{28.09 \text{ g/mole}}{2.33 \text{ g/cm}^3} = 12.06 \text{ cm}^3/\text{mole}.$$

The volume of 1 mole silicon dioxide is

$$\frac{\text{Molecular weight of SiO}_2}{\text{Density of SiO}_2} = \frac{60.08 \text{ g/mole}}{2.21 \text{ g/cm}^3} = 27.18 \text{ cm}^3/\text{mole}.$$

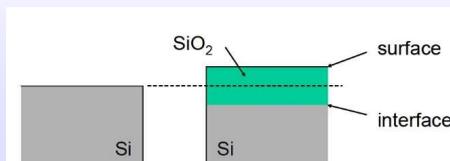
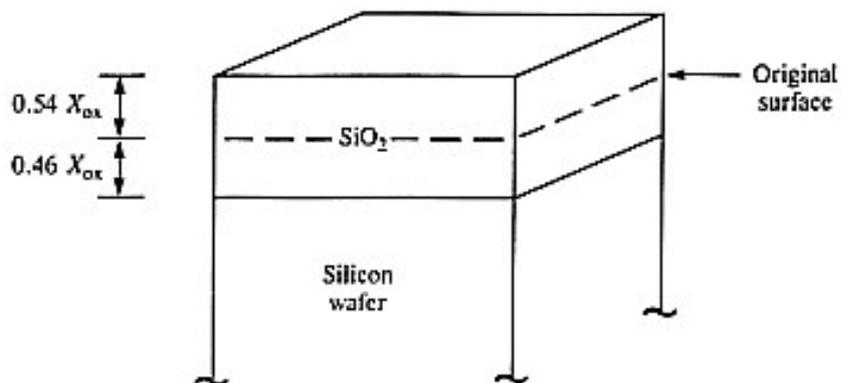
$$\frac{\text{Thickness of Si} \times \text{area}}{\text{Thickness of SiO}_2 \times \text{area}} = \frac{\text{volume of 1 mole of Si}}{\text{volume of 1 mole of SiO}_2}$$

$$\frac{\text{Thickness of Si}}{\text{Thickness of SiO}_2} = \frac{12.06}{27.18} = 0.44$$

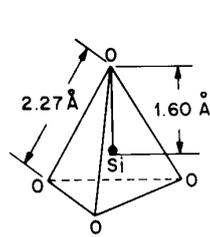
Thickness of silicon = 0.44(thickness of SiO<sub>2</sub>).



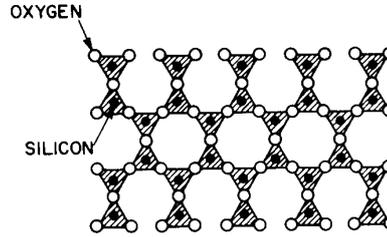
## Espessura Final



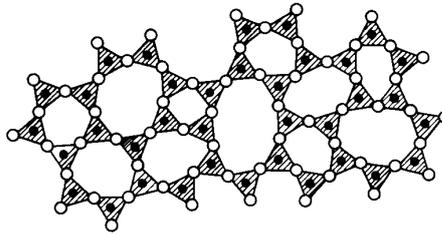
## Estrutura do SiO<sub>2</sub>



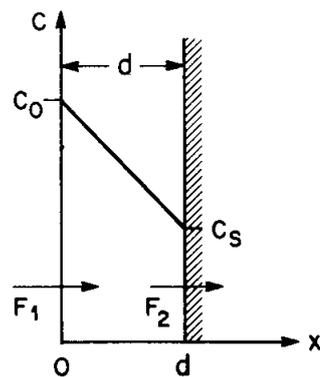
Basic structural unit of silicon dioxide.



Two dimensional representation of a quartz crystal lattice.



Two dimensional representation of the amorphous structure of silicon dioxide.



$C_0$  is  $5.2 \times 10^{16}$  molecules/cm<sup>3</sup>  
 $C_s$  at the surface of silicon

Basic model for the thermal oxidation of silicon.

