

PROBLEM SET #7

Issued: Tuesday, Oct. 14, 2014

Due: Friday, Oct. 24, 2014, 8:00 a.m. in the EE 143 homework box near 140 Cory

- **Electroplating**

1. Suppose you want to fabricate MEMS clamped-clamped beam structures on a silicon wafer by electroplating nickel through a photoresist mold similar to the process discussed in the electroplating lecture. Assume the exposed area (which is not covered by the photoresist mold) is 15 cm^2 , the applied current is regulated at a constant level of 20 mA, and nickel cations in the electrolyte are Ni^{2+} . Estimate the time required to electroplate a 2- μm thick nickel structural layer. (Ni has an atomic weight of 58.69 g/mol and a density of 8.9 g/cm^3 .)

The required volume of nickel = $15 \text{ cm}^2 \times 2 \mu\text{m} = 0.003 \text{ cm}^3$

Required weight of nickel, $w = 0.003 \text{ cm}^3 \times \text{density} = 0.003 \times 8.9 \text{ g} = 0.0267 \text{ g}$

Here, current, $I = 20 \text{ mA}$

Atomic weight of nickel, $A = 58.69 \text{ g/mol}$

Avogadro number, $N_A = 6.022 \times 10^{23}$

If the electroplating time is t , charge flown in that time, $Q = It$

Number of nickel ions in Q amount of charge = Q/qn

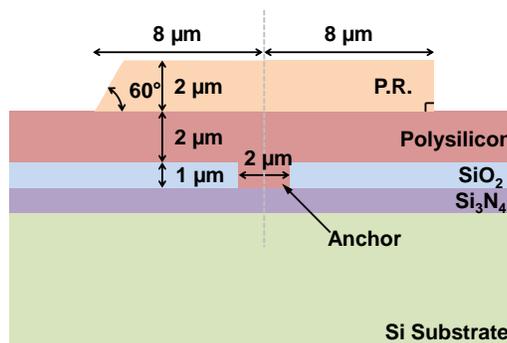
where q is the elemental charge and n = valence of the nickel ions = 2.

Weight of Q/qn nickel ions = $\frac{A}{N_A} \times \frac{Q}{qn} = \frac{AIt}{N_A qn}$

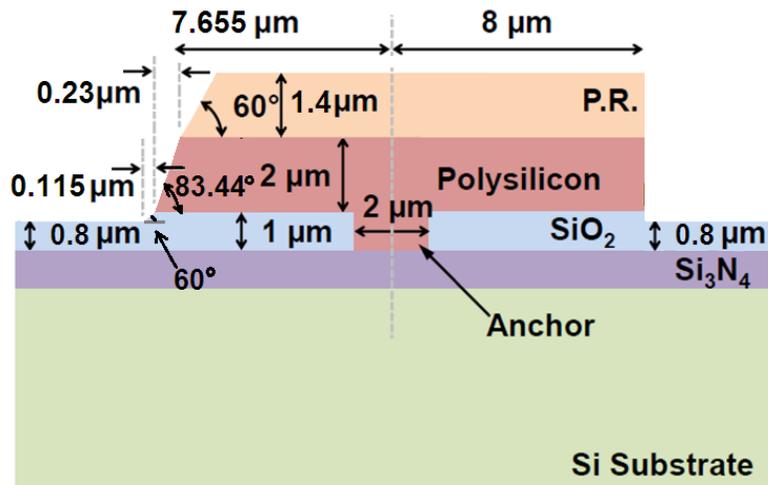
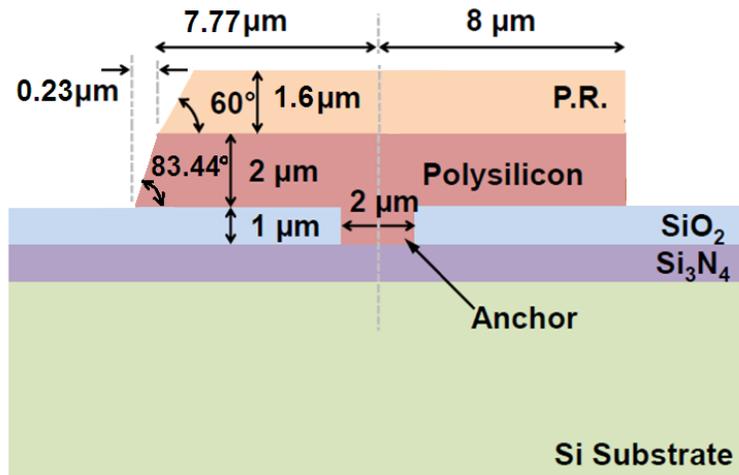
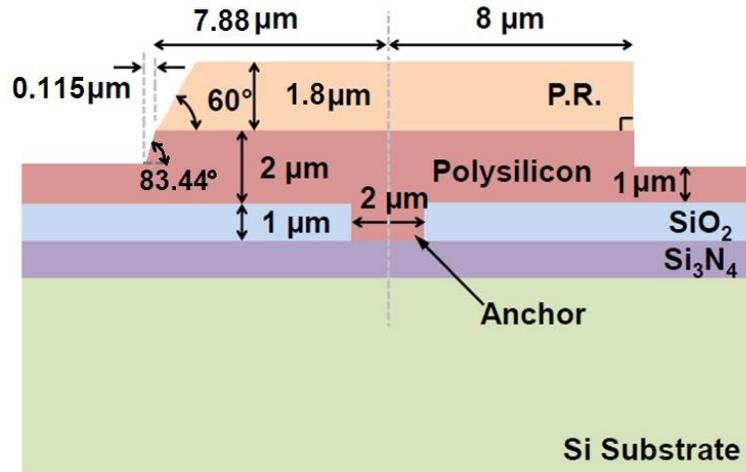
According to the requirements, $w = \frac{AIt}{N_A qn}$, so $t = \frac{wN_A qn}{AI} = 1.22 \text{ hrs}$

