Electrical Engineering – Written PhD Qualifier Exam
Spring 2014

Friday, February 7th 2014

Please do not write your name on this page or any other page you submit with your work. Instead use the exam number

Student exam Number: ___________________________

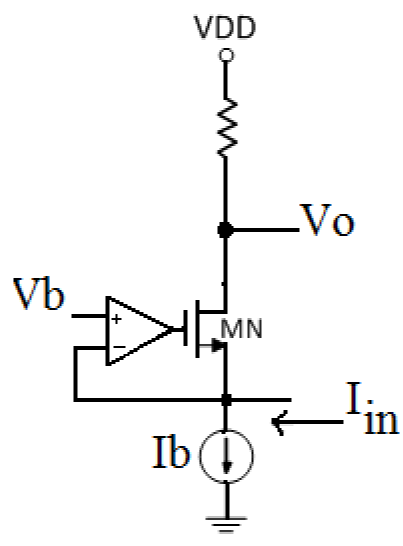
Monolithic Amplifier Circuits
EE202

Problem 1 (20 Points)

A- There exist four types of amplifier circuits depending on the nature of the input and the nature of the output (current or voltage). For the four different types fill in the following table with either {High} or {Low} [8points]

	Input Resistance (Rin) [1point each]	Output Resistance(Ro) [1point each]
Voltage Amplifier (A=Vo/Vin)		
Current Amplifier (A=Io/Iin)		
Transresistance Amplifier (Rm=Vo/Iin)		
Transconductance Amplifer (Gm=Io/Vin)		

B- For the circuit shown, assume all transistors working in saturation. [12 points] (State any reasonable assumptions you make)



Calculate

1- Input Resistance (Rin) [4 points]
2- Output Resistance (Ro) [4 points]
3- Transresistance gain (Rm=Vo/Iin) [4 points]

Monolithic Amplifier Circuit
EE202

Problem 2 (20 Points)

The buffer circuit shown in Fig 1.A suffers from a DC voltage offset between the input voltage and the output voltage. The circuit proposed in Fig 1.B is designed to reduce such DC offset.

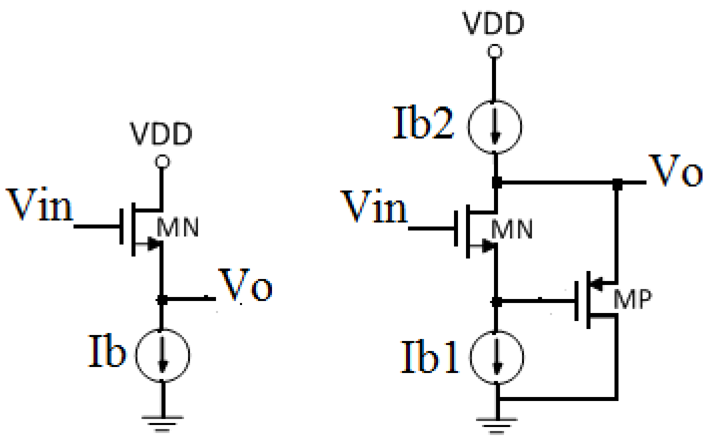


Fig 1.A Fig 1.B

Calculate the following (State any reasonable assumptions you make):

1- DC voltage offset between Vin and Vo for Circuit A [2 points]
2- AC voltage gain (Vo/Vin) for Circuit A [3 points]
3- How can you reduce the DC offset for Circuit A? How does your proposal affect the AC voltage gain? [3 points]
4- DC voltage offset between Vin and Vo for Circuit B [4 points]
5- AC voltage gain (Vo/Vin) for Circuit B [4 points]
6- How can you reduce the DC offset for Circuit B? How does your proposal affect the AC voltage gain? [4 points]

Solid State Device Laboratory
EE203

Problem 1 (20 Points)

1a) Arrange the following processes to establish the correct process flow for Si wafer fabrication. [12 points]

i. Wafer lapping
ii. Electronic inspection
iii. Wire saw
iv. Laser mark
v. Epitaxial deposition
vi. Crystal growth
vii. Edge profiling
viii. Wafer etching
ix. Wafer cleaning
x. Crystal eval./crop/grind/notch
xi. Wafer polishing
xii. Finished wafers shipping in cassette.

