Electrical Engineering – Written PhD Qualifier Exam
Fall 2013

Saturday, September 7th 2013
Room 3119, level 3, Building 1

Please do not write your name on this page or any other page you submit with your work.

Please return your solutions to only 5 questions

Student Identification Number: ___________________________

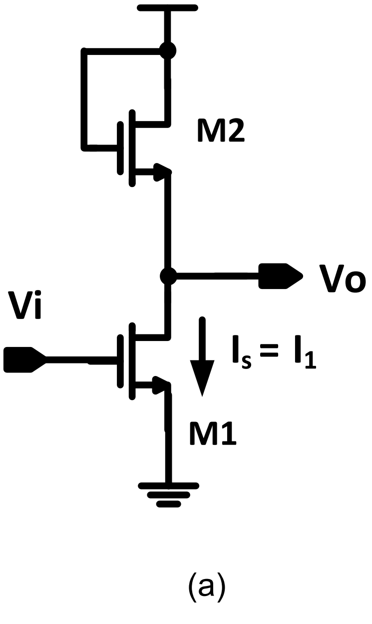
Monolithic Amplifier Design

EE 202

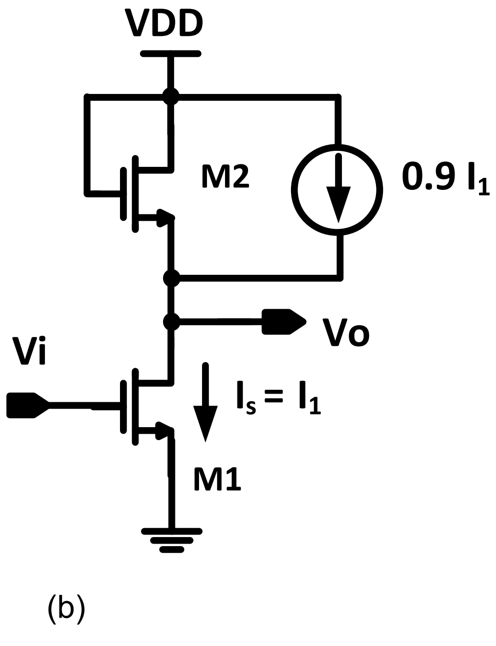
Problem 1 [20points] For the two circuits below come up with an expression for:

a) DC gain (ie Vo/Vi) [7 points]
b) Frequency response of the circuit (ie the 3dB point). Assume the circuit is driving a load capacitance C [7 points]
c) The power consumed from the supply [3]
d) Compare the two circuits with respect to the expressions you derived. [3 points]

(assume long channel effect, make any reasonable assumptions to simplify your answer)



(a)



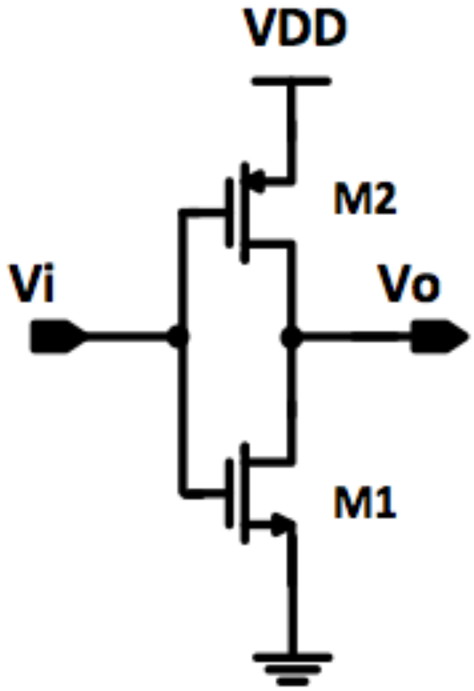
(b)