$D$  is the diffusion coefficient  
 $x$  is the thickness of the oxide layer already present.

$F_1 = D \frac{dC}{dx} \simeq \frac{D(C_0 - C_s)}{x}$

$F_2 = kC_s$

Equacionamento

$k$  is the surface reaction rate constant for oxidation.

$F_1 = F_2 = F.$

$$F = \frac{DC_0}{x + (D/k)}$$

$$\frac{dx}{dt} = \frac{F}{C_1} = \frac{DC_0/C_1}{x + (D/k)}$$

$$x^2 + \frac{2D}{k}x = \frac{2DC_0}{C_1}(t + \tau) \quad \tau \equiv (d_o^2 + 2Dd_o/k)C_1/2DC_0$$

$$x = \frac{D}{k} \left[ \sqrt{1 + \frac{2C_0 k^2(t + \tau)}{DC_1}} - 1 \right]$$


Equação de crescimento do óxido

$$X_{ox} = \frac{A}{2} \left[ \sqrt{1 + \frac{(t + \tau)}{A^2 / 4B}} - 1 \right]$$

Para tempos longos ( $t \gg \tau$ ) o processo é controlado por difusão através do óxido → lei de crescimento parabólico

$$X_{ox}^2 = Bt$$

Para tempos curtos ( $t \ll \tau$ ) não depende da difusão dos oxidantes → lei de crescimento linear

$$X_{ox} = \frac{B}{A}(t + \tau)$$


## Aproximação:

Parabólica larger values  $x \approx \sqrt{\frac{2DC_0}{C_1} (t + \tau)}$

Linear small values  $x \approx \frac{C_0 k}{C_1} (t + \tau)$

Para tempos longos ( $t \gg \tau$ ) o processo é controlado por difusão através do óxido → lei de crescimento parabólico

$$X \frac{2}{ox} = Bt$$

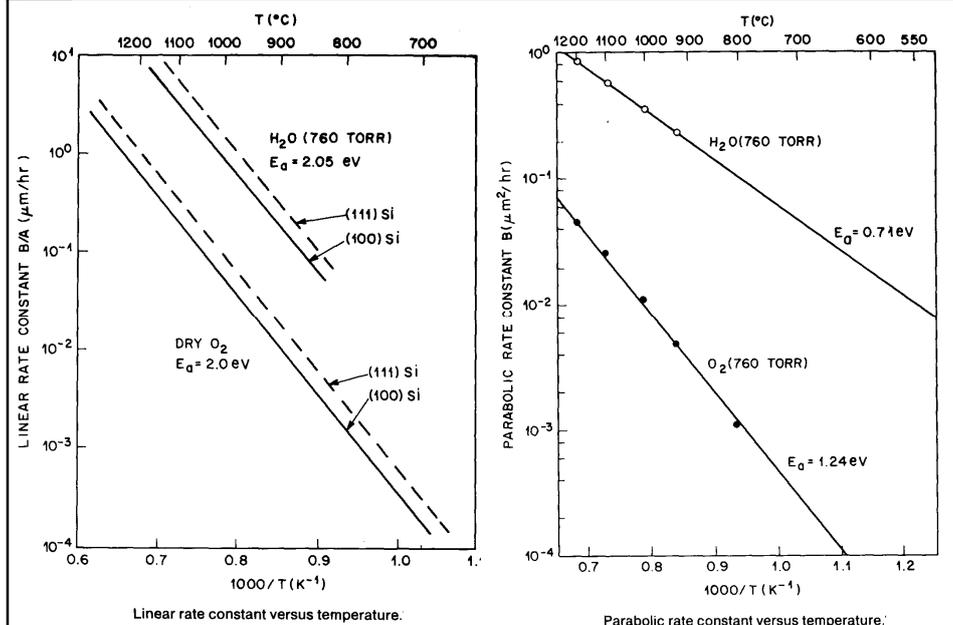
Para tempos curtos ( $t \ll \tau$ ) não depende da difusão dos oxidantes → lei de crescimento linear

