Department of Electrical Engineering and Computer Science
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6.777 Design and Fabrication of Microelectromechanical Devices

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DESIGN PROBLEM: Resonant Cantilever Microbalance

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Problem Statement

Real-time detection methods for the adsorption of DNA, proteins, or cells on a solid surface are of great importance for many biological assays. The current methods are primarily based on fluorescent or radioisotope labeling of the adsorbed species that often increase the complexity of the sample preparation. A cantilever microbalance can detect *unlabelled* species. However, when operated in liquids, the mass resolution is severely limited because the Q of the resonator is typically reduced to a value of order one.

This project addresses the use of a microfabricated cantilever as a microbalance to detect the mass of molecules and particles that become attached to the cantilever surface. The basic project is to create a device that can detect small mass changes in air ambient. Assuming these goals can be met, a follow-on question will be to address whether it can successfully be used in liquids for biological assays.

Design Specifications

The specific goal of this project to a design 1) a microfabricated cantilever that integrates the drive actuator and displacement sensor, and 2) the electronics for driving the cantilever into oscillation and detecting the frequency shift resulting from changes in cantilever mass. The target mass-change sensitivity is one fg (10^{-15} grams).

The cantilever design should include a thin-film piezoelectric actuator (for example, ZnO) and a displacement sensor consisting of either the piezoelectric actuator or an underlying silicon piezoresistor. There is no particular size restriction on the cantilever other than the overall requirement that it fit easily within a normal silicon chip and can be fabricated with reasonable manufacturing tolerances.

You can assume that your fabrication facility has the following special capabilities:

- A system for depositing and etching stress-free films of ZnO with a thickness range of 1-4 um.
- Deep reactive-ion etching for silicon
- Access to silicon-on-insulator (SOI) wafers with a handle-wafer thickness of 400 um, buried oxide of 2 um, and top silicon thickness ranging from 0.1 - 10 um.

The electronics should include an oscillator circuit for driving the cantilever at resonance as well as an FM demodulator for frequency readout. (A transistor-level circuit design is not required; function blocks can be used. However, the various electronic functions put into the system must be realizable within the constraints of present circuit technology.) The primary noise sources for an oscillating system are: thermal vibrations of the cantilever, noise from the displacement sensor, and noise from the electronics. Because the oscillator circuit is a nonlinear system, it is necessary to consider how the various noise sources contribute to the overall noise level. Ultimately, it is necessary to understand what noise bandwidth must be used to reach the target mass sensitivity.

Ideally, your mass sensor should be portable and capable of analyzing small sample volumes. Discuss the limitations associated with packaging in terms of the device design and electronic circuit configuration.

Overview
The design process is described below in terms of several distinct tasks. However, it will be quickly recognized that all these tasks interact. The goal of the team is to delegate tasks and provide communication between tasks so that the final merged device design meets the requirements.

First-Order Device Concept
Select the materials, geometry, and fabrication process for a suitable cantliever. This will require a determination of the required resonance frequency and overall mass needed to reach the required sensitivity.

First-Order Circuit Design
Design a circuit configuration which will drive the cantilever into oscillation at a stable amplitude, and devise the means for extracting the measured frequency shift.

Coupled Modeling
The interaction between the resonator and the circuit must be modeled to determine how changes in the characteristics of the cantilever propagate to changes in resonant frequency.

Noise Analysis
The various noise sources, and how they affect mass sensitivity, should be modeled to determine whether the design can meet the required goal within a reasonableand useful noise bandwidth.

Damping
If the device is operated in air, what Q values can be obtained? How does the Q affect the mass sensitivity?

Packaging
A first-level packaging scheme is required. This means that you will need to understand how your "Customer" expects to use the device. (Your Mentor is also your Customer.)

Second-order Effects

Since the cantilever will be small, how much variation in behavior is expected from normal fabrication tolerances? How can the device be calibrated? What is the effect of ambient temperature?

Integrate the Design

Iterate as needed to verify that the device concept, circuit design, fabrication process, and packaging scheme work together to meet the required specification.

And if there's time. . . .

Consider what would happen if you try to operate the device in a liquid. Project the mass sensitivity that can be achieved in that case.