Monolithic Amplifier Design

EE 202

Problem 2 [20 points] Assuming the threshold voltage of NMOS transistor is equal in magnitude to the PMOS transistor. And the mobility of the NMOS transistor is twice that of PMOS transistor and that the width of M2 is twice M1's and both have same length. Answer the following:

a) Sketch the transfer function of the circuit (ie Vo versus Vi) indicating the region of operation of each transistor. No need to come up with expressions. [6 points]
b) What's the function of the circuit [2 points]
c) If the circuit to be used as an amplifier what's the best DC operating point and why [2 points]
d) Expression for output Resistance (Ro) [3 points]
e) Value of input resistance (Rin) [2 points]
f) What's the DC gain of the circuit (ie Vo/Vi) [5 points]
(assume long channel effect, make any reasonable assumptions to simplify your answer)

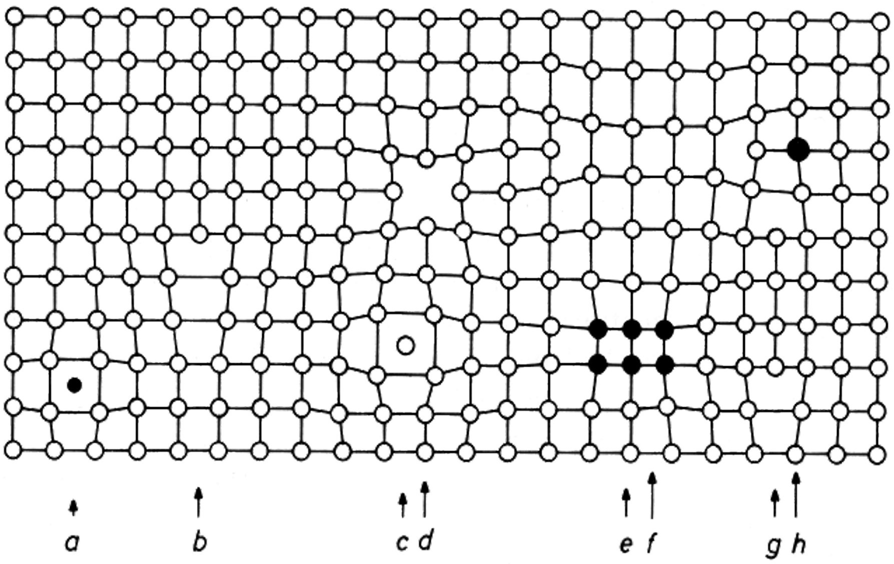


Solid-State Devices

EE 203

Problem 1 [20 points]

1a) Write down name of all the crystal defects (a – h) shown in the figure below. [8 points]



a)

b)

c)

d)

e)

f)

g)

h)

1b) Identify the **POOR** results in the following table comparing various thin film processes for the given benchmarks. [4 points]

Method	ALD	CVD	Sputter	Evaporation
Thickness uniformity				
Film density				
Step coverage				
Interface quality				
Number of materials				

1c) Describe the *difference in the range of implant* and the *damage* done to the target (assume Si) for boron and arsenic ions implanted at the same voltage and dose? [4 points]

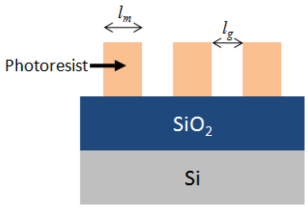
1d) 1 micron of SiO_2 is grown on a wafer. You subsequently determine that the oxidation step has caused the doping concentration near the surface to rise (compared to the bulk). Explain why this has happened, and what this means about the segregation coefficient and the diffusion constant of this dopant. [4 points]

Solid-State Devices

EE 203

Problem 2 [20 points]

2a) You need to fabricate a diffraction grating of SiO_2 lines on Si. The lines are to have a square cross section, l x l, and a gap of l. See figure. What must be the dimensions of the mask, l_m, and its window, l_g, in terms of l to achieve the desired grating. Assume the etch anisotropy is A = 0.85. [4 points]



2b) What are the advantages (two are sufficient) of using Cu-Mn as a self-forming barrier for Cu wiring technology? [4 points]

2c) Fill up the gaps in the following table. [12 points]

	Sputtering	Evaporation
Deposition rate		
Purity		
Stoicheometry		
Thickness control		
Adhesion		
Uniformity		

