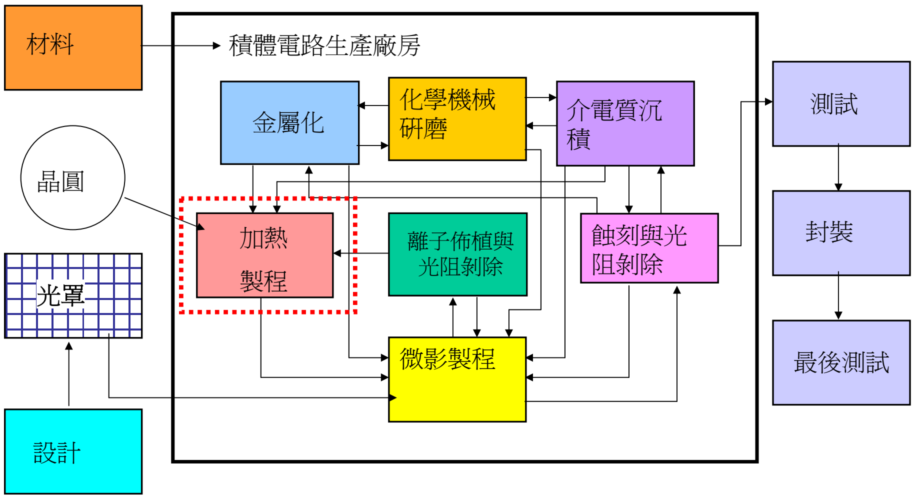
Ch5 Oxidation and Diffusion (氧化與擴散)

Introduction to
Semiconductor Processing

Overall View



材料

積體電路生產廠房

金屬化

化學機械研磨

介電質沉積

晶圓

加熱製程

離子佈植與光阻剝除

蝕刻與光阻剝除

光罩

微影製程

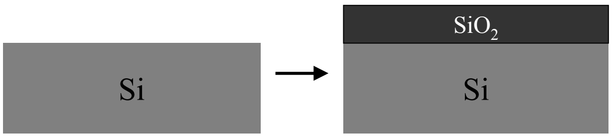
設計

測試

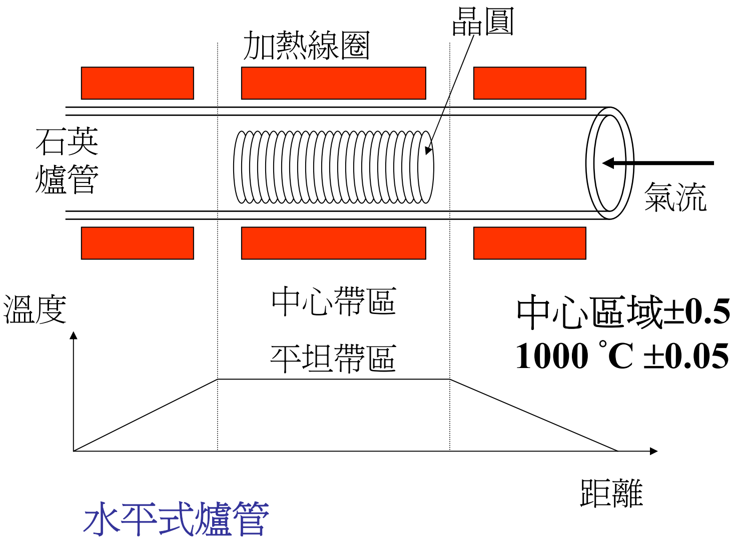
封裝

最後測試

Ch5 -1 Oxidation



Horizontal Furnace

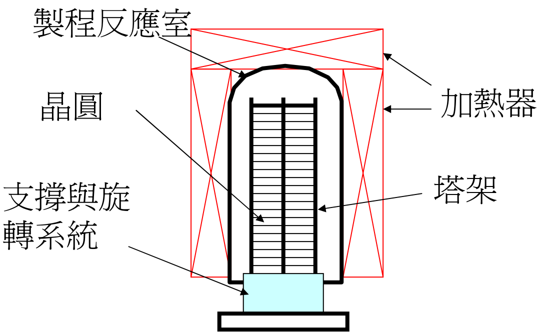


中心區域±0.5 ˚C
1000 ˚C ±0.05%!

水平式爐管

Vertical Furnace 垂直式爐管

Why vertical furnace:
- Smaller footprint
- Better contamination control
- Easier wafer handling



- Dummy wafers
- 1 Test wafer
- Production wafers
- 1 Test wafer
- Production wafers
- 1 Test wafer
- Dummy wafers

Furnace Material Considerations

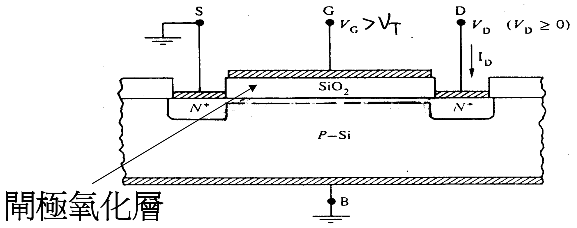
- High purity quartz
  - Pros
    - stable at high T
    - Cleanliness
  - Cons
    - Fragile
    - Contain metallic ions
    - Not a sodium barrier
    - Small flakes at T>1200 °C (glassy substrates → crystalline solids)