- **Etching**

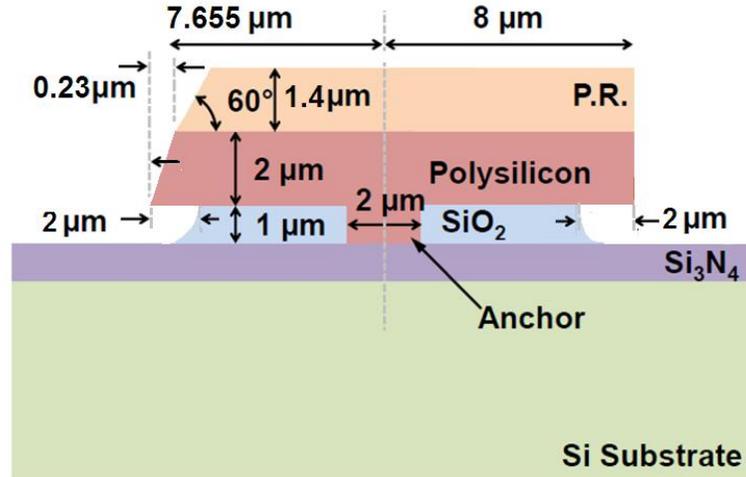
2. The cross-section below is to be etched via reactive ion etching (RIE) of polysilicon. Assume that the RIE is 100% anisotropic for all materials and that the RIE etches polysilicon at a rate of $1 \mu\text{m}/\text{min}$ with the selectivity of polysilicon: SiO_2 :photoresist = 5:1:1.



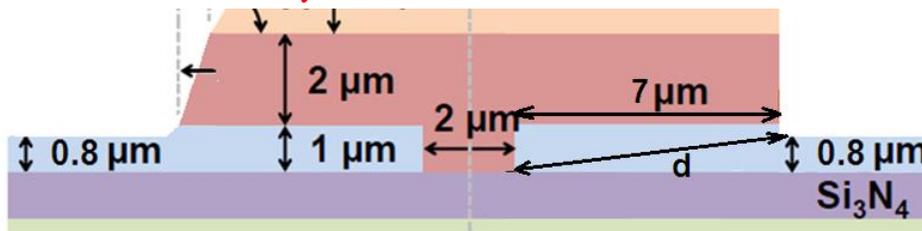
(a) Draw cross-sections of the structure with dimension labeled after etching for (a) 1 min; (b) 2 min; and (c) 3 min.