Introduction to MEMS

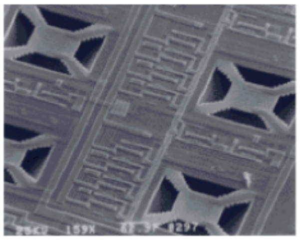
EE 205

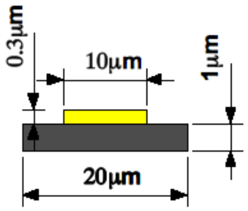
Problem 1 [20 points]

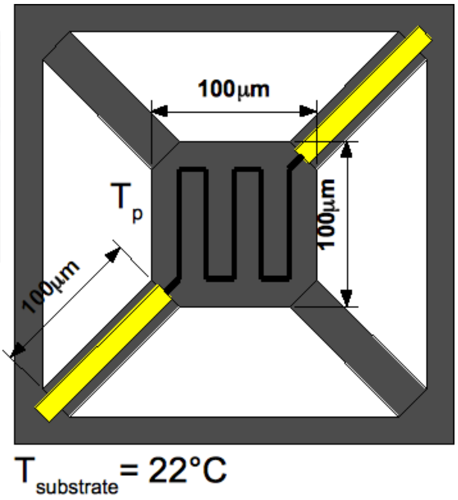
For the thermal pixel with dimensions given in the following figure you may assume: the structure is in vacuum, treat everything as rectangles, the pixel platform is at a uniform temperature. Constants are as given.

Constants you may or may not need.

$0\ ^\circ\mathrm{C} = 273\ \mathrm{K}$
$R_{heater} = 2\ \mathrm{k}\Omega$
$\varepsilon_{platform} = 0.7$
$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$
$\kappa_{SiN} = 16\ \mathrm{W\ m^{-1}\ K^{-1}}$
$\kappa_{Au} = 318\ \mathrm{W\ m^{-1}\ K^{-1}}$
$\rho_{SiN} = 3290\ \mathrm{kg\ m^{-3}}$
$\rho_{Au} = 19300\ \mathrm{kg\ m^{-3}}$
$sh_{SiN} = 170\ \mathrm{J\ kg^{-1}\ K^{-1}}$
$sh_{Au} = 129\ \mathrm{J\ kg^{-1}\ K^{-1}}$







a) Draw the electrical equivalent thermal circuit.

b) Given that we want the thermal pixel to operate at 800°C how much power must be supplied to the resistive heater?

c) What is the efficiency of the thermal pixel ie, radiated power vs. input power?

d) What is the efficiency of the thermal pixel if you increase the operating temperature to 900°C.

e) Now neglecting radiation losses, what is the thermal time constant of the pixel platform? How long does the pixel take to reach 95% of its final temperature?

Introduction to MEMS

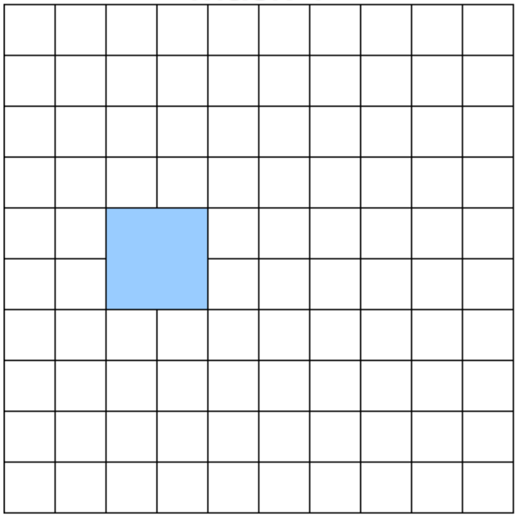
EE 205

Problem 2 [20 points]