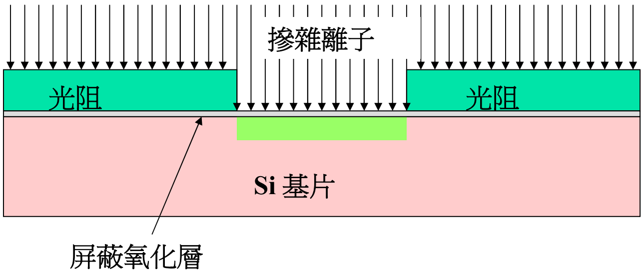
- SiC
  - Pros
    - Better thermal stability
    - Better barrier
  - Cons
    - Heavy
    - Expensive
  - Only for critical parts, but not the chamber body.

Oxygen Sources

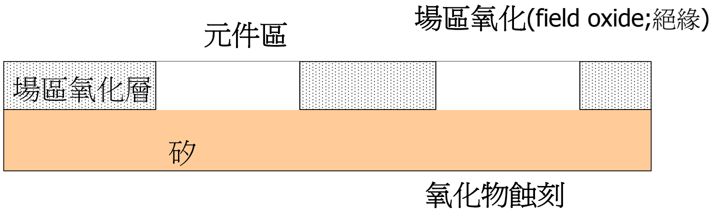
- 乾氧氣 (Si+ O_2 → SiO_2)
- 水蒸氣 (Si+ $2H_2O$ → SiO_2 + $2H_2$
  - 起泡計
  - Flash systems
- 氫氣和氧氣, $H_2 + O_2 \rightarrow H_2O$
- 少量氯，爲減小閘極氧化的移動離子
  - 無水氯化氫 HCl
  - 三氯乙烯 (TCE, 致癌), 三氯乙烷 (TCA)

乾氧化 (薄): 閘極氧化層、屏蔽氧化層





濕氧化 (厚): 場氧化層、阻擋層


元件區

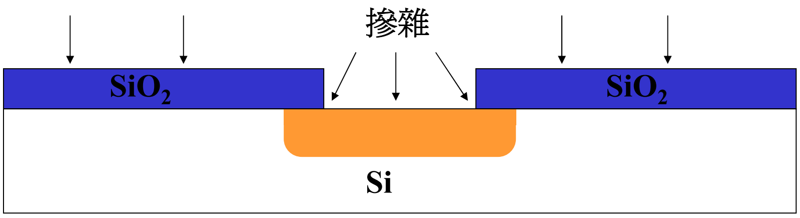
場區氧化(field oxide;絕緣)

場區氧化層

矽

氧化物蝕刻

擴散阻擋層、離子植入屏蔽氧化層…等


摻雜

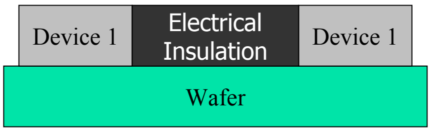
SiO_2

SiO_2

Si

Special Topic: Isolation Techniques

Goal:

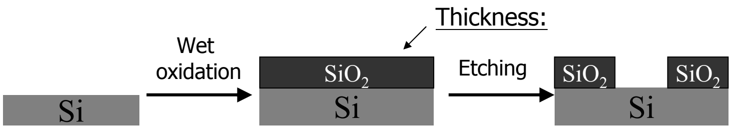

Device 1

Electrical Insulation

Device 1

Wafer

Field Oxide (Early 80's)


Si

Wet oxidation

SiO_2

Si

Thickness:

Etching

SiO_2

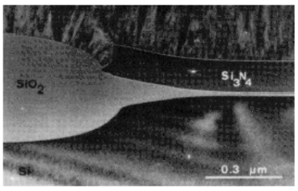
SiO_2

Si

Problems:
1.
2.

Isolation Techniques (LOCOS)

LOCOS (Local Oxidation of Silicon), ~ mid 90's



Isolation Techniques (STI)

STI (Shallow Trench Isolation), mid 90's~

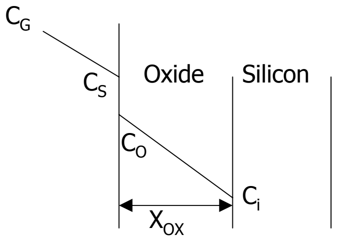
RCA 清洗 (一種常見的清洗協定)

- Kern 和 Puotinen於1960 於RCA中發展
- IC廠中最常使用的製程
- SC-1-- $NH_4OH:H_2O_2:H_2O$比例爲1:1:5到1:2:7，在 70至80 °C 以移除有機污染物
- SC-2-- $HCl:H_2O_2:H_2O$用1:1:6比例爲1:2:8，在70到80 °C 以移除無機污染物
- 去離子水潤洗
- HF沈浸或HF 蒸氣蝕刻以移除原生氧化層

