EE C245 / ME C218
Introduction to MEMS Design
Fall 2003

Homework 6: Integration and Microfluidics
Solutions
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1. **Integrated SOI MEMS**.
   a. Is this process a MEMS-first, CMOS-first, or interleaved integration process? [CMOS-first]
   b. What layers does the triple-stack substrate consist of? Include thickness, material, and purpose. [10 μm mirror layer made of Si (100) and including optical coatings, 10-80 μm thick sacrificial spacer layer made of Si (100) which sets gap, full thickness handle Si (100) wafer for actuation electrodes and interconnects]
   c. How many masking steps does the MEMS portion of this process flow add to the circuit process? [6]
   d. Referring to Figure 3, what is the circuit isolation trench filled with? [lined with LPCVD SiO_2 and filled with doped polysilicon].
   e. During the MEMS release step, why is removing the oxide on the back of the mirror especially important? [A 1 μm thick film would introduce substantial mirror curvature if left only on the backside of the mirror.]

2. **Fluidics: Dimensional Analysis.**

	viscosity	density	
Sweet clover honey	8750 cP	1.42 g/mL	
Olive oil	81 cP	0.92 g/mL	
Water	1.025 cP @ 25°C	1 g/mL	(OK if $\eta = 8.91 \times 10^{-4}$ Ns/m^2 from
Molasses	50,000 cP	1.50 g/mL	lecture notes used instead.)

Hydraulic diameter D_h for hemicylindrical channel = 4×(area)/perimeter
= $2\pi r^2/(\pi r+2r)$
= 61.1 μm

Reynolds number (microfluidic chip) = $\rho V D_h/\eta$
= $(1000\ \mathrm{kg/m^3})(0.001\ \mathrm{m/s})(61.1\times10^{-6}\ \mathrm{m})/(1.025\times10^{-3}\ \mathrm{Pa\ s})$
= 0.0596 (or 0.0686 for $\eta = 8.91 \times 10^{-4}$ Ns/m^2)

a) 1 mm/s? Use olive oil.
Reynolds number (scale model, olive oil)
= $(920\ \mathrm{kg/m^3})(0.001\ \mathrm{m/s})(6.11\times10^{-3}\ \mathrm{m})/(81\times10^{-3}\ \mathrm{Pa\ s})$
= 0.0694

b) 6 mm/s? If you saw the correction to 6 cm/s, use honey. Otherwise, use olive oil.
Reynolds number (scale model, honey)

$$= (1420\ kg/m^3)(0.06\ m/s)(6.11\times10^{-3}\ m)/(8750\times10^{-3}\ Pa\ s)$$
$$= 0.0595$$

c) Suggest a liquid you could use for v_{model} = 100 mm/s. Or, for 340 mm/s (correction). Molasses works for 340 mm/s (Re = 0.062). Anything will work if ρ/η in SI units is ~30.

http://www.engnetglobal.com/tips/convert.asp?catid=10 : this website is useful for converting crazy units, like slugs/ft sec!

While writing this problem, I found out that because ketchup is non-Newtonian, it has a reduced viscosity at a high shear rate, which is why it can explode out of the bottle if you whack the bottom of the bottle!

3. **Microfluidics: Pumping.**

a. The pressure drop ΔP needed to achieve a flowrate, Q, of 0.02 μL/s

$$\Delta P = 12\eta LQ/Wh^3 = 12(1.025\times10^{-3}\ Pa\ s)(0.01m)(2\times10^{-11}\ m^3/s)/(100\times10^{-6}m)(20\times10^{-6}m)^3$$
$$= 3.075\ kPa\ (\text{or } 2.68\ kPa \text{ for } \eta = 8.91\times10^{-4}\ Ns/m^2)$$

b. The pressure drop needed if the depth is reduced to 2 μm.

For reduction of depth by factor of 10, ΔP goes up by 1000:

$$= 3.075\ MPa\ (\text{or } 2.68\ MPa)$$

c. The electric field needed to achieve a volumetric flowrate Q by electroosmosis of 0.02 μL/min. . The glass wall potential φ_w is 100 mV, $\varphi_w = \sigma_w L_D/\varepsilon$, and the Debye length for pure water is 1 μm.

$Q = Vdw$; where V is the velocity, d is the depth and w is the width.

$V = \sigma_w E L_d/\eta$ from lecture notes

Using $\varphi_w = \sigma_w L_D/\varepsilon$, $(100\times10^{-3}V) = \sigma_w(10^{-6}\ m)/(80)(8.85\times10^{-12}\ C^2/Nm^2)$

$\sigma_w = 7.1\times10^{-5}\ C/m^2$

$$E = Q\eta/(dw\sigma_w L_d)$$
$$= (2\times10^{-11}\ m^3/min)(1\ min/60\ s)(1.025\times10^{-3}\ Pa\ s)/(20\times10^{-6}m)(100\times10^{-6}m)(7.1\times10^{-5}\ C/m^2)(10^{-6}\ m)$$
$$= 2413\ V/m\ (= 2.41\ kV/m = 24.1\ V/cm)\ (\text{or } 2102\ V/m \text{ using other } \eta \text{ value.})$$

4. **Microfluidics: Electroosmotic Injection**.

a. Sample is electrokinetically driven from sample well 1 to sample waste well 2 with pinching from side channels 3 and 4. $V_1>V_2$, $V_{3,4}>V_{J-A}$.
b. For a short time, flow is reversed from sample waste 2 to the sample well 1. $V_2>V_1$, $V_{3,4}=V_{J-B}$.
c. Buffer is driven from left to right with pullback into sample well 1 and sample waste well 2, resulting in injection of narrow sample plug. $V_{1,2}<V_{J-C}$, $V_3>V_4$.