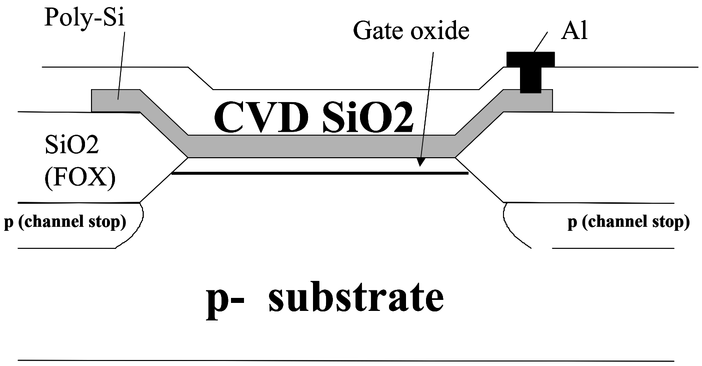
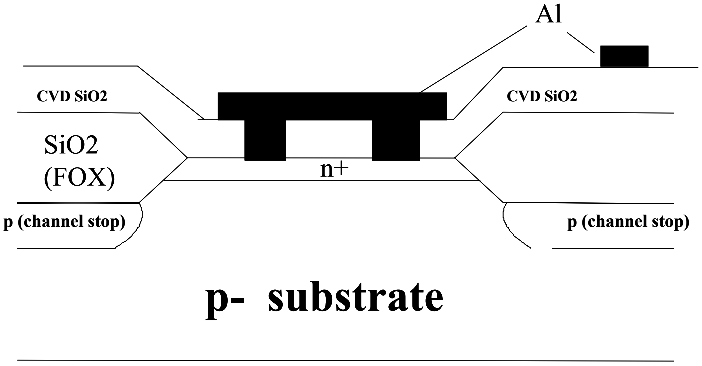
Midterm Exam #1 Solutions **EE143, Fall F2003**

Problem 1

(a) Cross-section along B-B'



(b) Cross-section along C-C'



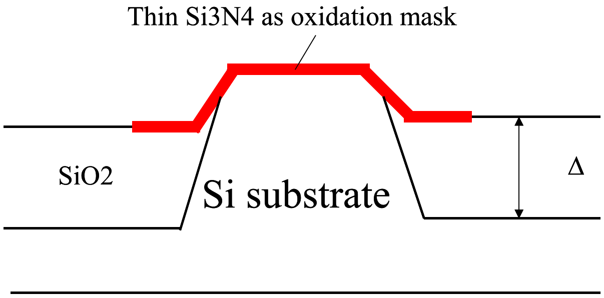
(c) Mask 1 – LOCOS patterning to define active device area
Mask 2 - Poly gate patterning
Mask 3 – contact hole opening through oxide
Mask 4 – Al metal patterning

This process sequence needs 4 lithography steps. [Note: the source and drain is fabricated by a blanket implant using poly-gate as the blocking pattern. No need for an additional mask to form S/D doping].

(d) No. There is an implantation annealing step at ~900C after S/D implant . If the Al gate is present, it will be molten.

Problem 2

(a)



(b) $\frac{d\,x_{ox}}{dt} = \frac{B}{A+2x_{ox}}$

From $0.48 = \frac{B}{A+0.5\times 2}$ and $0.266 = \frac{B}{A+1\times 2}$, we get

$A=0.243\ \mu m$, **$B= 0.597\ \mu m^2$/hour** and **$B/A = 2.46\ \mu m$/hour**

(c) The oxidation rate goes up with gas pressure ($\propto$ to P)

(i) For a given needed oxide thickness , the oxidation time can be shorter. Therefore, higher throughput.

(ii) For a given needed oxide thickness and same oxidation time, a lower oxidation temperature can be used. This will minimize mechanical stress generated by the difference in thermal expansion/contraction between oxide and Si. Less crystalline defects are expected.

(iii) For a given needed oxide thickness and same oxidation time, a lower oxidation temperature can be used. This will minimize dopant redistribution during the high-temperature oxidation cycle.

(d) **Mobile ion charges** – use HCl during oxidation to neutralize the mobile K+ or Na+ ions
Interface charges near and at oxide interface – anneal in forming gas after metallization step to passivate broken bonds with hydrogen.
Trapped oxide charge – mainly due to device operation or radiation damage.

Problem 3

(i)

From range curves, phosphorus ion energy ~ 150 keV to create $R_p = 0.2\ \mu m$.

The corresponding straggle ΔR_p is $0.065\ \mu m$.

(ii)

$$C_{max} \exp\left[\frac{-\ (0.2\ \mu m)^2}{2(\Delta R_p)^2}\right] = N_B = 10^{16} \Rightarrow\ C_{max}\ = 1.14 \times 10^{18}/cm^3$$

$$C_{max} = \frac{\phi}{2.5\Delta R_p} \Rightarrow\ \ \phi = 1.85 \times 10^{13}\ /cm^2$$

(iii) R_S of full gaussina profile’s is equivalent to two R_S of haf-gaussians in parallel.

Note the equivalent x_j is now only $0.2\ \mu m$ for these half-gaussians.

Using the n-type Gaussian Irvin curve with $C_o= 1.14 \times 10^{18}/cm^3$ and $N_B = 10^{16}$

$R_S x_j = 450$ ohm-μm or $R_S= 450/0.2 = 2250$ ohm/square

Therefore , **R_S of implant layer is 1125 ohm/square**.

(iv)

With a 7-degree tilt, the incoming ions will experience random scattering. A small fraction of the scattered ions will enter other crystallographic axes or planes. The channeling of these “lucky” ions will penetrate deeper than expected as compared with a truly random implantation depth profile, giving a small tail in the implant profile distribution.

(v) The annealing step is to : (1) restore Si crystallinity by annealing out defects , and (2) place dopants into Si substituitional sites to make them electrically active.

Problem 4

(a) Using Irvin curve with p-erfc profile (p into n) and $N_B = 10^{15}/cm^3$ and $C_o = 3.9 \times 10^{20}\ /cm^3$

$R_s\ x_j = 20\ \Omega$-μm

From $C(x,t)=C_S\ \text{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$

$3.9 \times 10^{20}\,\text{erfc}[\frac{x_j}{2\sqrt{Dt}}] = 10^{15} \Rightarrow \frac{x_j}{2\sqrt{Dt}} = \text{erfc}^{-1}\,(2.6 \times 10^{-6}) = 3.32$

$x_j = 3.32 \times 2 \times (\,6.6 \times 10^{-15} \times 600)^{1/2} = 0.132\ \mu\text{m}$

Therefore R_S= 20/0.132 = **150 ohm/square**

(b)

$D \approx h \times D_i^{+}\frac{p}{n_i}$

(c) Yes.

For low concentration diffusion, both diffusion profiles are Gaussian and represented by: $\frac{Q}{\sqrt{\pi Dt}}\exp^{\frac{-x^2}{4Dt}}$

Therefore , can choose same $Q = \frac{2C_s(\sqrt{Dt})_{\text{predep}}}{\pi}$ for As predep

and choose drive-in cycle for As with the same (Dt) of Gaussian

(d) The excess interstitials and vacancies created by ion implantation will enhance dopant diffusion. These excess point defects will recombine with thermal annealing. After they recombine completely, there will be no more enhanced diffusion. That is why this effect is only transient during the dopant diffusion cycle.

For shallow junction formation, the diffusion enhancement during the transient stage will already drive the dopants much deeper than the targeted junction depth. This is not a desirable mechanism.