Cleaning

- Cleaning before oxidation, remove
  - Particulates, organic and inorganic residues, and native oxide
- Sequence of not well-cleaning:
  - ____________, ____________
- DI water: ultra pure water (UPW), ultra high purity,
  - high resistivity > 18MΩ-cm
  - Total organic content < 5μg/L
  - Oxygen content <10 μg/L
    - Check your bottle water
- Water supply is not trivial→
  - 1500 8-in (200mm) wafer processing fab (a small TSMC fab)
  - 500 gallons hazardous chemicals
  - 10~20 million gallons or more UPW

Silicon Oxidation Model



C_G: concentration of O_2 in the gas phase, $=P_G/RT$

C_S: Concentration of O_2 at the gas-solid interface

C_0: O_2 solubility in $SiO_{2(S)}$; $C_0=H*C_S$;
H: Henry's Constant

C_i: O_2 concentration at SiO_2-Si interface

$r_1=h_G(C_G-C_S)$,
if define $C_A=H*C_G$
$\rightarrow r_1=(h_G/H)(C_A-C_0)=h(C_A-C_0)$, where $h=h_G/H$ $\Longrightarrow$ $C_i = \dfrac{C_A}{1+k_S/h+k_S X_{OX}/D}$
$r_2=D*(C_0-C_X)/X_{OX}$
$r_3=k_s*C_i$
At steady state, $r_1=r_2=r_3$

Silicon Oxide Model – Oxide Growth Rate

Define N_1= number of oxygen atoms per unit volume of SiO_2 ($4.6*10^{22}$ cm^{-3})

$$N_i\frac{dX_{OX}}{dt}=k_sC_i=\frac{k_sC_A}{1+k_S/h+k_SX_{OX}/D}$$

At t=0, XOX=Xi (initial oxide thickness)

$$X_{OX}{}^2+AX_{OX}=B(t+\tau)$$

$$where \quad A=2D(\frac{1}{k_s}+\frac{1}{h})$$

$$B=2DC_A/N_1$$

$$\tau=(X_i^2+AX_i)/B$$

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

Oxidation Model – Limiting cases

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

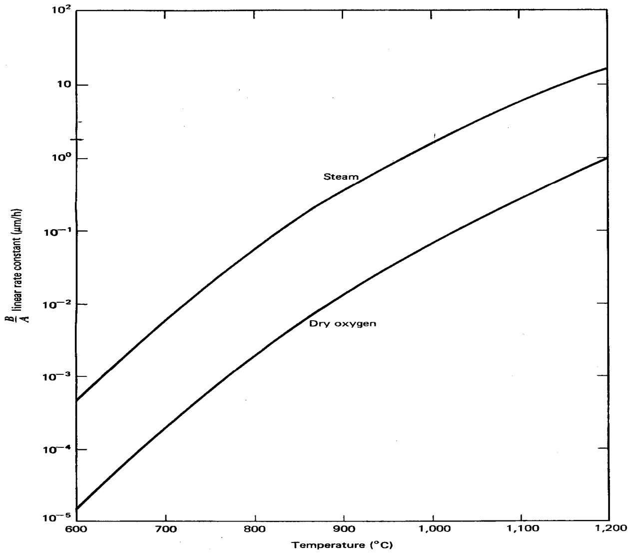
Case 1: For short time, $t+\tau \ll A^2/4B$

Linear growth region
Linear growth rate constant:________

Case 2: For long time, $t \gg \tau$

Parabolic growth region
Parabolic growth rate constant:________

B/A: Linear Rate Constant



Source: "Microelectronics: processing and device design", R. A. Colclaser, J. W. & S. 1980

B: Parabolic Rate Constant

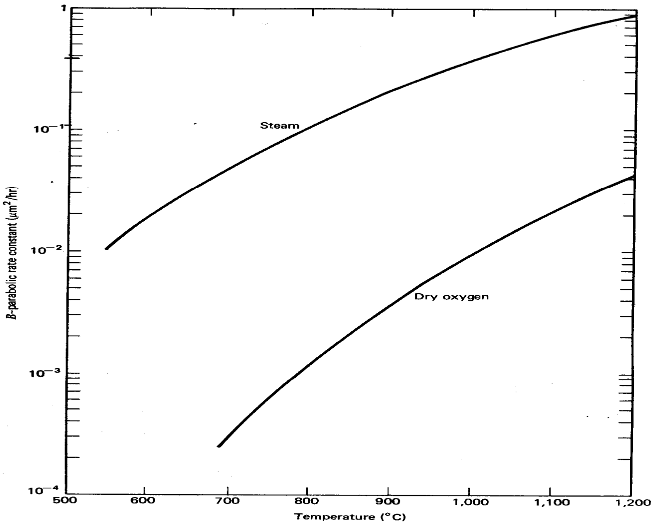
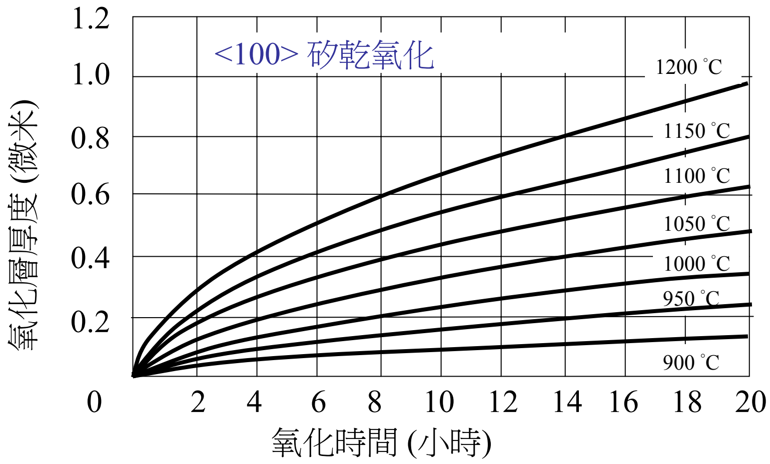


Figure 5-4. The parabolic rate constant for steam and dry oxygen oxidations of silicon (11). Reprinted by permission of the author.

