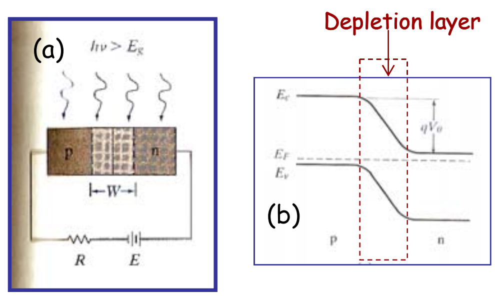
FINAL EXAMINATION
Take-home

Due: before 4 p.m. on Friday, Dec. 14, 2007

For your Final Exam, please choose ONE of two projects described below. One project is the fabrication of a **Si Solar Cell.** The other project is the fabrication of a **Si cantilever structures** as high quality sensors. For the sake of readability and clarity, please give me **printed** (rather than hand-written) exams (if you want to draw the figures by hand, that's fine).

I. SILICON SOLAR CELL

Efficient and inexpensive Solar Cell technology continues to be an important technological challenge. Commercially-available solar cells are primarily silicon-based. The principal device concept is to use a p-n junction, (1) create electron-hole pairs generated by sunlight and (2) separate and then collect the electrons and holes through the 'built-in electric field' at the 'p-n' junction.



(a) Schematic of p-n junction, and (b) band diagram From Streetman, *Solid State Electronic Devices*

Figure 2, shows a cross-section and a top-down view of a silicon solar cell[1]: YOU CAN CHOOSE STARTING MATERIAL THAT IS EITHER p-type Silicon or n-type Silicon. The major design issues are: (1) making ohmic contacts to both the p-type Silicon and n-type Silicon so that you can *collect* the photo-generated electrons and holes, and (2) ensuring that you have enough surface area illuminated by the sunlight. This is basically all you have to know about the solar cell: you *do not* have to fully understand the operation of a solar cell. *You are welcome to read further on solar cells and their design. A basic semiconductor device text, like Streetman's Solid State Electronic Devices is a good resource.*

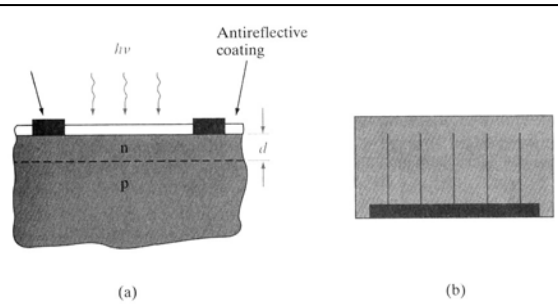


Figure 2. Solar cell structure (a) cross section and (b) top-down view, showing metal contact 'fingers' (from Streetman)

DESIGN A SET OF MASKS AND A PROCESS TO FABRICATE A SILICON SOLAR CELL.

1. Starting material: you may choose either p-type silicon or n-type silicon as the starting material. State the doping level of the starting material. The *precise* doping value is not important, but state whether you generally want the material to have a high or low resistivity, and why.

[1] Streetman & Banerjee, Solid State Electronic Devices, 6th Edition

2. For the choice of metal contact, *use Aluminum* for both n-type and p-type contacts (this will be good enough for this device design).

See Section III.

II. SILICON BIOSENSORS

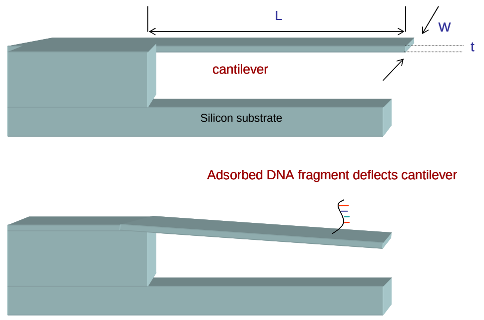


Figure 3. Silicon cantilevers with, and without adsorbed DNA fragment

Structures that are micromachined out of materials like silicon are finding increasing applications in the biological sciences. **Micromachined cantilevers** can give extremely sensitive measurements of mass (mass as small as 7 x 10^{-13} grams has been measured. This measurement uses the same principle behind the quartz crystal monitor of thin film deposition, but the cantilevers have potentially much greater sensitivity, even to the limit of single molecule detection). A schematic of the cantilever and the detection method is shown in Figure 3. The cantilever has a length, L, a width, W, and thickness, t. The adsorption of a fragment of single stranded DNA (oligonucleotide) deflects the cantilever, and this deflection can be measured optically or electrically. What makes this structure a really elegant and sensitive *biosensor*, is that the single-stranded DNA fragment will selectively bind only to the complementary fragment (a process called hybridization). The hybridization can in turn be detected through the deflection of the cantilever: see Fritz et al., 'Translating Biomolecular Recognition into Nanomechanics', *Science* **288,** 316 (2000) (will be on class website).

