6.777J/2.732J Design and Fabrication of Microelectromechanical Devices
Spring Term 2007

Massachusetts Institute of Technology

PROBLEM SET 1 (12 pts)

Issued: Lecture 2 Due: Lecture 4

MIT Server/MATLAB orientation
If you are not familiar with Matlab, work through the Matlab Primer so that you can enter variables, set up matrices, make simple graphs, and create an M-file script to define a function. Postscript and PDF versions of the Matlab Primer are available on the 6.777 web site.

If you are having trouble with MIT Server access or with this Matlab introduction, let a TA know immediately.

Problem 2.6 (4pts): Dynamics with Matlab and Simulink

Dynamic modeling of MEMS devices will require us to perform time integrations of vector functions. In this problem we will develop some of the nitty-gritty details needed to do these integrations successfully. It will be necessary to become familiar with functions defined by M-files, and with the integration functions (e.g., ode45). There are also some syntactical issues that must be handled correctly. In addition to the plots, please include your m-file or Matlab diary showing your work.

(a) Consider a linear time-invariant dynamical system described by the following transfer function $H(s)$ relating an input $X(s)$ to an output $Y_1(s)$:

$$H(s) = \frac{Y_1(s)}{X(s)} = \frac{1}{s^2 + 2s + 4}$$

This transfer function models some of the kinds of 2^{nd}-order systems that we will encounter in this course (e.g., accelerometer). Determine the differential equation relating $y_1(t)$ to $x(t)$. Write the system as a pair of coupled first-order differential equations with state variables $y_1(t)$ and $y_2(t) = \dot{y}_1(t)$. Use the Matlab command ode45 to integrate these equations forward in time from an initial state $y_1(0) = y_2(0) = 0$ subject to a step input $x(t)=u(t)$. Plot $y_1(t)$ to show that this corresponds to an underdamped 2^{nd}-order system.

(b) An alternate approach is to define Matlab LTI models using the control systems toolbox. Define your transfer function in Matlab using the tf command and plot its step response and Bode plot using step and bode.

(c) Simulink can also be used to model dynamical systems. Create a Simulink model of this dynamical system, using either a transfer function or differential equation formulation, and plot $y_1(t)$ in response to a unit step as above.

Problem 3.8 (2 pts): KOH etched diaphragm

We intend to use KOH etching to form a diaphragm on a (100) silicon wafer. It will be a square membrane with a thickness well-defined by an etch stop (e.g., electrochemical etch stop or SOI wafer), such that there are no first order thickness variations in the diaphragm itself. What feature size is required to produce a square diaphragm with 400 μm side length and 20 μm thickness on a silicon wafer that is 500 μm thick (the wafer thickness includes the membrane thickness)? What is the edge-length variation of the diaphragm if the etch mask is misaligned 1° to the <110> direction? Assuming that the sensitivity of a pressure sensor varies as the inverse fourth power of the diaphragm edge length, what percentage of variation can be attributed to mask misalignment?

Problem 4.15 (2 pts): Crayon engineering: Debug and recreate a process and mask set for a pressure-sensing silicon diaphragm

You are a young junior faculty member who has just hired your first graduate student, Wayford Roppar. You have developed an idea for using a sealed-cavity pressure-sensing silicon diaphragm (1 mm across and 15 μm thick) that you're sure will make you famous and assure your tenure. You ask Wayford to design a process flow for creating this simple structure, and Wayford returns with the process flow detailed in Figure 1.

Being a seasoned MEMS designer, you immediately notice several critical errors with Wayford's process (things that won't work or won't produce the result that Wayford shows in the cross sections). Please find the critical errors in this process flow and, where possible, suggest alternate approaches. Do not worry about the accumulation of errors, but rather treat each step assuming that the structure up to that step could be created.

Then recreate a correct process flow along with the device cross sections at each step and the associated mask set (with dimensions).