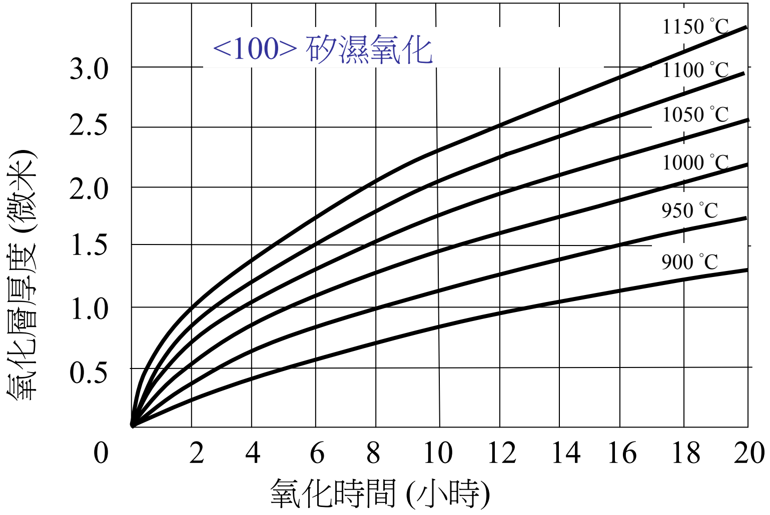
Source: "Microelectronics: processing and device design", R. A. Colclaser, J. W. & S. 1980

<100> 矽乾氧化



Example: Silicon Oxidation Rates

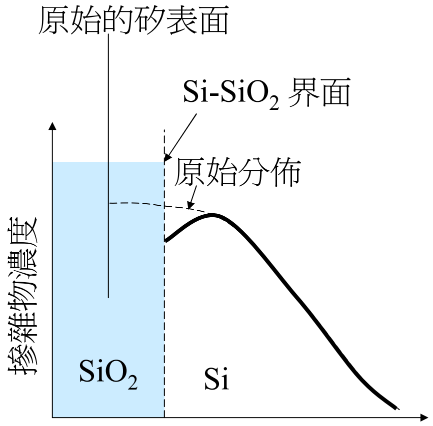
<100> 矽濕氧化速率



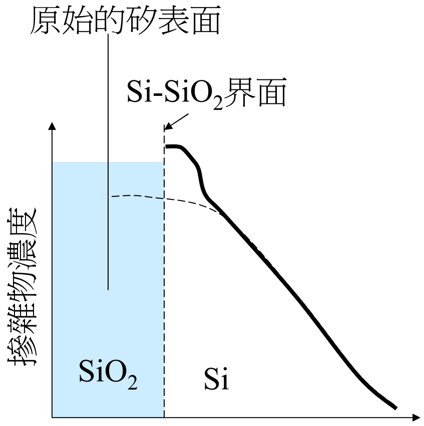
Oxidation vs. Diffusivity of O_2 and H_2O

空乏及堆積效應

空乏及堆積效應



P型摻雜物的空乏現象



N型摻雜物的堆積現象

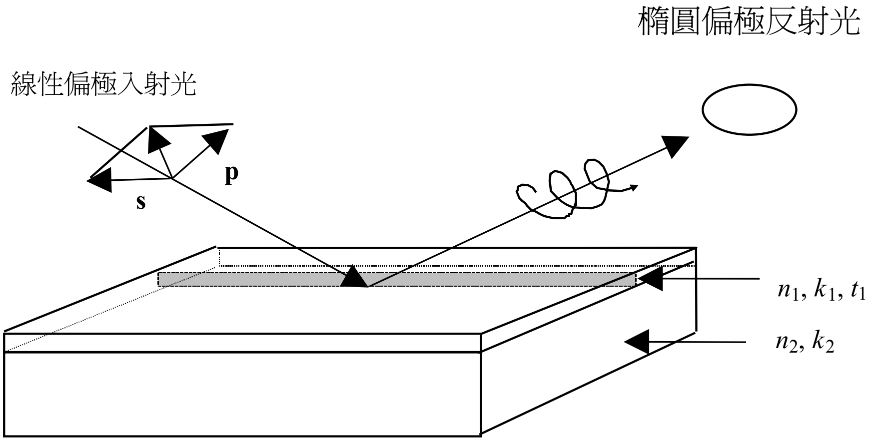
快速加熱氧化

Conventional oxidation process is a multi-wafer batch process→ hard to precisely control the temperature at every points