1b) Write down the growth rate and the process temperature of the most commonly used precursor gas for future generation PMOS channel material? [4 points]

1c) Briefly explain the advantages of CVD film growth with good uniformity in the regime that is limited by gas transport (as opposed to reaction limited). Mention factors that control film growth rate and the stability of this growth rate. [4 points]

Solid State Device Laboratory
EE203

Problem 2 (20 Points)

2a) To calculate the diffusion length for boron in an un-doped Si crystal for 30 min at 900^{o}C, what parameters you need to know and how can you collect them? [4 points]

2b) Draw the step coverage vs. deposition rates plot with various deposition techniques. [6 points]

2c) How dry-wet-dry cycle helps good quality oxide growth? [3 points]

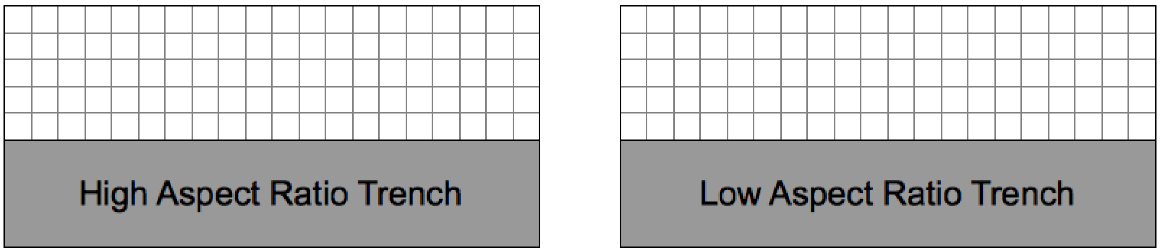
2d) What are the four thermal oxide charges? Draw their location. [4 points]

2e) What is the difference between Rapid Thermal Processing and Rapid Thermal Annealing? [3 points]

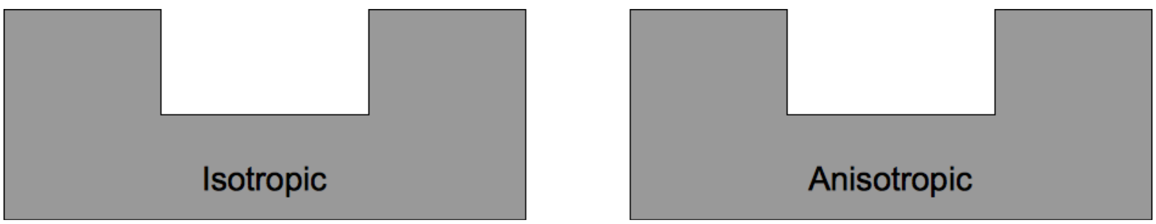
Introduction to MEMS
EE205

Problem 1 (20 Points)

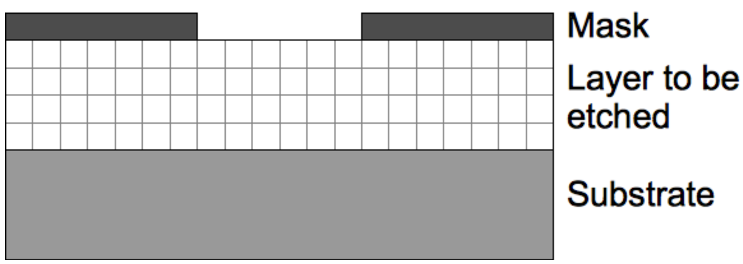
a) Using the grids below draw a high aspect ratio trench and a low aspect ratio trench. (Make both have the same cross sectional area) (4 marks)



b) On the following two trench structures show an ideal isotropic deposition and an ideal anisotropic deposition. Assume a point source far above the center of the sample. (4 marks)



c) Draw on the following structure an ideal isotropic etch exposing the same width of substrate as the opening in the mask. (the grid is there to help you draw it) Assume there are no mass transport limitations. (4 marks)



d) Name 4 forms of heat transfer. (4 marks)