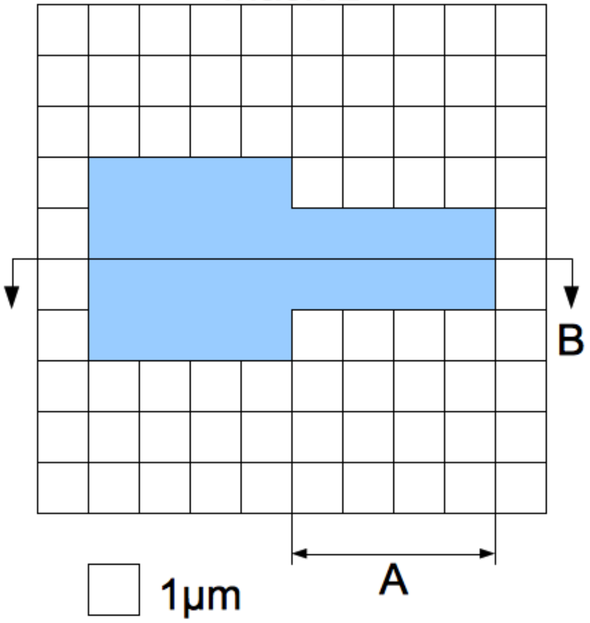
Use the following fabrication sequence and depicted masks to solve the following questions. Note only the blue colored areas on the masks are opaque, the grid and notations are just so you can see scale. Assume perfect alignment.

1. Start with a silicon substrate.
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 500nm thick negative resist and Mask 1. (Resist is stripped before next step.)
4. Isotropic deposition of polysilicon to a thickness of 500nm.
5. Patten the polysilicon layer with anisotropic dry etch masked using a 500nm thick positive resist and Mask 2. (Resist is stripped before next step.)
6. Release the structure using HF followed by super critical CO_2 drying.

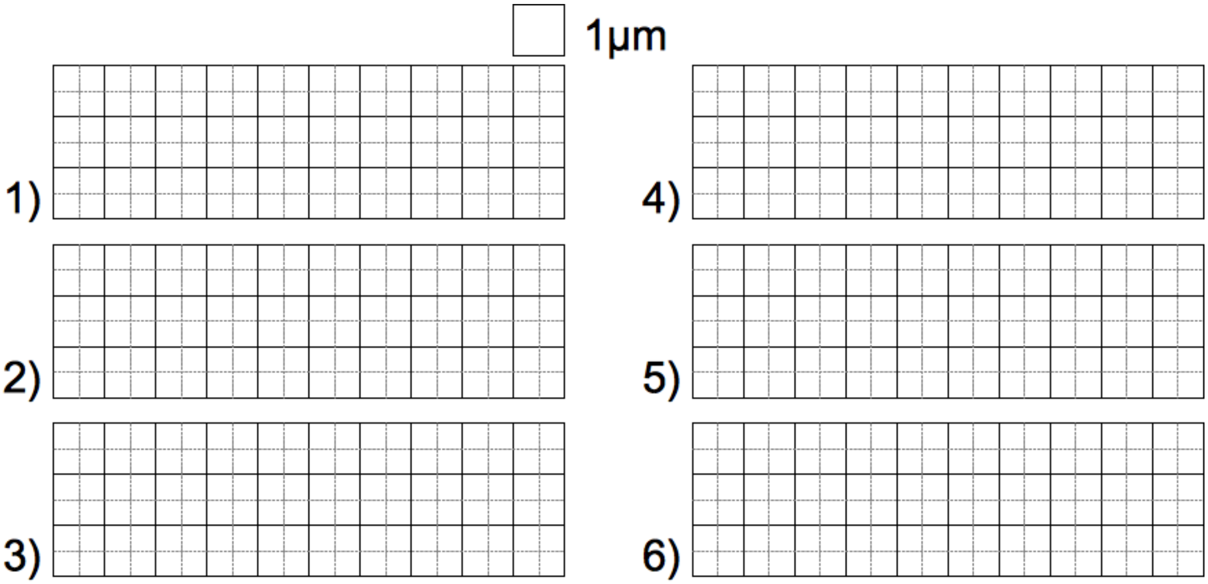
Mask 1



Mask 2



a) Draw cross-section B of the structure for each step of the fabrication sequence. (Show only the top 1µm of the silicon substrate. Steps including resist should show the resist. Ie cross-section prior to stripping)



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) In a case such as above in part c. Would the resonant frequency of the structure increase or decrease when the length is doubled? Why?