Rapid Thermal Oxidation, RTO

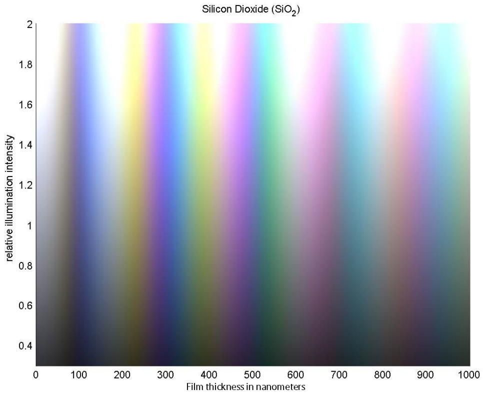
- Process features and applications:
- ______________________
- ______________________
- ______________________
- Integrate with HF native oxide removal
- O_2 + HCl
- 深次微米元件的閘極氧化層

Film thickness measurements: 橢圓儀



Empirical Thickness Estimation

SiO$_2$

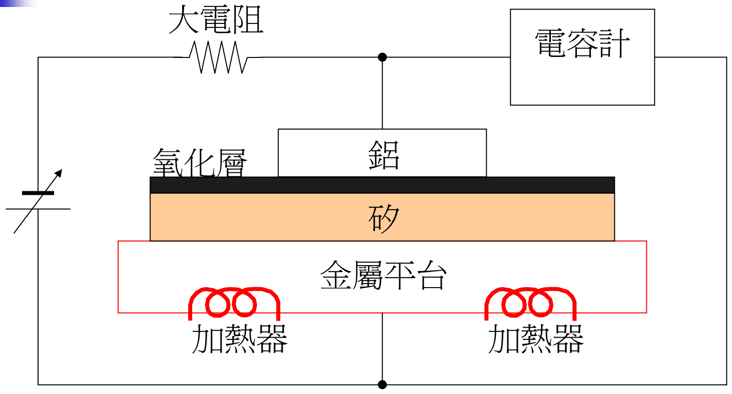


http://www.ee.byu.edu/cleanroom/color_chart.parts/sio2_chart.jpg

Titanium

But, DONOT always trust your eyes!!

C-V 測試組合

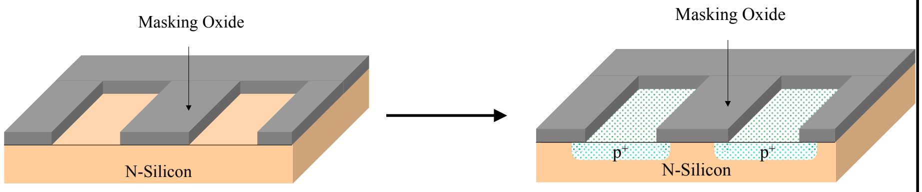


Test for:

1:

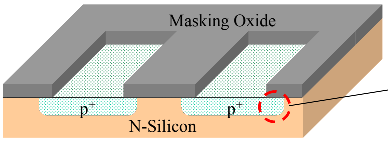
2:

Ch5 -2 Diffusion



擴散摻雜製程

- Materials disperses from high concn. to low concn.
- SiO_2 as the diffusion mask
- Was widely used for doping
  - Replaced by ion implantation for better control from mid 70's
  - Still being used in drive-in for ____________.

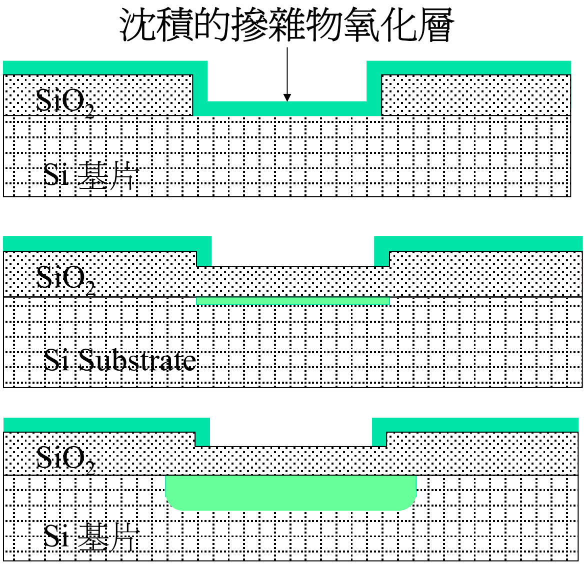


Major concern:

____

- 預積 (Pre-deposition): $B_2H_6 + 2\ O_2 \rightarrow B_2O_3 + 3\ H_2O$
  $2\ B_2O_3 + 3\ Si \rightarrow 3\ SiO_2 + 4\ B$
- Thermal oxidation: remove un-reacted gas, oxide formation that covers the dopant.
- 驅入 (Drive-in)
  - 硼擴散進入矽基材

Major Steps



Pre-deposition

Determines:

