INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Mid-Autumn Semester Examination 2024-25

Date of Examination: Slot D Session __ Duration 2 hrs

Subject No. : CH62049 Subject Name: Microscale Transport Process

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required: No

Special Instructions (if any): Assume any data you feel are missing

---

Q1. In reference to the Deal and Grove Model, consider a case, where the flux from the gas phase to the oxide surface should be considered in tandem with the diffusion of oxygen through SiO_2 layer, and the reaction with Si. The flux from the gas phase to the oxide surface can be approximated as h ($C_g^* - C_s$), and is to be included in the calculation for thickness of oxide layer. Here, h is a constant representing interfacial mass transfer, C_g^* and C_s are representative concentration of oxygen in the gas phase and the concentration of oxygen in the oxide phase respectively. Assuming initial thickness of SiO_2 as zero, derive an expression for SiO_2 thickness as function of time.

5 Marks

Q2. Obtain the equations under the two following conditions to express velocity of a liquid front in a horizontal capillary that represent a feature of a mold with ambient air in the void space.

i) The other end of the capillary is open to atmosphere

ii) The other end of the capillary is closed

Obtain the equations that will lead to the position of the front as a function of time for the above two cases. Derive an expression for the position of the front in the two cases, and if it is not possible to obtain analytical expression, suggest a way to obtain the information.

5 Marks

Hagen Poiseuille Equation: $\frac{\Delta P}{L} = \frac{8v\mu}{r^2}$

Q3.

(i) Compare through schematic pictures the shapes of etched groove on silicon by wet etching, physical dry etching, chemical dry etching, reactive ion etching, and physicochemical dry etching with inhibitor respectively. Give justification for the shape in each case.

(ii) What happens to the spin-coated film in the two limiting cases, where the spinning rate is too high or too low? Give justification.

(iii) What is the role of (i) pressure in low pressure CVD, and (ii) plasma in plasma-enhanced CVD?

(iv) Define mixing quality and mixer effectiveness.

4×2=8 Marks

Q4. Answer the following (6x1 = 6)

Consider both the statements from i) to iv) and **even if one of them** is wrong, mark the entire answer as false, else mark it true. **You must provide a one-sentence explanation.**

i) At low temperatures, viscous forces are dominant in the vapor flow down the heat pipe. At extremely low operating temperature, the vapor pressure difference between the closed ends of the evaporator may be extremely small. Hence the viscous forces within the vapor region may prove to be dominant, thereby limiting the heat pipe operation.

Inside the heat pipe, as the vapor and liquid move in the opposite directions, a shear force exists at the vapor-liquid interface. If the vapor velocity is high, a limit can be reached when the liquid is torn from the surface of the wick and entrained in the vapor.

True

False

ii) In a micromixer, the fluids rest for few seconds or less, which is detrimental to slow reactions. Reactions with high energy demand are also deemed unsuitable for micro devices.

True

False

iii) The ratio of wall thickness to channel diameter is high in microchannel devices. Hence, a considerable amount of heat is transferred through the wall parallel to the flow direction, which lowers the driving temperature difference and decreases the amount of the transferred heat.
The parasitic heat flux must be considered for highly conductive wall materials like copper, alumina, or silicon, and for low heat capacity flow of the transfer media, such as gases or low flow velocities.
True
False

iv) For high flow rates, small channels induce a higher-pressure loss due to their high surface-to-volume ratio. Hence, high viscosity fluids are preferred for application in microchannels due to a tolerable pressure loss
In curved channels, the hydraulic diameter influences the pressure loss only marginally, but convective effects determine the pressure loss coefficient ξ. With increasing device length dimensions, the pressure loss becomes proportional to the square of the Reynolds number.
True
False

v) What is the significance of Jacob number? Choose the correct option with reason
Ratio of latent heat for reaching saturation temperature to the sensible heat
Ratio of sensible heat for reaching saturation temperature to the latent heat
Ratio of latent heat for reaching less than saturation temperature to the sensible heat
Ratio of sensible heat for reaching less than saturation temperature to the latent heat

vi) Capillary pressure difference near evaporator section in heat pipe is more in the presence of (add one line explanation)
a. No body forces
b. Adverse body forces
c. Surface forces
d. None of them

Q4. Answer these questions briefly (3x2=6)

i) It is desired to fabricate a series of equidistant microchannels on a silicon wafer with a semicircular cross-section and make the channel interiors super hydrophobic. Briefly describe the strategy to make this design. Would a top-down methodology be more advantageous to achieve this design over a bottom-up process? Explain.

ii) Discuss the importance of surface tension while choosing a coolant for a micro-heat pipe.

iii) Explain the phenomena "Flow reversal" in a few sentences.

Useful relations

$$\Delta p=\left(C_f\frac{l}{d_h}+\zeta\,\mathrm{Re}\right)\frac{\rho v^2}{2}\frac{\mathrm{Re}}{d_h^2} \qquad \Delta p=P_L-P_V=-\sigma K \qquad \Delta P=\sigma_{lv}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)=\sigma_{lv}K$$

$$\Delta p=\left(C_f\eta l+\zeta\frac{V}{N}\right)\frac{\rho}{2}\frac{V}{N d_h^4} \qquad \Delta p=\left(C_f\nu\frac{l}{d_h}+\zeta d_h\bar{w}\right)\frac{\rho}{2}\frac{\bar{w}}{d_h}=C_f\frac{\eta l}{2d_h}\bar{w}+\zeta\frac{\rho}{2}\bar{w}^2$$

$$Bo=\frac{g(\rho_l-\rho_v)\dot{L}^2}{\sigma} \qquad Ca=\frac{\mu V}{\sigma} \qquad We=\frac{LG^2}{\rho\sigma} \qquad Ja=\frac{\rho_L}{\rho_V}\frac{c_{p,L}\Delta T}{h_{LV}}$$