$$X_{ox} = \frac{B}{A}(t + \tau)$$

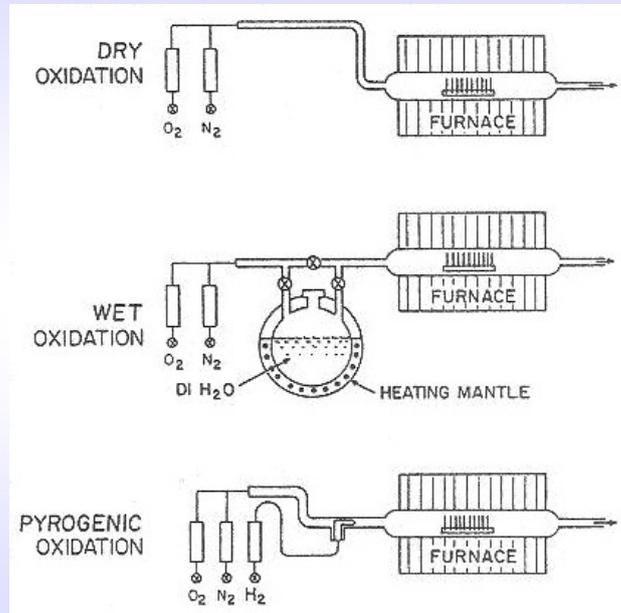


4.19

## Taxa Linear e Parabólica

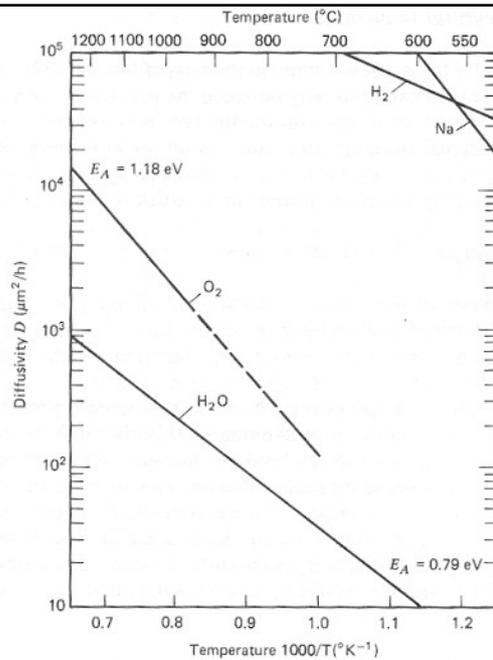


## Tipos de Oxidação



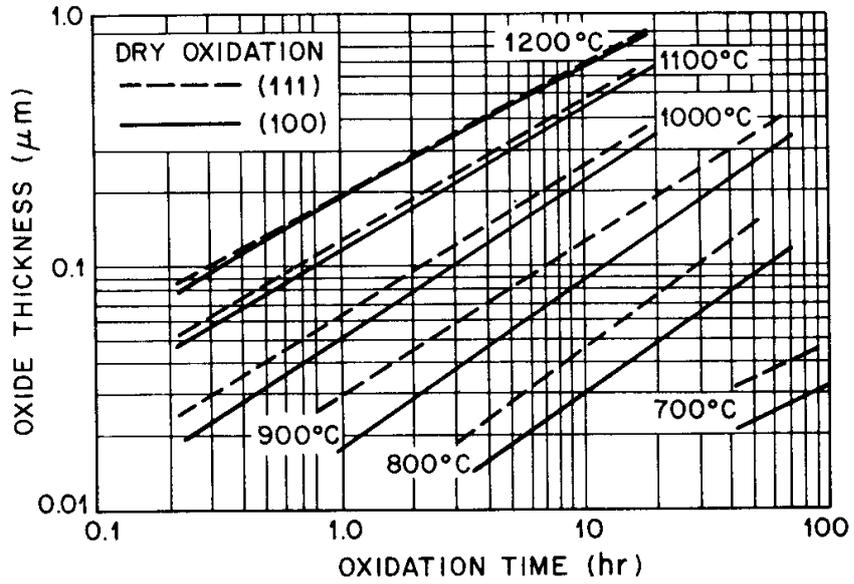
## Difusividade

Escolha do tipo de oxidação

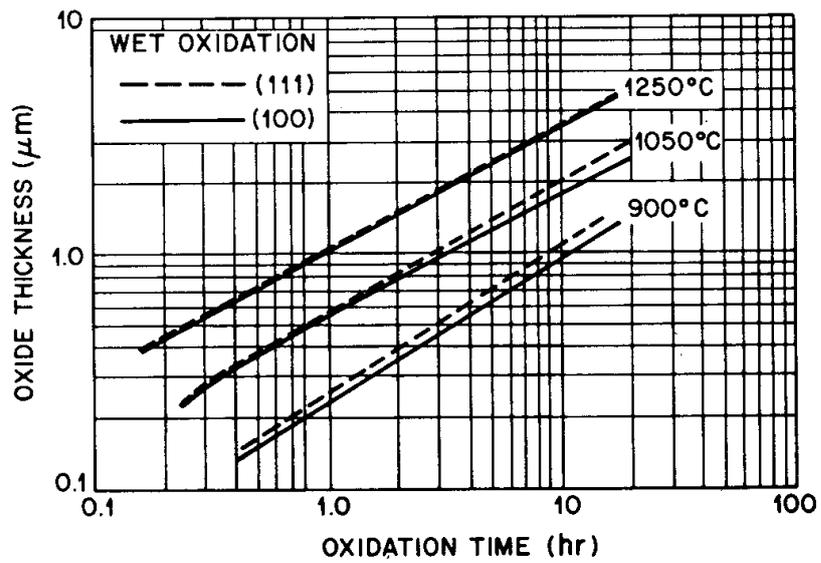