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e) What are the two main types of electrons used to image samples in an SEM. (4 marks)

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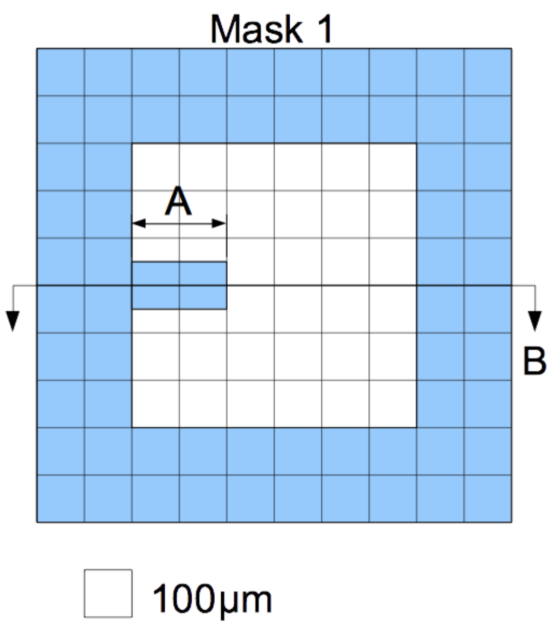
Introduction to MEMS
EE205

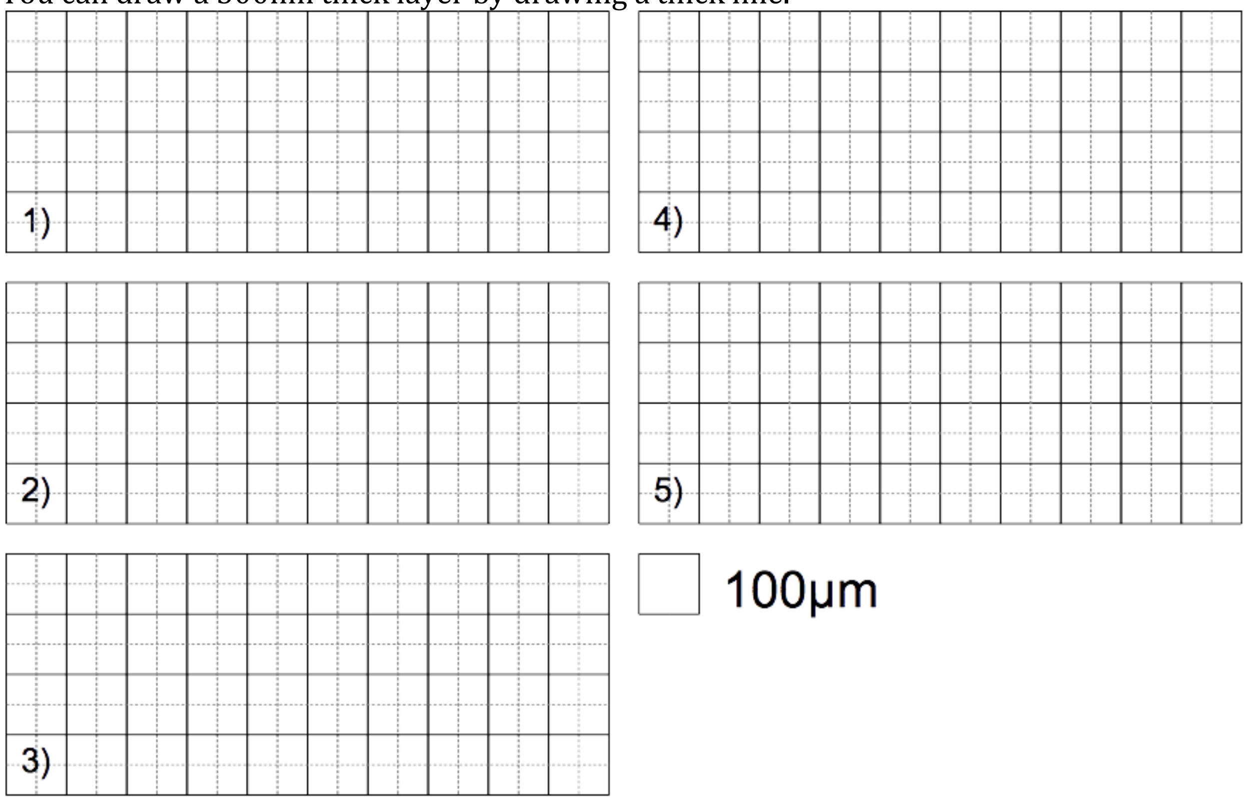
Problem 2 (20 Points)

