FINAL EXAMINATION
Take-home

Due: before 2 p.m. on Friday, Dec. 12, 2008

For your Final Exam, please choose ONE of two projects described below. One project is the fabrication of **Silicon Nanowires** that might be used as thermoelectric devices**.** The other project is the fabrication of a very sensitive **Silicon Sensor**, based on a Wheatstone Bridge on-a-chip. 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 NANOWIRES FOR THERMOELECTRIC DEVICES (Thanks to Peter Burke)

There has been some interest in *Silicon Nanowires* as new *thermoelectric* materials. These are materials that could convert differences in temperature to differences in electrical potential, so that we could either (a) actively cool structures by applying an electrical signal (voltage) or (b) make better use of excess heat that is generated (such as heat from the operation of high density integrated circuits). Figure 1. shows a device structure that was used recently to evaluate the quality of Si nanowires (which you can't see clearly in the figure).[1] You have all the process skills you need to create a series of nanowires from silicon, if you begin with *silicon on insulator* starting material (Figure 2).

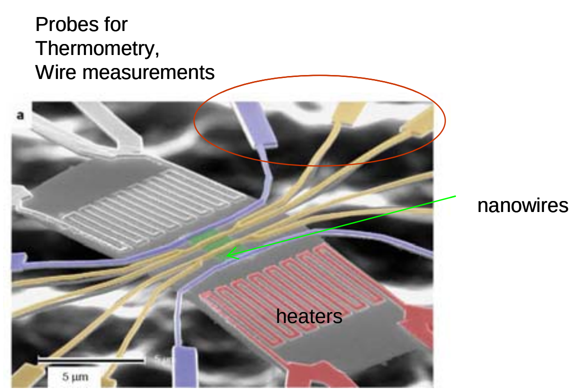

Figure 1. Silicon nanowires for thermoelectrics. Ref. 1.

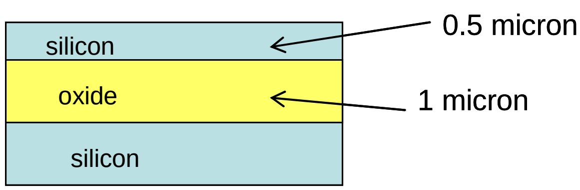

Figure 2. Silicon-on-insulator structure.

You can form the nanowires by first defining wires (or resistors) in the silicon using diffusion doping and the optical lithography you have used in the lab. Then you can fine-tune the diameter of the Silicon by *successively oxidizing the wires and selectively etching away the oxide*. Or, you may choose a design that simply successively etches away the wire to achieve smaller diameters.

The major design issues are: (1) determining the doping level of the wires (2) determining the ideal dimensions of the final fires, (3) the relationship between the dimensions of the wires that you begin with, and the final, desired dimensions, (4) placement of metal contacts to measure the resistances of the wires. For these experiments, it will be very important to have good test structures or ways of evaluating the process as you are carrying it out.

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[1] Boukai et al., *Silicon Nanowires as Efficient thermoelectric materials*, Nature, p. 168 (2007)

DESIGN A SET OF MASKS AND A PROCESS TO FABRICATE AN ARRAY OF SILICON NANOWIRES.

1. The starting material will be the 'SOI' material shown in Figure 2, with a half-micron of Silicon on top of 1 micron of silicon oxide. *You* can specify the doping of the silicon.
2. How will the wires be formed? What are the beginning dimensions of the wires? How will you fine-tune the dimensions of the wires?

See Section III.

II. SILICON WHEATSTONE SENSORS (Thanks to Steve Honig)

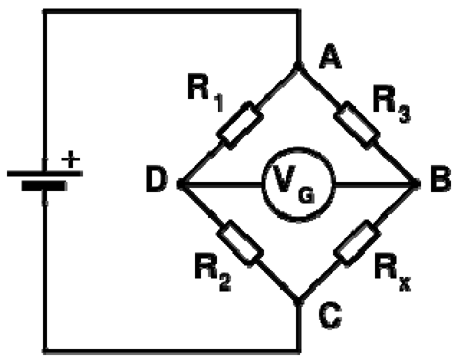

Figure 3. Schematic of a Wheatstone Bridge.
http://en.wikipedia.org/wiki/Wheatstone_bridge

A *Wheatstone Bridge* is used to make very precise measurements of resistance. An unknown resistance, Rx, can be balanced against three known resistors and the current through the *galvanometer*, V_G. Imagine incorporating this Wheatstone Bridge on a silicon chip, with R_x as a *sensor resistor*.

The 'sensing' principle is that an 'analyte' (unknown) is allowed to be placed in close contact with the surface of the resistor, and will *change the depletion depth* of the resistor, thus changing the value of the resistance. Placing Rx within the Wheatstone Bridge should make it possible to detect even very small changes in resistance.

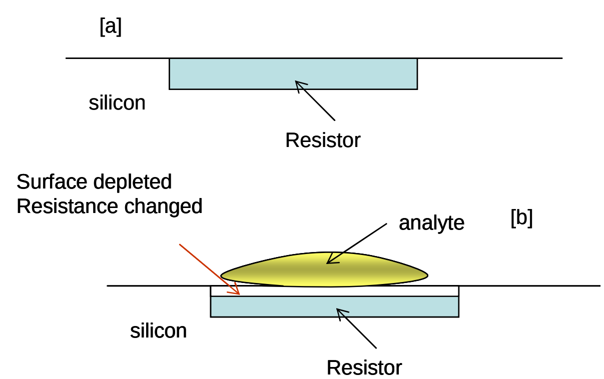

Figure 4. [a] R_x, as-fabricated, and [b] R_x in contact with an *analyte*. The analyte DEPLETES the surface of the resistor, and changes the resistance of R_x.

DESIGN A SET OF MASKS AND A PROCESS TO FORM THE WHEATSTONE BRIDGE SENSOR.

1. Think about the main components of the device:
   a. Resistors, formed by diffusion-doping
   b. Metal pads, so you can measure a current across DB, and so you can apply a voltage across C and A.
   c. Oxide isolation: where do you need this? How much would you need?
   d. How to introduce the analyte? What is the surrounding geometry of the device?
   e. What material would you begin with: n or p-type Si? What level of doping? Why?
2. YOU determine the dimensions of the device, including
   a. What should the dimensions of the resistors be? What resistance would you expect to get?
   b. Are the metal pads large enough so that you can comfortably probe the structure?

c. You don't have to do a detailed calculation of depletion depths for a starting value of semiconductor doping, but you should give at least a qualitative discussion of *the doping level* you are aiming for, and the depth of doping. Into the silicon.

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. <u>What calibrations/experiments</u> 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 wafer, 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.