Exercises

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Processing part (chapter 2)

3.1 How long does it take to grow 100 nm of oxide in wet oxygen at 1000 °C (assume 100 silicon)? In dry oxygen? Which process would be preferred?

Oxide growth

$x_i = 100$ nm thick layer $\rightarrow 100 \cdot 10^{-9}$ m $= 10^{-7}$ m

wet oxygen 1000 °C $\rightarrow$ 1273 K

$C_1 = 2{,}14 \cdot 10^{2}$ µm/h

$C_2 = \frac{8{,}95}{1{,}68} \rightarrow 5{,}327 \cdot 10^{7}$ µm/h

(1,68 — <100> orientation)

$E_1 = 0{,}71$ eV $\quad E_2 = 2{,}05$ eV

$B = C_1 \cdot e^{-E_1/kT} = 0{,}3308$ µm/h

$k = 8{,}61739 \cdot 10^{-5}$ eV/K

$\frac{B}{A} = C_2 \cdot e^{-E_2/kT} = 0{,}4080$ µm/h

$x_i = 0{,}1$ µm

$T = \frac{x_i^2}{B} + \frac{x_i}{B/A} = 0{,}275$ h $= 16{,}52$ min

$= 16$ min 31 s

Ch 2 ex 9

Length to etch $L = 100\,\mu m$

Etch rate $R = 1\,\mu m/min$ for sacrificial layer.

a) Time $s = \frac{L}{R} = \frac{100\,\mu m}{1\,\mu m/min} = 100\,min = 1\,hour\ 40\,min$

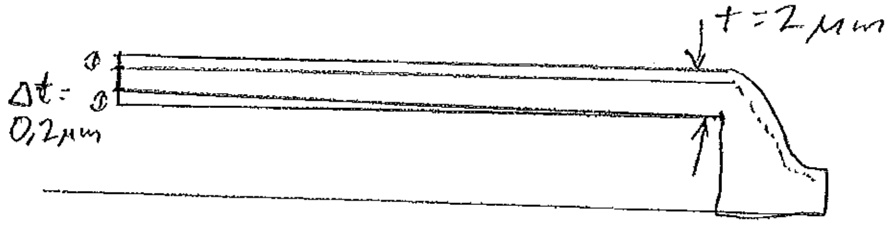
b) Selectivity 500:1

Starting point: Same etch time as oxide.

Etch depth $\frac{100\,\mu m}{500} = 0{,}2\,\mu m$

End point: Nothing removed

c)



d) $t_{min} = 2 - 0{,}2 - 0{,}2 = 1{,}6\,\mu m$

$t_{max} = 2 - 0{,}2 = 1{,}8\,\mu m$

EXERCISES

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1) Calculate the maximum deflection and maximum stresses for a square silicon membrane of thickness 10 µm and side length 2 mm for an applied pressure of 1000 Pa.
For silicon, E = 190 GPa and ν =0.28.

2) A silicon cantilever beam with a piezoresistor located at the point of maximum stress is subjected to a point load Q at the end of the beam. Q is 10 µN, the length of the beam is 1000 µm, and the beam thickness is 3 µm. Calculate the beam width that results in a 3% resistance change for the piezoresistor due to the load Q. Assume the beam lies perpendicular to the silicon <110> lattice direction.

3) What is the resonant frequency F_o for a silicon cantilever beam 1000 µm long, 100 µm wide, and 3 µm thick? The density of silicon is 2.3 g/cm³.

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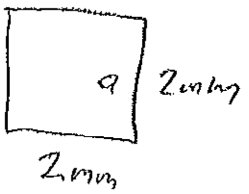
1)



Membrane stiffness $D = \frac{Et^3}{12(1-\nu^2)}$

$$D = \frac{190 \cdot 10^9 \cdot (10 \cdot 10^{-6})^3}{12(1-0{,}28^2)} = 1{,}718 \cdot 10^{-5} \text{ Pam}^3$$

$$W_{max} = 0{,}001265 \cdot \frac{Pa^4}{D} = 0{,}001265 \cdot \frac{10^3 \cdot (2 \cdot 10^{-3})^4}{1{,}718 \cdot 10^{-5}}$$

$$= 1{,}18 \cdot 10^{-6} \text{ m} = 1{,}18 \text{ µm}$$

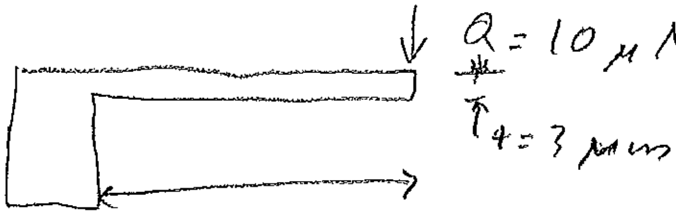
Max longitudinal stress $\sigma_l = 0{,}3081 \cdot \frac{Pa^2}{t^2} = 0{,}3081 \cdot \frac{10^3 (2 \cdot 10^{-3})^2}{(10 \cdot 10^{-6})^2}$

$$= 12{,}3 \text{ MPa}$$

Max transverse stress $\sigma_t \approx \nu \sigma_l = 0{,}28 \cdot 12{,}3 = 3{,}5 \text{ MPa}$