____

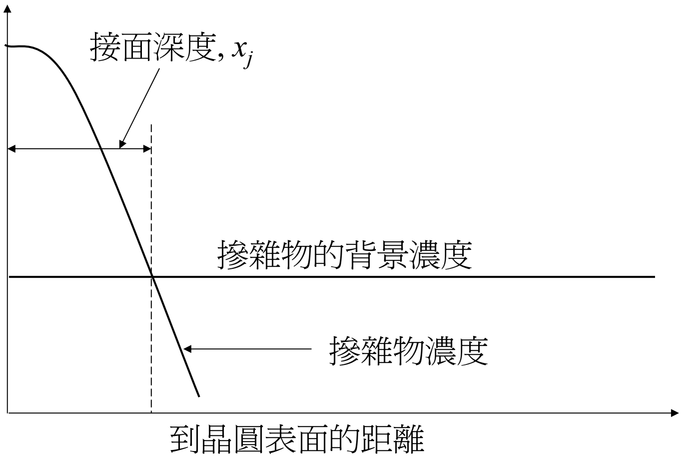
Cap oxidation

Drive In

Determines:

____

接面深度之定義



擴散系統

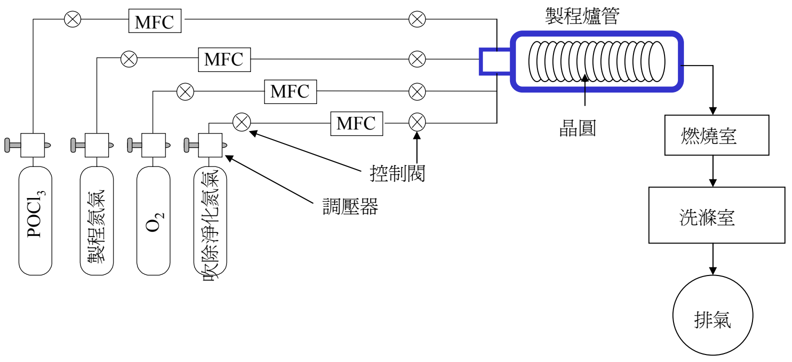
Regulator (調壓器):

MFC(質量流量控制計):

Control valves(控制閥):

燃燒室:

洗滌室:

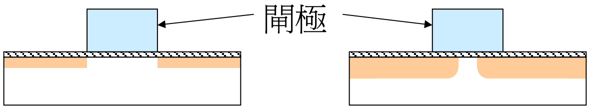


熱積存（thermal budget)

- 摻雜原子在高溫中快速擴散

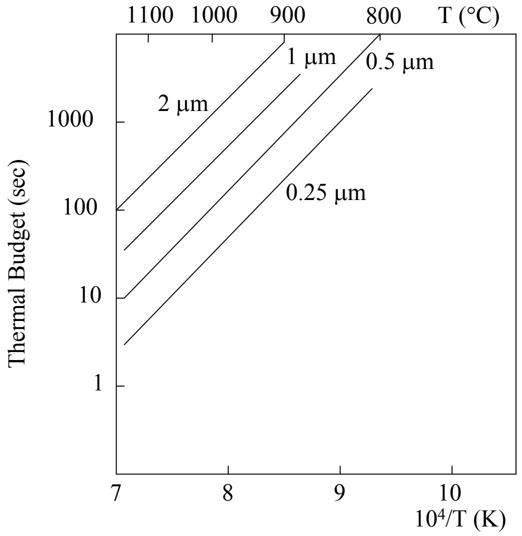
$$D = D_0 \exp(-E_A/kT)$$

- 較小的元件，較少的摻雜物熱擴散空間，較少的熱積存
- 熱積存指在離子佈植後的加熱製程中的時間及溫度組合



S/D 離子佈植　　　過量的熱積存

Thermal Budget

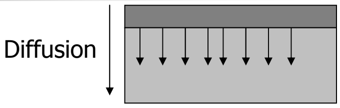


Source: Chang and Sze, *ULSI Technology*

Diffusion Model

1-D diffusion problem without bulk flow

$$\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2}$$



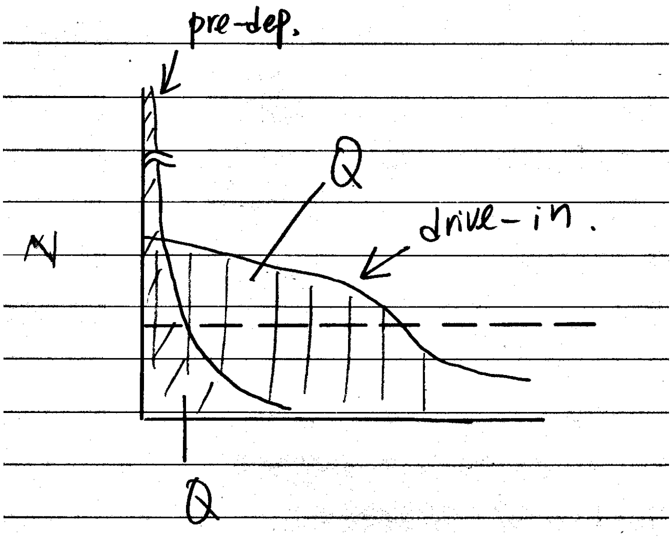
*Same governing equation for **pre-deposition** and **drive-in** steps

