

MICROELECTRONIC TECHNOLOGIES

EXAMS NOTES

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...Scooby-doo?...

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Chapter 1

Exams notes

1.1 Ion implant range and +1 model

Given an implant of an element with a dose Q and an energy E we can find from tables the values of

- R_p the projected range of our implant that is the maximum of our gaussian distribution that we expect
- ΔR_p the standard deviation of our gaussian distribution

So we will have a distribution like

$$C(x) = C_p \exp\left(-\frac{(x - R_p)^2}{2\Delta R_p^2}\right) \quad (1.1)$$

where C_p is the concentration at the peak of our distribution.

The total dose implanted will be $Q = \sqrt{2\pi\Delta R_p^2} C_p$ and so $C_p = \frac{Q}{\sqrt{2\pi\Delta R_p^2}}$ doing so we can write

$$C(x) = \frac{Q}{\sqrt{2\pi\Delta R_p^2}} \exp\left(-\frac{(x - R_p)^2}{2\Delta R_p^2}\right) \quad (1.2)$$

If we want to know the dose that is present after a certain depth x

$$Q_{imp} = \int_x^{+\infty} C_p \exp\left(-\frac{(x - R_p)^2}{2\Delta R_p^2}\right) dx \quad (1.3)$$

That becomes

$$Q_{imp} = \frac{Q}{2} \operatorname{erfc}\left(\frac{x - R_p}{\sqrt{2}\Delta R_p}\right) \quad (1.4)$$

The function erfc has the following proprieties

- $\text{erfc}(x)=1-\text{erf}(x)$ if $x > 0$
- $\text{erfc}(x)=1+\text{erf}(x)$ if $x < 0$

If we want to estimate the amount of interstitial caused by an implant using the +1 model we can say that the concentration of interstitial is equal to the dose Q implanted in silicon. If the silicon is fully amorphised and then re-crystallized there are no interstitial due to ion implantation since in an amorph crystal do not exist interstitials or defects.

1.2 Ion implant and dopant diffusion

After an implant (with a certain dose Q and having also R_p and ΔR_p) there will always be a thermal annealing process for a certain time t at a temperature T. The profile of the doping will be a gaussian with the standard deviation modified by the diffusion due to thermal treatment so like

$$C(x) = \frac{Q_i}{\sqrt{2\pi(\Delta R_p^2 + 2Dt)}} \exp\left(-\frac{(x - R_p)^2}{2(\Delta R_p^2 + 2Dt)}\right) \quad (1.5)$$

From this we can know the concentration of dopants for all x. Beware to correctly set Q depending on the symmetry of the system.

1.3 CZ-growth

CZ growth of silicon gives different doping concentrations for the wafers depending on the distance from the top of the ingot.

The parameters that we need to have the doping concentration at a certain value x are the segregation coefficient k and the initial dose of doping C_0

$$C = C_0 k (1 - f)^{k-1} \quad (1.6)$$

where f is the % of the ingot where we are.

From the concentration we can derive the resistivity of the wafer as

$$\rho = \frac{1}{q\mu C} \quad (1.7)$$

1.4 Deal-Grove model

Using the correct table parameters we can derive the coefficients B and B/A for wet or dry oxidation through their Arrhenius form

$$B = C_1 \cdot \exp\left(-\frac{E_1}{kT}\right) \quad B/A = C_2 \cdot \exp\left(-\frac{E_2}{kT}\right) \quad (1.8)$$

or in an alternative way with their expressions

$$B = \frac{2DHP_G}{N} \quad B/A = \frac{HP_G}{N \left(\frac{1}{k_s} + \frac{1}{h} \right)} \quad (1.9)$$

remember that

- B is related to the transport through the present oxide so it isn't dependent on cristal orientation.
- B/A is related to the interaction with the surface it's activation energy it's $\simeq 2eV$ that is the energy to break one Si-Si bond and it's strongly dependent on cristal orientation in fact

$$\left(\frac{B}{A} \right)_{\langle 111 \rangle} = 1.68 \left(\frac{B}{A} \right)_{\langle 100 \rangle} \quad (1.10)$$

Notice that none of the mentioned parameters depends on pressure.