- (b) (Continuing from (a)) After etching for 3 minutes in part (a), the sample is then dipped in a liquid HF solution to etch the SiO₂ layer. Assuming the SiO₂ etch rate in HF is 2 μm/min, draw the cross-section after etching in HF for 1 min. Estimate the time needed to etch the entire SiO₂ layer.



Time needed to etch the SiO₂ layer = distance to be etched, $d \div$ Etch rate.



The SiO₂ structure on the right has a bigger volume than the structure on the left. So we are considering the time to etch the right one only.

$$d = \sqrt{7^2 + 0.8^2} = 7.04 \mu m$$

So time needed for etching = $7.04/2 = 3.52 \text{ mins}$

3. Suppose in the polysilicon gate patterning lab the deposited polysilicon thickness is $T_{Poly} = 400 \text{ nm}$ with a $\pm 10\%$ variation across the wafer and its etch rate in wet polysilicon etchant, $E.R._{Poly}$, has a $\pm 10\%$ variation.

- (a) What is the smallest percent overetch required to ensure that the polysilicon on the field area is removed? (The percent we're looking for is relative to the main etch time given by $T_{Poly}/E.R._{Poly}$)

Maximum thickness of polysilicon = $1.1T_{Poly}$

Minimum etch rate in wet polysilicon etchant = $0.9E.R._{Poly}$

$$\text{Maximum time required for etching polysilicon completely} = \frac{1.1T_{Poly}}{0.9E.R.Poly} = \frac{1.22T_{Poly}}{E.R.Poly}$$

So required overetch = 22%

- (b) Estimate the worst-case undercut distance of the polysilicon gate due to the main etch and overetch calculated in (a). Assume that the photoresist has an infinite selectivity against the polysilicon etchant.

Assuming the etching to be completely isotropic, the maximum undercut due to the main etch and 22% overetch is given by

$$\begin{aligned} \text{Maximum undercut} &= \text{total etch time} \times \text{maximum etch rate} \\ &= \frac{1.22T_{Poly}}{E.R.Poly} \times 1.1E.R.Poly = 1.344T_{Poly} = 537.78 \text{ nm} \end{aligned}$$

- (c) Continuing from (b), estimate the worst-case variation of the saturation drain current $I_{D(sat)}$ due to the polysilicon undercut on a fabricated NMOS device with a drawn gate length $L = 4 \mu\text{m}$. Assume the lithography step perfectly patterns the photoresist with the same dimensions as that drawn on the mask (i.e., $L = 4 \mu\text{m}$). (Recall that $I_{D(sat)} = \frac{1}{2}\mu C_{ox} \frac{W}{L} (V_G - V_{th})^2$.)

Ideal gate length, $L = 4 \mu\text{m}$

Worst case gate length,

$$L' = (4 - 2 \times \text{maximum undercut}) \mu\text{m} = (4 - 2 \times 0.5378) \mu\text{m} = 2.924 \mu\text{m}$$

Hence worst-case variation of the saturation drain current

$$\frac{I_{D(sat)}(\text{ideal}) - I_{D(sat)}(\text{worst case})}{I_{D(sat)}(\text{ideal})} \times 100\% = \frac{L - L'}{L} \times 100\% = 26.89\%$$

• Ion Implantation

4. Problem 5.3 and 5.8 in the textbook.

5.3

Projected range, $R_p = 1 \mu\text{m}$.

Required energy = 900 keV [From Figure 3.1]

Straggle, $\Delta R_p = 0.19 \mu\text{m}$ [From Figure 3.2]

5.8

Implant energy = 20 keV

Projected range, $R_p = 0.023 \mu\text{m} = 23 \text{ nm}$. [From Figure 3.1]

Straggle, $\Delta R_p = 0.012 \mu\text{m} = 12 \text{ nm}$ [From Figure 3.2]

Peak concentration, $N_p = \frac{Q}{\sqrt{2\pi}\Delta R_p} = \frac{10^{15}}{\sqrt{2\pi} \times 0.012 \times 10^{-4}} = 3.325 \times 10^{20} \text{ cm}^{-3}$

Background concentration, $N_B = 10^{16} \text{ cm}^{-3}$

Junction depth, $x_j = R_p + \Delta R_p \sqrt{2 \ln \left(\frac{N_p}{N_B} \right)} = 77.759 \text{ nm}$