1. Pre-deposition: Constant (Saturated) surface concentration

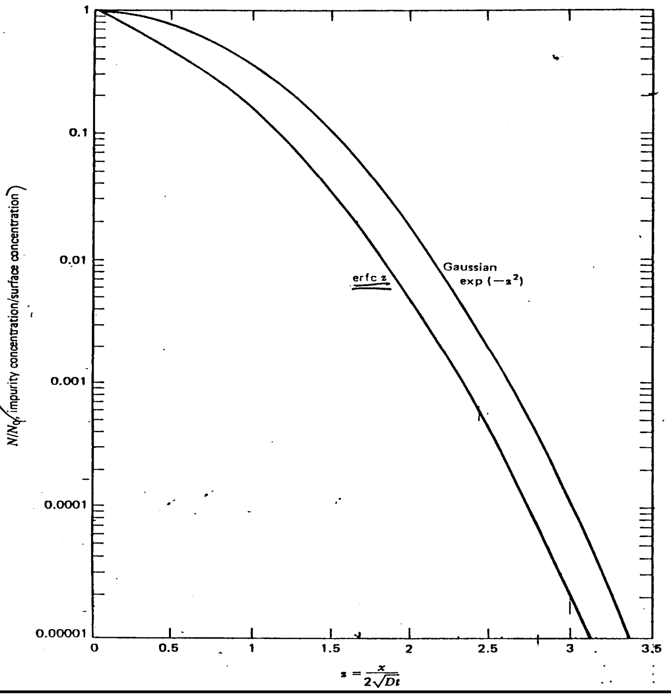
Diffusion Model - Conti.

2. Drive In: Constant (Saturated) surface concentration

Diffusion: Spatial Profile



REF 1



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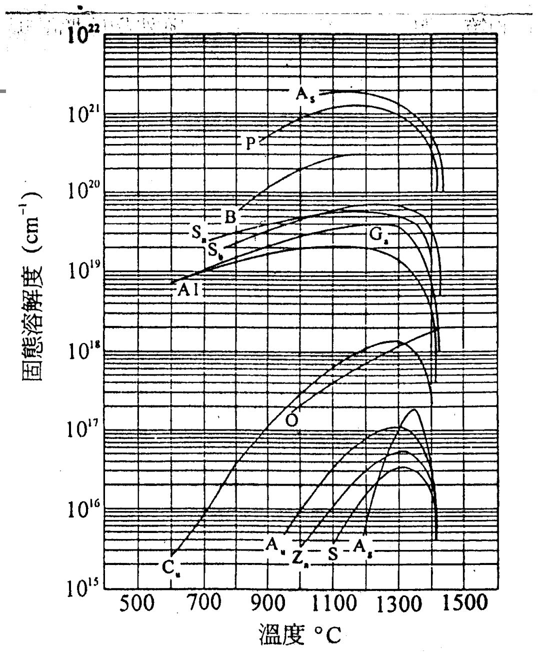
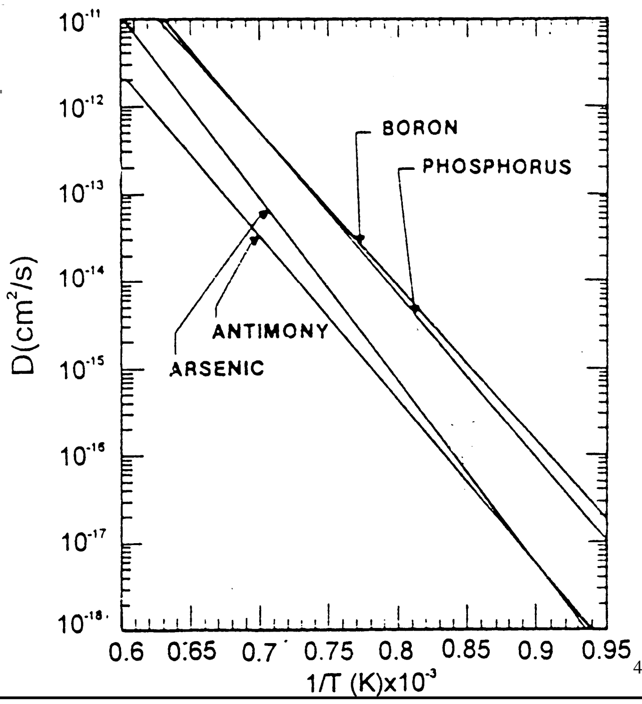


Source: 莊達人 "VLSI製造技術"