The model gives us the following expression

$$\frac{x^2}{B} + \frac{x}{B/A} = t + \tau \quad (1.11)$$

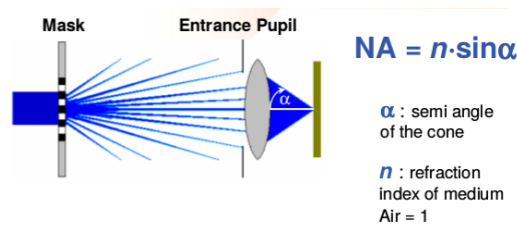
The boundary between the 2 regimes ,parabolic and linear, is given by the following thickness

$$x_b = \frac{B}{2B/A} \quad (1.12)$$

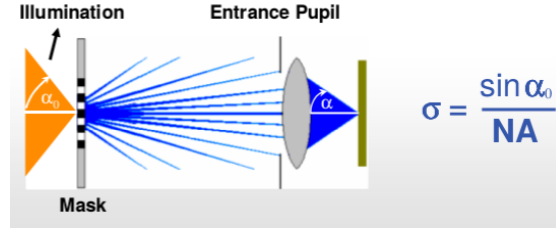
Beware that 46% of the SiO_2 grows inside the silicon and the other 56% over it.

1.5 Lito resoution limit

Defining some parameters of our lito tool as:



NA determines the maximum number of diffraction orders that can be captured by projection lens and thus the quality of the reconstructed image.



It defines the illumination of the mask, depends from source extension. For $\sigma = 0$ we have coherent illumination $\sigma = 1$ incoherent illumination.

For a coherent illumination that means a light perpendicular to the mask we have that the minimum resolution is

$$R = \frac{1}{2} \frac{\lambda}{NA} \quad (1.13)$$

For a partially coherent illumination that means a light tilted by an angle θ the resolution is

$$R = \frac{1}{2} \frac{\lambda}{(1 + \sigma)NA} \quad (1.14)$$

1.6 Lito contrast value

Given a certain profile of aerial image the contrast value is

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (1.15)$$

With equal values of contrast it's better to choose the one with higher I_{max}

1.7 Technology scaling; propagation delay

Propagation delay of a metal wire can be modelled as

$$\tau \simeq 0.89 \cdot \varepsilon_{oxide} \varepsilon_0 \rho \frac{A}{F_{min}^2} \quad (1.16)$$

1.8 Electromigration

The critical lenght of the cluster can be expressed as

$$L_{crit} = \frac{2\sigma_{crit}\Omega}{Z^*q\rho J} \quad (1.17)$$

Where Ω is the volume of the atom of metal and σ_{crit} the value of the maximum stress.

1.9 Ion enanced etch rate

Two process cooperating the ion etch and the byproducts deposition.

We can assume the number of deposited byproducts as

$$D = S_c(1 - \theta)F_c \quad (1.18)$$

With F_c flux of chemical species, S_c sticking coefficient and $(1-\theta)$ number of avabile sites. The number of byproducts removed as

$$R = K_i\theta F_i \quad (1.19)$$

with K_i sputtering efficiency, F_i flux of ionic species and θ number of occupied states. In stationary conditions $D=R$ so we can extract θ as

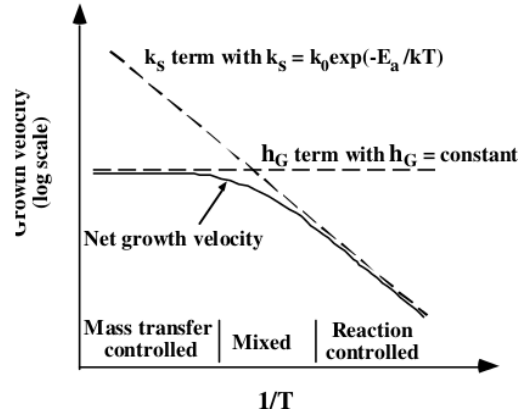
$$\theta = \frac{1}{1 + \frac{K_i F_i}{S_c F_c}} \quad (1.20)$$

so substituting this into the R expression we get the etch rate as

$$E = \frac{1}{N} \left(\frac{1}{K_i F_i} + \frac{1}{S_c F_c} \right) \quad (1.21)$$

with N density of the material to be etched.

1.10 CVD regimes



The velocity of deposition of a material in APCVD is determined by the slowest of two proces that operates in parallel; the transport of byproducts through the stagnant layer and the "reaction" with the surface.

The velocity can be mathematically described as

$$v = \frac{k_s h_g}{k_s + h_g} \frac{C_T}{N} Y \quad (1.22)$$

where k_s is the chemical surface reaction rate (has an Ahrrenius form so strongly dependent on temperature) and h_g the mass transport coefficient (independent form temperature).

We can distinguish in two case

- $k_s \ll h_g$ we are in surface reaction controlled regime; the geometry of the reaction does not matter so much this is the best case

- $h_g \ll k_s$ mass transport controlled regime; the geometry of the reactor is fundamental to control the stagnant layer

We can increase the value of h_g since we hope to stay in surface reaction controlled regime decreasing the value of the pressure since

$$h_g = \frac{D_g}{\sigma_g} \quad (1.23)$$

where D_g is the diffusivity of the gas and σ_g the stagnant layer thickness and $D_g \simeq 1/P$.