Semiconductor Optoelectronic Devices

EE208

Problem 1 [20 points] A double heterostructure edge emitting laser can be designed using the $In_xGa_{1-x}As$ as the active layer, $In_xGa_{1-x}As_yP_{(1-y)}$ as upper and lower cladding layers, and InGaAs as the contact or cap layer. The lower cladding can be grown lattice-match to a InP substrate.

a. Suggest typical thicknesses, doping concentrations, and for the contact, upper and lower claddings and the active layers. Also, suggest suitable x and y compositions in the $In_xGa_{1-x}As_yP_{(1-y)}$.

[2]

b. Sketch the to-the-scale (thickness and bandgap energy) band-diagram of the laser under thermal equivalent.

[3]

c. Sketch the band diagram of the laser under forward bias.

[2]

d. Sketch the band diagram of the laser under reverse bias.

[2]

e. Justify all numbers (type of material, doping concentration, thickness, etc) used in your design.

[3]

f. Estimate the peak emission wavelength of the laser.

[1]

g. Discuss methods for tuning the wavelength (permanent and temperately), and estimate the wavelength range of tunability.

[2]

h. Sketch the structure of a surface emitting laser with all layers properly labeled based on the similar material system.

[3]

i. Discuss a potential application for your laser.

[2]

Semiconductor Optoelectronic Devices

EE208

Problem 2[20 points] The power-current relation for an LED can be expressed as: $P_{act}=h\upsilon(J/qd)\beta_{sp}\tau_n[p_o+n_o+(\tau_n J/qd)]$.

a. Derive the above equation from the first principle [5]

b. Sketch the light-current (L-I) curve of the LED under high and low injection. [2]

c. Explain why optical power increase linearly with current under low injection and increase with direct proportional to J^2 under high injection. [2]

d. Compared to the low injection, would you expect to see blue or red-shift in peak emission wavelength if the device is operated under high current injection. Why? [2]

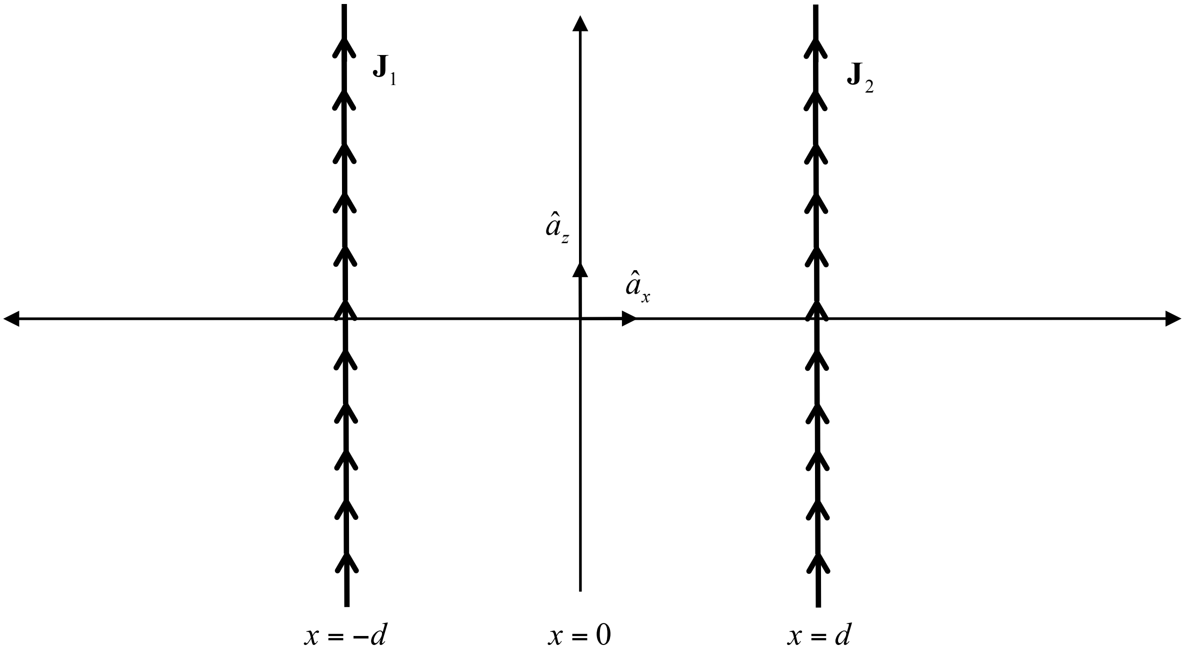
e. Suggest methods to increase the emission power of the LED. [2]