Use the following fabrication sequence and depicted mask to solve the following questions. Note only the blue (dark) colored areas on the masks are opaque, the grid and notations are just so you can see scale. Assume perfect alignment.

1. Start with a 354μm thick <100> silicon wafer.
2. Thermal growth of SiO_2 to a thickness of 500nm.
3. Pattern the SiO_2 layer with an anisotropic dry etch masked using a Positive resist and Mask 1 aligned to the wafer flat.
4. Put in a bath of KOH at 80°C (assume infinite etch selectivity) and etched to completion.
5. Rinse the structure off followed by super critical CO_2 drying.



a) Draw cross-section B of the structure for each step of the fabrication sequence. You can draw a 500nm thick layer by drawing a thick line.



b) What type of structure have you fabricated?

c) If force X was used to displace the tip of the structure by 50nm. How much would the tip displace given the same force if length A was doubled (2A)?

d) If force X was used to displace the tip of the structure by 50nm. How much would the tip displace given the same force if the SiO_2 thickness was 250nm?

Semiconductor Optoelectronic Devices
EE208

Problem 1 (20 Points)

(a) Briefly explain the followings:

- (i) Bandgap [1 pts]
- (ii) Direct and indirect gap semiconductors [1 pts]
- (iii) Basic principle of operation of diodes (p-n junction) [2 pts]
- (iv) Zener and Avalanche breakdown effects [2 pts]

(b) Sketch the band diagrams (band-alignment) for (i) homojunction [3pts], and (ii) heterojunction [3 pts] at equilibrium and under forward bias.

(c) Design (sketch) a double heterostructure AlGaAs/GaAs laser structure [2 pts]. Suggest two methods for improving the temperature characteristic of a double-heterostructure laser [3 pts].

(d) Strained quantum-well structure is known to induce splitting of heavy-hole (hh) and light-hole (lh) in the valance band. Explain why splitting of hh and lh helps to improve the threshold current of a semiconductor laser? [3 pts]

Optoelectronic Devices
EE208

Problem 2 (20 Points)

(a) Three important optical processes in semiconductor are (i) absorption, (ii) spontaneous emission and (iii) stimulated emission. With the aid of simple energy band diagrams, explain (i)-(iii) [3 pts].

(b) List optical/optoelectronic devices (two devices each) that utilize the effect of (i) absorption, (ii) spontaneous emission and (iii) stimulated emission [6 pts].

(b) Photodetectors and solar cells can be made using simple p-n configuration. With the aid of I-V characteristics and simple biasing or load circuits, briefly discuss the operations of these two devices. [6 pts]

(c) Discuss, from the angle of fundamentals of optics and materials science, methods for improving the conversion efficiency of a solar cell. [5 pts]

Electromagnetic Theory
EE221

Problem 1 (20 points)

Assume that an electric field given by $\mathbf{E}^{\text{inc}}(x,y) = \hat{a}_z E_0 e^{-jk_0(x\cos\theta_i + y\sin\theta_i)}$, which originates in the half space $-\infty < x < 0$, $-\infty < y,z < \infty$ with permeability μ_0 and permittivity ε_0, is incident on the half space $0 < x < \infty$, $-\infty < y,z < \infty$ permeability μ_0 and permittivity $\varepsilon_{\text{p}} = \varepsilon_0(1 - \omega_{\text{p}}^2/\omega^2)$. Here, θ_i is the angle of incidence, ω_{p} is the plasma frequency and ω and $k_0 = \omega\sqrt{\varepsilon_0\mu_0}$ are the frequency and wavenumber of the incident field, respectively. Find expressions of reflected and transmitted electric fields, $\mathbf{E}^{\text{ref}}(x,y)$ and $\mathbf{E}^{\text{tra}}(x,y)$ for $\omega = \omega_{\text{p}}$.