Diffusivities of hydrogen, oxygen, sodium, and water vapor in silica glass.

## Oxidação Seca



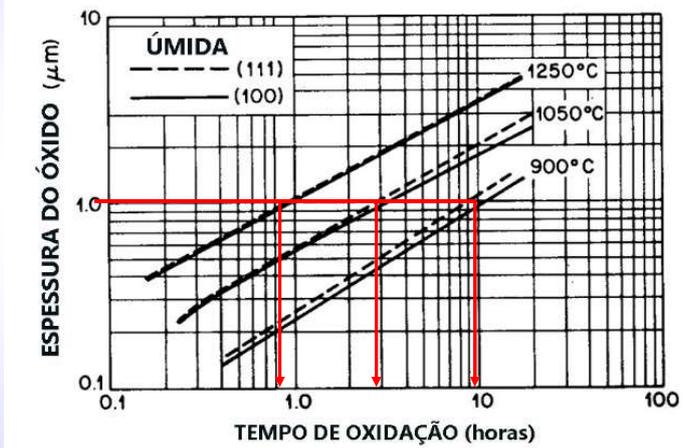
## Oxidação Úmida



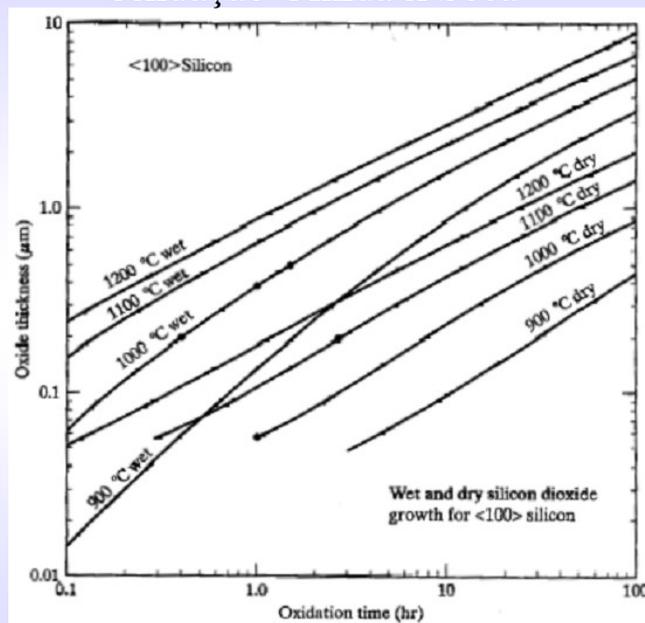
## Oxidação Úmida

Uma espessura de 1  $\mu\text{m}$  pode ser obtida por:

