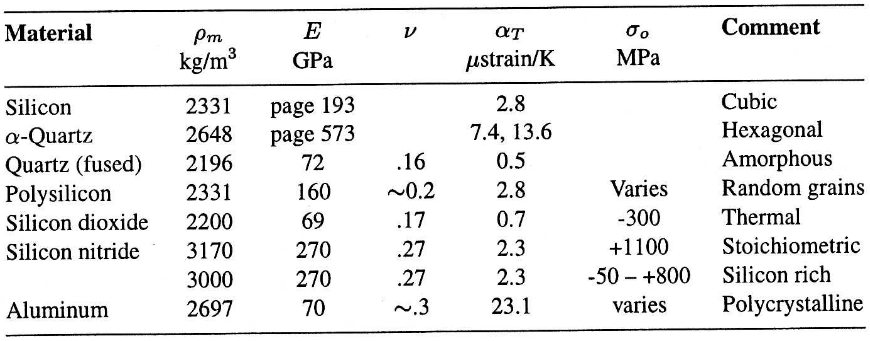
Spring 2001 EE M250B Prof. Ming C. Wu
Final Exam



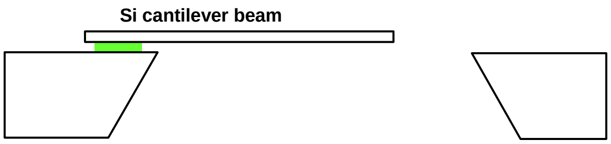
Material	ρ_m kg/m^3	E GPa	ν	α_T μstrain/K	σ_o MPa	Comment
Silicon	2331	page 193		2.8		Cubic
α-Quartz	2648	page 573		7.4, 13.6		Hexagonal
Quartz (fused)	2196	72	.16	0.5		Amorphous
Polysilicon	2331	160	~0.2	2.8	Varies	Random grains
Silicon dioxide	2200	69	.17	0.7	-300	Thermal
Silicon nitride	3170	270	.27	2.3	+1100	Stoichiometric
	3000	270	.27	2.3	-50 – +800	Silicon rich
Aluminum	2697	70	~.3	23.1	varies	Polycrystalline

Useful constants:

ε_0	Free-space permeativity	$8.854\text{x}10^{-12}$	F/m
μ_0	Free-space permeability	$4\pi\text{x}10^{-7}$	Henry/m

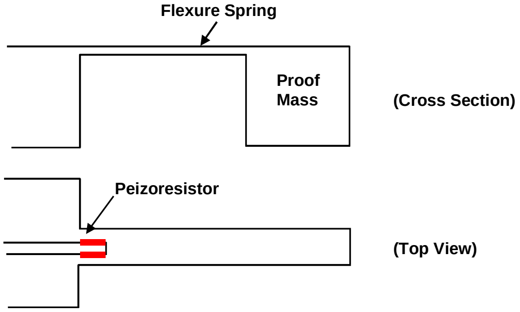
For all problems: if you need to make assumption for solving the problem, make sure you state your assumption clearly.

1) A Si cantilever beam (1 μm thick, 500 μm long, and 100 μm wide) is fabricated on SOI.



   a) Find the resonant frequency of the fundamental mode for the cantilever beam. (Assume the Young's modulus of Si is 164 GPa).

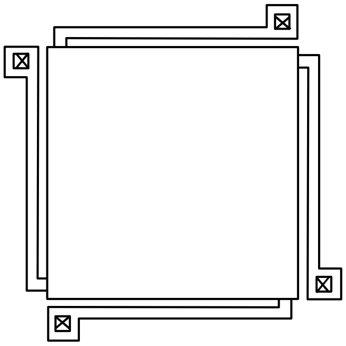
2) Consider the following simplified peizoresistive accelerometer made in Si: it consists of a flexure spring (1 μm thick, 1000 μm long, and 100 μm wide) along [110] direction and a proof mass (100 μm x 100 μm x 500 μm). The acceleration is sensed by a piezoresistor as shown in the top-view plot.



   a) To obtain maximum response, should n-type or p-type material be used for the piezoresistor?
   b) What is the percentage change of the piezoresistance when the accelerometer is subject to an acceleration of 100 g?
   c) If DRIE is used to fabricate the device so the direction of the spring can be along any direction. Assume the substrate is (100) Si. What direction would you choose for the

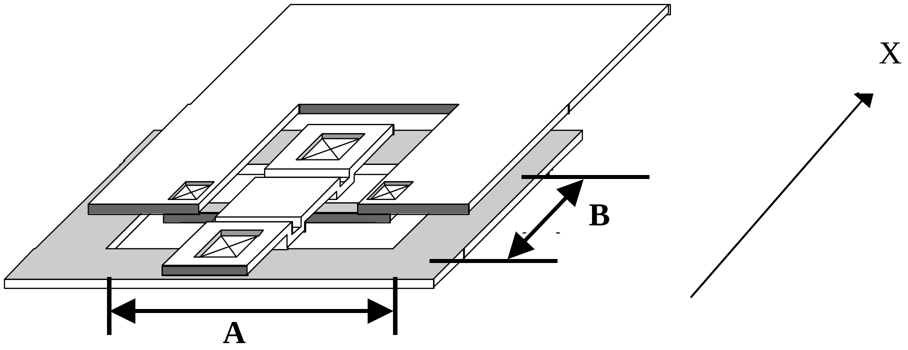
flexure spring to maximize the response? Which dopant type would you use? What is the response (percentage change of piezoresistance) under 100 g?

3) Consider the design of a vertical gap-closing actuator (area of 100 μm x 100 μm) suspended by four symmetric cantilever beams (100 μm long):



   a) If MUMPs process is used, what is the maximum *stable* displacement you can achieve?
   b) If Sandia's SUMMiT-V process is used, what is the maximum *stable* displacement you can achieve?
   c) Using MUMPs process, what is the lowest pull-in voltage you can get? Keep the length of the flexure spring at 100 μm.
   d) Using SUMMiT-V process, what is the lowest pull-in voltage you can get? Keep the length of the flexure spring at 100 μm.

4) Consider the following hinge structure made by MUMPs process. The shaded plate is made of POLY1, and the white plate is made of POLY2.



   a) Identify the function of this hinge.
   b) Follow MUMPs design rules, find out the minimum area needed for the hole in POLY1 (A and B marked on the figure).
   c) Find the maximum linear displacement allowed in the X direction (see figure) in this hinge design.