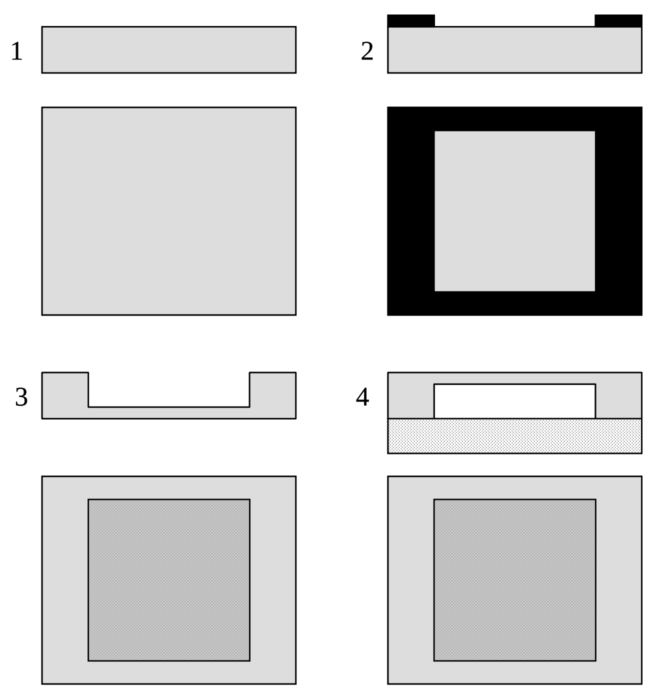

Figure 1: Process flow for a pressure-sensing silicon diaphragm.

Process steps:

1. **Start with a double-side-polished n-type silicon wafer.**
2. **Perform photolithography using 1-µm-thick positive photoresist to define the diaphragm area.**
3. **Deep-reactive-ion etch the silicon to form the diaphragm; ash resist.**
4. **Anodically bond the silicon wafer to a pyrex wafer.**

Problem 4.13 (4 pts): Crayon engineering: Create process and mask set for a DEP trap

Figure 2 shows an electrical trap that uses dielectrophoresis (DEP) to trap cells. Using the principles of "crayon engineering", design a process and mask set that will produce this structure (not to scale). Both metal layers must be 0.5-µm-thick gold (though other metals are acceptable beneath the gold). The substrate B and layer A both must be electrical insulators. The gold linewidth is 10 µm, and all other critical parameters are specified in the figure.

You are asked to create a table of process steps as shown in *Table 4.1* in the book, along with process flow cross-sectional diagrams and masks as shown in *Figure 4.1*. Specify materials and the proposed etch methods, and be sure to include as steps in your process the required wafer cleans, application of photoresist, and stripping of photoresist. You do not need to include dimensions in your mask set in this problem (but do draw the geometries correspondingly).

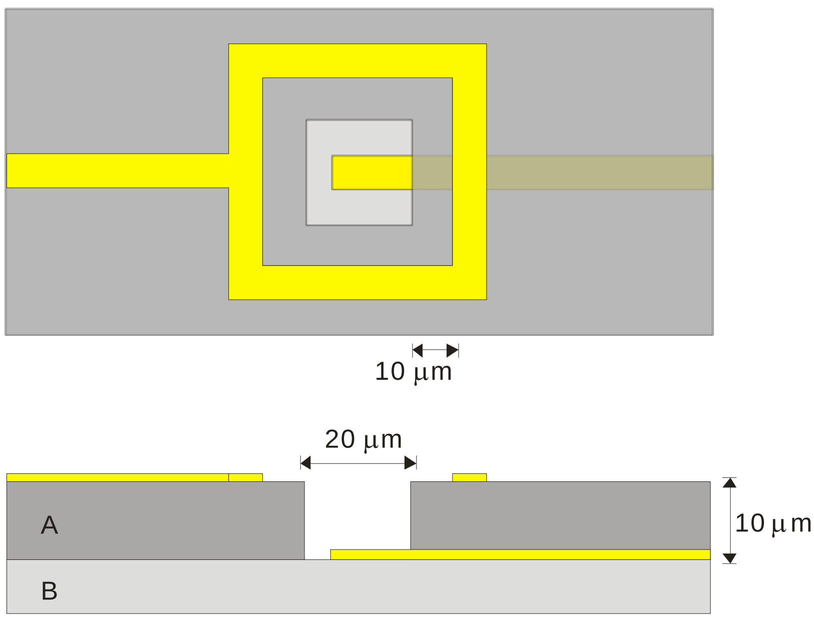

Figure 2. Schematic of a DEP trap (not to scale)