- 1h a 1250°C
- 3,2h a 1050°C
- 10,2h a 900°C



## Oxidação Úmida x Seca

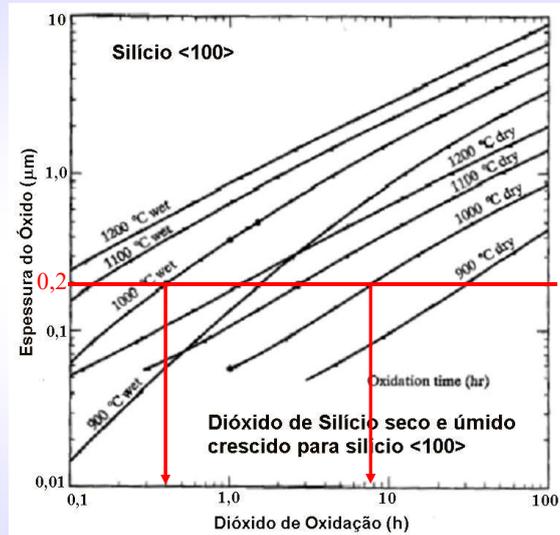


## Oxidação Úmida x Seca

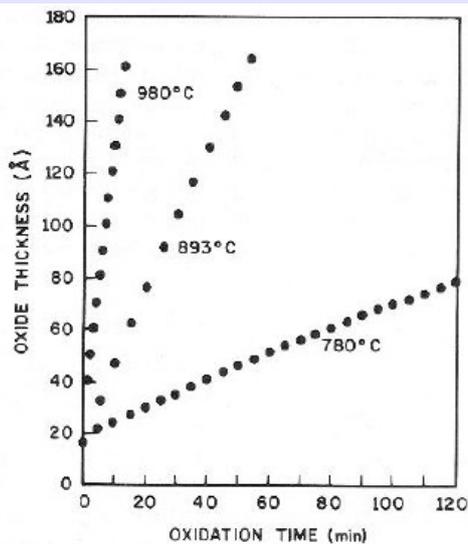
Uma espessura de 0,2  $\mu\text{m}$  pode ser obtida por:

0,4h (24 min)  
a 1000°C (úmida)

8h a 1000°C (seca)