Electromagnetic Theory
EE221

Problem 2 (20 points)

(a) (10 points) Let $\mathbf{E}(\mathbf{r}) = \hat{a}_x E_0 \sin kz$ and $\mathbf{H}(\mathbf{r}) = \hat{a}_y (E_0/\eta)\cos kz$ define an electromagnetic field. Here, $k = \omega\sqrt{\varepsilon\mu}$ and $\eta = \sqrt{\mu/\varepsilon}$ are the wave number and impedance and ε and μ are the permittivity and permeability, respectively.

(i) (8 points) Show that the velocity of energy propagation is given by

$$v_e = \frac{1}{\sqrt{\varepsilon\mu}} \frac{\sin(2kz)\sin(2\omega t)}{1 - \cos(2kz)\cos(2\omega t)} .$$

(ii) (2 points) Show that $v_e \le 1/\sqrt{\varepsilon\mu}$ is always satisfied.

Mathematical identities you <u>may</u> want to use:

$\sin(2x) = 2\sin(x)\cos(x)$

$\cos(2x) = \cos^2(x) - \sin^2(x) = 1 - 2\cos^2(x) = 2\sin^2(x) - 1$

(b) (10 points) Let $\mathbf{E}(\mathbf{r}) = \hat{a}_x (Ae^{-jkz} + Ce^{jkz})$ define an electric field, where A and C are real numbers, $k = \omega\sqrt{\varepsilon\mu}$ is the wave number and ε and μ are the permittivity and permeability, respectively.

(i) (8 points) Assuming $A \ne C$, show that the phase velocity of this wave is

$$v_p = \frac{1}{\sqrt{\varepsilon\mu}} \left[\frac{A+C}{A-C}\cos^2(kz) + \frac{A-C}{A+C}\sin^2(kz) \right].$$

(ii) (2 points) Describe what happens when $A = C$.

<u>Hint:</u> Bring the expression of $\mathbf{E}(\mathbf{r})$ into a form where you can clearly identify the phase of the field.

Mathematical identities you <u>may</u> want to use:

$e^{jx} = \cos(x) + j\sin(x)$

$a + jb = \sqrt{a^2 + b^2}\, e^{j\tan^{-1}(b/a)}$

$\tan(x) = \sin(x)/\cos(x)$

$\frac{d}{dx}\tan(x) = 1/\cos^2(x), \quad \frac{d}{dx}\tan^{-1}(x) = 1/(1 + x^2)$

Microwave Circuits
EE 223

Students are allowed to use calculators and the formula sheet provided

Problem 1 (20 points)

A 6 m long TEM transmission line having a Z_o of 150 Ω is driven by a source with $V_g(t) = 5\cos(8\pi x10^7 t)$ V and $Z_g = Z_o$. If the line has a relative permittivity of 2.25 (corresponding to a phase velocity of $2x10^8$ m/s) and is terminated in a load Z_L = 150 –j50 Ω , find

i) the wavelength on the line [2 marks],
ii) the reflection coefficient at the load [3 marks],
iii) the input impedance [3 marks],
iv) the input voltage (in the phasor domain and in the time domain) [6 marks]
v) the power available from the source and the power delivered to the load [6 marks].

Microwave Circuits
EE 223

Students are allowed to use calculators and the formula sheet provided

Problem 2 (20 points)

A 4cm square waveguide is filled with a dielectric with complex permittivity $\varepsilon_c = 16\varepsilon_o(1 - j10^{-4})$ and is excited with the TM_{21} mode. If the waveguide operates at 10% above the cutoff frequency,

(i) Calculate attenuation α_d (15 marks)?