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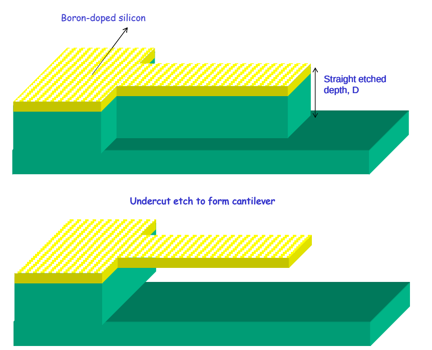

Figure 4. Formation of a cantilever through selective wet etching.

One approach to the creation of a cantilever is to use a *selective etch process* where the surface layer is not etched, but the underlying material is etched, shown in Figure 4. To create this etch selectivity, we note that very heavily doped with Boron, will *not etch* in a solution of KOH-water-isopropanol (see Figure 5).

Therefore, by starting with low-doped p-type Si (few times 10^{16} cm^{-3}), and *diffusing* a higher concentration of Boron into the surface of the Si you should be able to form cantilever structures.

Assume that the dimensions of your cantilever are 50 microns wide (W) by 1000 microns long (L). The thickness of the cantilever will be determined by the Boron-diffusion process.

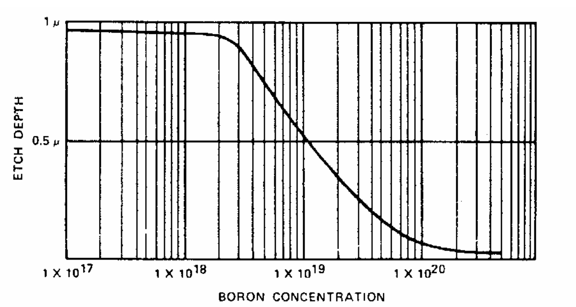

Fig. 11. Selective etching of silicon: Si ⟨100⟩ etch rate per minute versus boron concentration. Etchant system is KOH–H_2O–isopropyl alcohol at 80°C (from Kuhn and Rhee [348], reprinted by permission of the publisher, The Electrochemical Society, Inc.).

Figure 5. Selective etch rate of B-doped Si

DESIGN A SET OF MASKS AND A PROCESS TO FORM SILICON CANTILEVERS/BIOSENSORS.

1. Diffusion-doping of the silicon with Boron: Assume that the diffusivity of the Boron in silicon is given by 0.037 exp {-3.46/kT} cm^2/sec. Give a reasonable temperature and time for the diffusion, state what assumptions you are making, and what kind of diffusion profile you want to obtain.
2. For the *non-selective etch of silicon, use* the 50:20:1 HNO3:H2O:HF solution that was used in your first homework assignment. *Assume* a fairly straight sidewall for the etched feature.
3. *Assume* that you can use photoresist as a mask for the KOH-$H_2$0-isopropanol etch.

III. FOR EITHER PROJECT YOU CHOOSE:

1. Use *only* processes that you have used or *are available* in the teaching cleanroom.
2. The mask you design can (and should be) VERY SIMPLE: state the dimensions of the features on the mask. Discuss alignment issues, if there are any.
3. Make a flowchart of your process, clearly indicating each important process step. Schematic diagrams of what the device would look like at each critical step would also be helpful.
   a. Use the insights you've gained from lab to make this process as *practical* as possible:
      i. What calibrations/experiments would you have to do (e.g. etch rates)?
      ii. If there are high temperature steps, state the approximate range of temperatures you expect.
      iii. If you are depositing a thin film, state the composition and thickness of the film.
   b. You don't have to go into details like spinning on resist, softbaking, exposure and development conditions – you can simply list 'lithography', mask 1. But you should tell me at what points you will remove the resist, when you will need to clean the wafe, where in the process you will do an inspection, what you will measure and what you will expect for that measurement.
4. Design as simple and robust a process as you can so that you can produce the finished structure. *Explicitly state any important assumptions you are making.* State what kinds of measurements, inspections and calibrations you would do, to ensure that your process is actually behaving the way you would want it do.