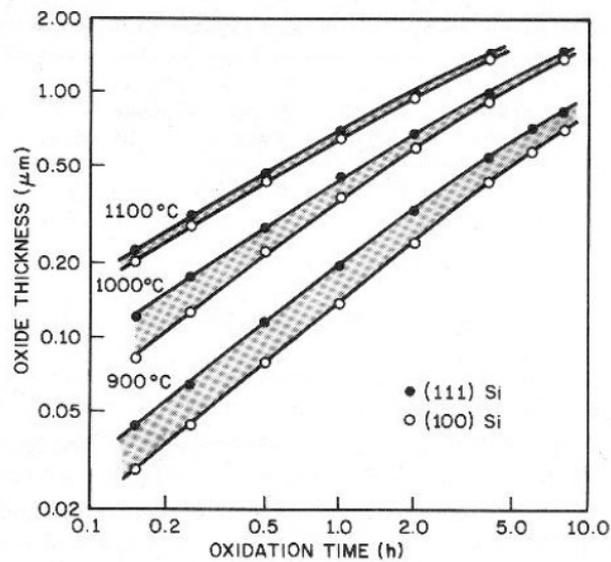


## Espessura x Tempo de crescimento

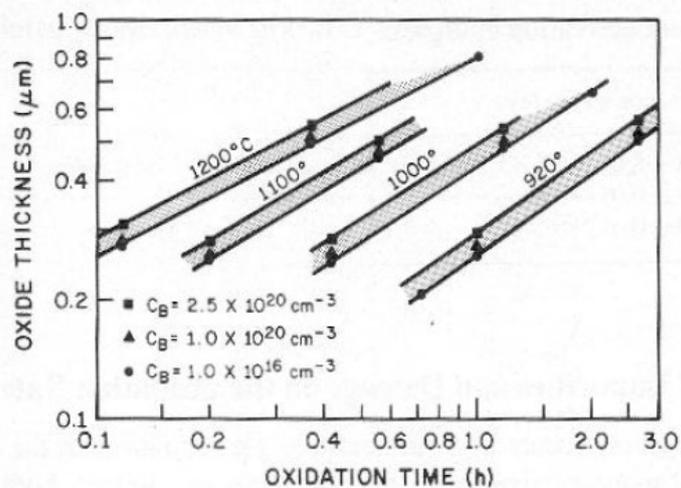


Oxide thickness versus oxidation time at 780, 893, and 980°C in dry oxygen.

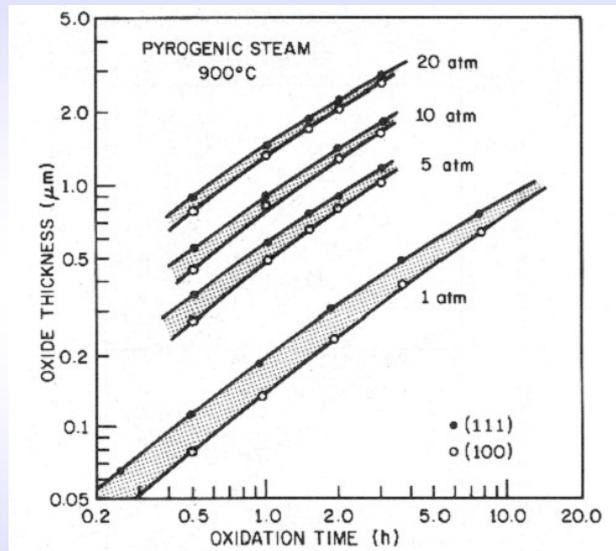
## Orientação Cristalográfica



## Dopagem do Substrato – oxidação úmida

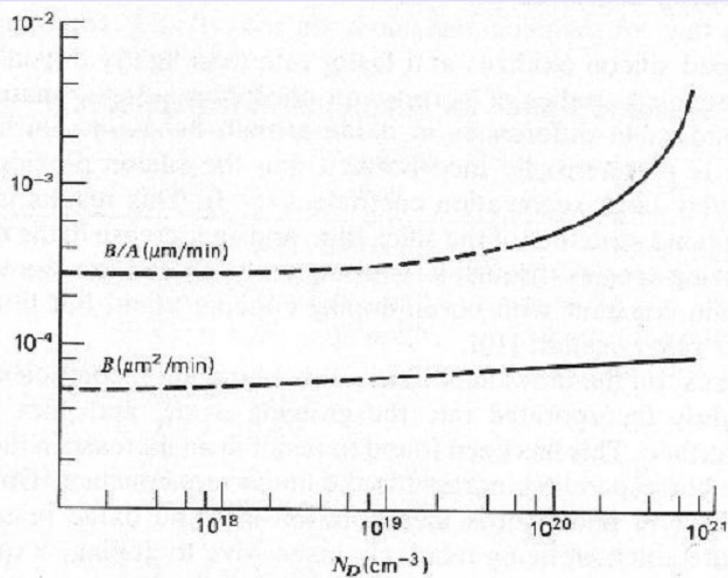


## Dopagem do Substrato – oxidação Seca



Oxidation thickness versus oxidation time for pyrogenic steam at 900°C for (100) and (111) silicon and pressures up to 20 atm.

## Coeficiente x dopagem do Substrato



Rate constant versus substrate phosphorus doping level for oxidation at 900°C.