(ii) How far can the wave travel down the guide before its magnitude is reduced by 20%? (5 marks)

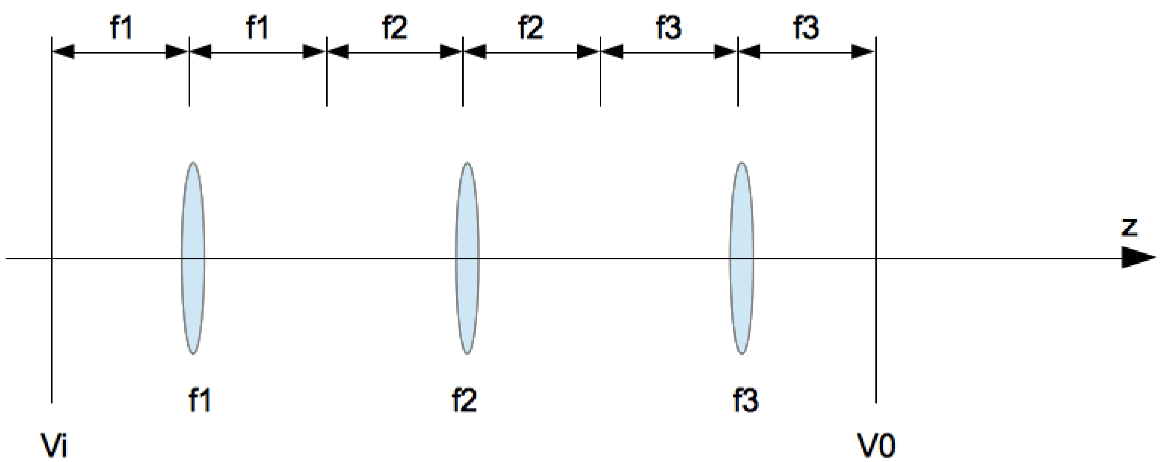
Hint: The imaginary part of the permittivity can be approximated as σ/ω. The wave amplitude reduces exponentially. You can use the following formula for the dielectric loss $\alpha_d = \frac{\sigma n}{2\sqrt{(1-\left(f_c/f\right)^2}}$ (where σ is the conductivity of the dielectric and *n* is the intrinsic impedance of the medium)

Principles of optics
EE 231

Students are allowed to use calculators and the approved cheat sheet

Problem 1 (20 points)

An input disturbance Vi(x)=Exp(-x^2/w^2) is launched in a system sketched below:



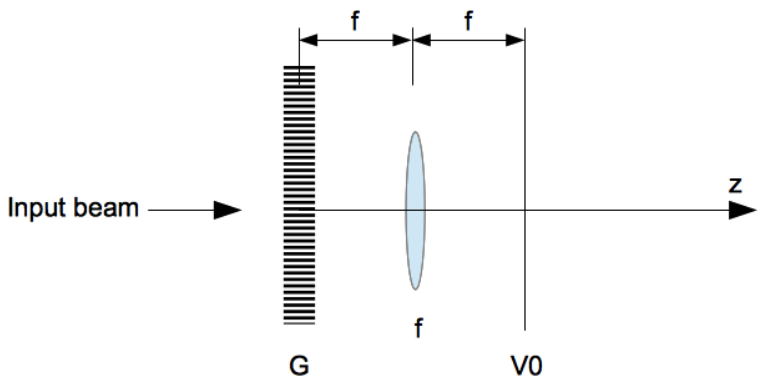
The system is characterized by three thin lenses of focal f1, f2 and f3. Calculate the output intensity I=|V0|^2.

Principles of optics
EE 231

Students are allowed to use calculators and the approved cheat sheet

Problem 2 (20 points)

An input plane wave with wavevector parallel to the propagation axis z is launched in the following system:



characterized by a grating G and a thin lens of focal f. The grating has the following transfer function T(x)=cos(2πx/L)+cos(4πx/L)+sin(8πx/L).
Calculate the intensity I=|V0|^2.