REF 3



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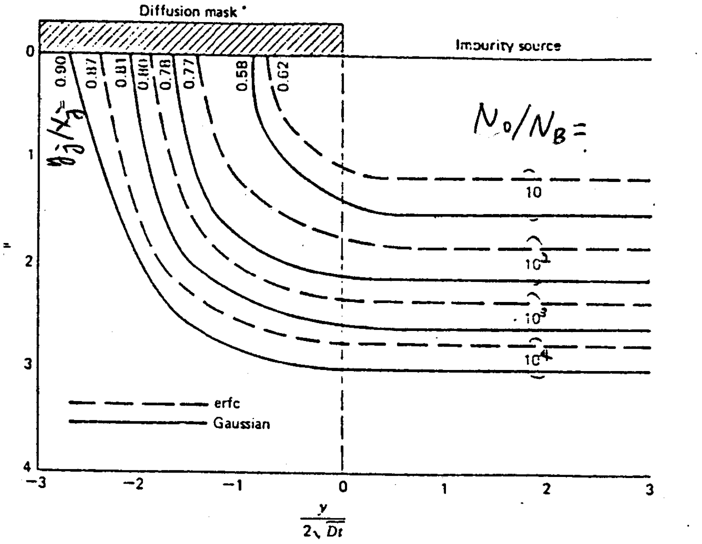
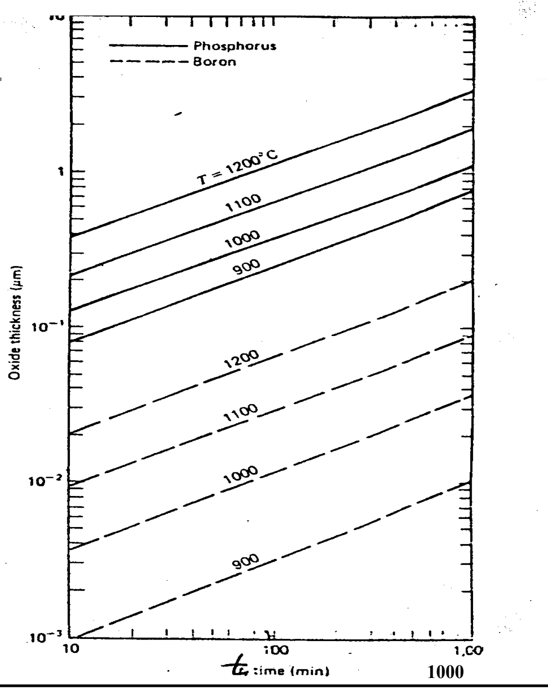

Diffusion mask
Impurity source
0.90
0.87
0.81
0.80
0.78
0.77
0.58
0.62
$y_j/x_j =$
$N_0/N_B =$
10
10^2
10^3
10^4
erfc
Gaussian
0
1
2
3
4
−3
−2
−1
0
1
2
3
$\frac{y}{2\sqrt{Dt}}$

REF 5

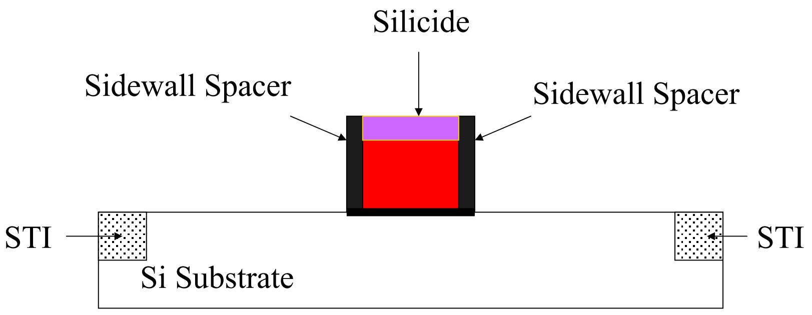

Phosphorus
Boron
T = 1200°C
1100
1000
900
1200
1100
1000
900
Oxide thickness (μm)
10
1
10^{-1}
10^{-2}
10^{-3}
10
100
1,000
1000
t time (min)

Special Topic: USJ Formation

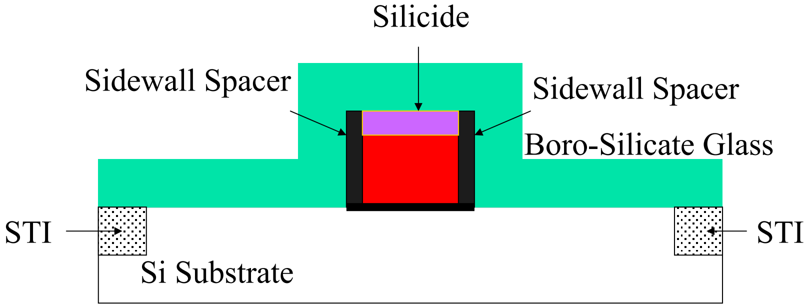
Diffusion for Boron USJ formation

- Small devices needs ultra shallow junction
- Boron is small and light, implanter energy could be too high for it goes too deep
- Controlled thermal diffusion is used in R&D for shallow junction formation

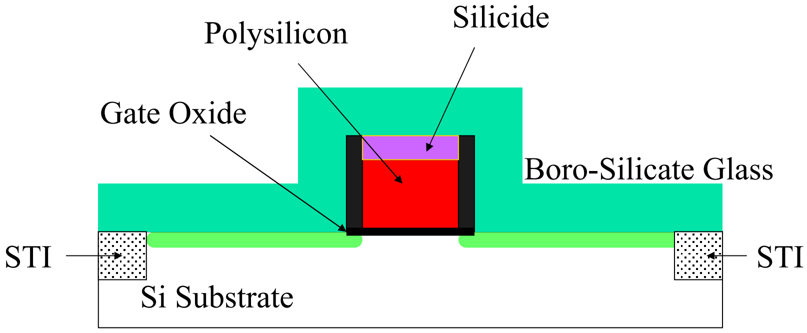
Surface Clean



BSG CVD



RTP Dopant Drive-in



Strip BSG