f. Sketch the current-voltage (I-V) characteristics of a InP-based LED. [1]

g. Comparing with the InP-LED with a GaN-based LED, would you expect to see (i) larger or smaller threshold voltage, (ii) differential resistance, (iii) withstand a higher or lower injection power, (iv) being able to operate at higher or lower? Explain your answers. [6]

Electromagnetic Theory and Microwave Circuits
EE 221 and EE 223

Problem 1 EE221 (20 points): Two infinite sheets of time-harmonic electric field current are located in free space as shown in the figure. The expressions for the current densities are given by $\mathbf{J}_1(x,y,z) = \hat{a}_z J_s \delta(x+d)$ and $\mathbf{J}_2(x,y,z) = \hat{a}_z J_s \delta(x-d)$. Here $\delta(.)$ represents the delta function and J_s is a constant.



(a) (16 points) Find electric and magnetic fields $\mathbf{E}$ and $\mathbf{H}$ in three regions: $x < d$, $-d < x < d$, and $x > d$.

(b) (2 points) Find values of d expressed in terms of the wavelength λ for which $\mathbf{E}$ and $\mathbf{H}$ are zero for $x > d$.

(c) (2 points) Find values of d expressed in terms λ for which $\mathbf{E}$ and $\mathbf{H}$ are zero for $x < -d$.

Electromagnetic Theory and Microwave Circuits
EE 221 and EE 223

Problem 2 EE223 (20 points)

A certain 75 Ω coax cable feeds an antenna of input impedance 80 + j15 Ω.

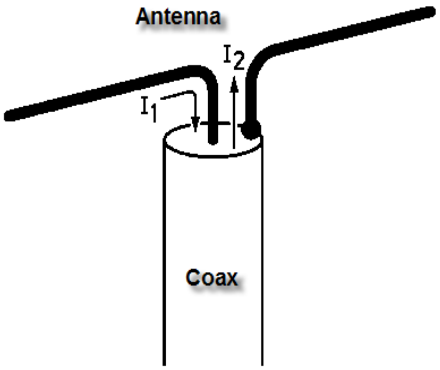
(a) Calculate the return loss in dBs. (3 marks)

(b) Calculate the percentage of forward wave power that is radiated. (7 marks)

The antenna is to be matched using a single series shorted stub.

(c) With the help of smith chart, calculate the position of attachment (how far from antenna) and length of this stub in terms of numbers of wavelengths (λ). (7 marks)

(d) Calculate the physical stub dimensions for signals at 350MHz. (3 marks)



Principles of Optics

EE 231

Problem 1 [20 points]:

A slab waveguide is characterized by a core refractive index ng=1.53, core thickness h=2000nm and is immersed in a glass matrix of refractive index nc=1.50. The waveguide is symmetric along y and light propagates along z.

Answer to the following questions:

A) Calculate the number of guided TE and TM modes at the wavelength l=500nm.

B) Draw a qualitative plot of the electric field Ey (i.e., component along y) distribution of the TE guided modes excited at l=500nm.

C) The first waveguide is now connected in series to a second slab waveguide, characterized by a normalized frequency V=π/2. A student now launches a magnetic field Hy, symmetric along x, at the beginning of the first waveguide. How much energy does he measure at the output of the second waveguide? Discuss your answer.

Principles of Optics

EE 231

Problem 2 [20 points]:
In a 2D geometry, two spherical waves emanate from symmetrically displaced point sources S+ and S- with coordinates:

S+ = (-a,b)

S- = (-a,-b)

Calculate, in the paraxial approximation, the intensity distribution of the resulting field in the plane P = (0,y).