Answer: Deflection $w = 1{,}18$ µm
Max stress: $\sigma_l = 12{,}3$ MPa

2



$\pi_{44} = 138,1 \cdot 10^{-11}$

<110> direction $\quad \frac{\pi_{44}'}{2} = 70 \cdot 10^{-11}$

$$\frac{\Delta R}{R} = \frac{\pi_{44}}{2}(\sigma_l - \sigma_t) \approx \frac{\pi_{44}}{2}\sigma_l = 3\%$$

$$\sigma_{MAX} = \frac{0,03}{70 \cdot 10^{-11}} = 4,29 \cdot 10^{7}\ Pa$$

$$\sigma_{MAX} = \frac{QL \cdot t}{2I} \quad \text{where } I = \frac{at^3}{12}$$

$$\sigma_{MAX} = \frac{QLt}{2} \cdot \frac{12}{at^{3}} = \frac{QL \cdot 6}{at^2}$$

$$a = \frac{6Q \cdot L}{t^2 \cdot \sigma_{MAX}} = 155\ \mu m$$

Answer: 155 μm beam width will result in 3% resistance change for the proposed design.

3

$$F_0 = 0{,}161 \frac{t}{L^2} \left(\frac{E}{\rho}\right)^{1/2}$$

$$\rho = 2{,}3 \ g/cm^3 = 2{,}3 \cdot 10^3 \ g/dm^3 = 2{,}3 \cdot 10^6 \ g/m^3$$
$$= 2{,}3 \cdot 10^3 \ kg/m^3$$

$$F_0 = 4{,}39 \ kHz$$

Magnetic sensors

Ex 5:3 Si plate doped

$N_D = 4 \cdot 10^{14}$ cm^{-3} $N_A = 4{,}001 \cdot 10^{+14}$ cm^{-3}

p-type $p \approx N_A - N_D = 1 \cdot 10^{11}$ cm^{-3}

$n \approx 0$

$$R_H = -\frac{r_n}{qp} = \frac{-0{,}7}{1{,}602 \cdot 10^{-19} \cdot 10^{11}} =$$

$$= 4{,}4 \cdot 10^{7} \text{ cm}^3/C$$

Ex 5:5

a) $R_H = \dfrac{-r_n}{qn}$ $nt_{min} = 1 \cdot 10^{12}$ cm^{-2}

$nt_{max} = 1 \cdot 10^{13}$ cm^{-2}

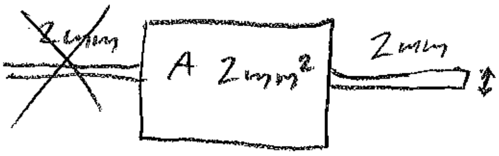
$r_n = 1{,}15$ $q = 1{,}602 \cdot 10^{-19}$

$R_H = 7180$ cm^2/C

b) $V_H = \dfrac{R_H \cdot I \cdot B}{t} =$ $V_{H\,max} = 62$ mV

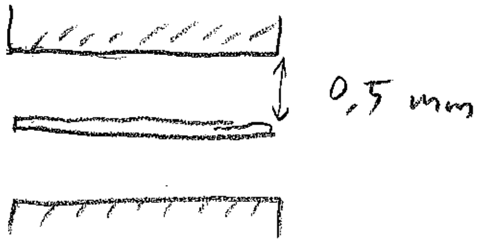
$V_{H\,min}$ $6{,}2$ mV

Floating membrane lecture 7



$W = 200\,\mu m$

$D = 5\,\mu m$



$K_{Si} = 150\ W/Km$

$K_{Ar} = 18\ mW/Km$

a) silicon beam

$$R_{th} = \frac{L}{W} \cdot \frac{1}{K_{Si} D} = \frac{2 \cdot 10^{-3}}{200 \cdot 10^{-6}} \cdot \frac{1}{150 \cdot 5 \cdot 10^{-6}}$$

$$= 1{,}33 \cdot 10^{4}\ K/W$$

Gas

$$R_{th} = \frac{L}{K_{Ar} \cdot A} = \frac{0{,}5 \cdot 10^{-3}}{18 \cdot 10^{-3} \cdot 2 \cdot 10^{-6}} = 1{,}39 \cdot 10^{4}\ K/W$$

Two gas ways. $\Rightarrow R_{th}^{Ar} = \frac{1{,}39 \cdot 10^{4}}{2} = 6{,}94 \cdot 10^{3}\ K/W$

The thermal transport in the beam is half that of the conduction in the gas.

b) $c_p = 1{,}6\ MJ/m^3K$ for Si

Thermal membrane capacity

$$C = V \cdot c_p = 2 \cdot 10^{-6} \cdot 5 \cdot 10^{-6} \cdot 1{,}6 \cdot 10^{6} = 1{,}6 \cdot 10^{-5}\ J/K$$

$$\tau_{beam} = C \cdot R_{th}^{beam} = 1{,}6 \cdot 10^{-5} \cdot 1{,}33 \cdot 10^{4} = 0{,}21\ s$$

$$\tau_{gas} = C \cdot R_{th}^{gas} = 1{,}6 \cdot 10^{-5} \cdot 6{,}94 \cdot 10^{3} = 0{,}11\ s$$