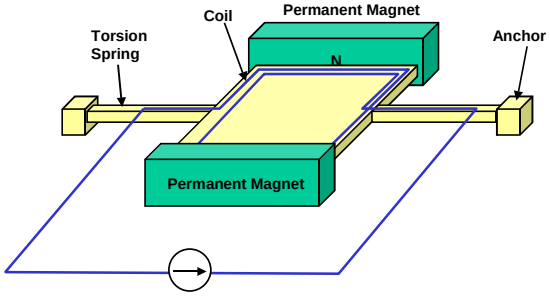
Material	ρ_m kg/m^3	E GPa	ν	α_T μstrain/K	σ_o MPa	Comment
Silicon	2331	page 193		2.8		Cubic
α-Quartz	2648	page 573		7.4, 13.6		Hexagonal
Quartz (fused)	2196	72	.16	0.5		Amorphous
Polysilicon	2331	160	~0.2	2.8	Varies	Random grains
Silicon dioxide	2200	69	.17	0.7	-300	Thermal
Silicon nitride	3170	270	.27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

Useful constants:

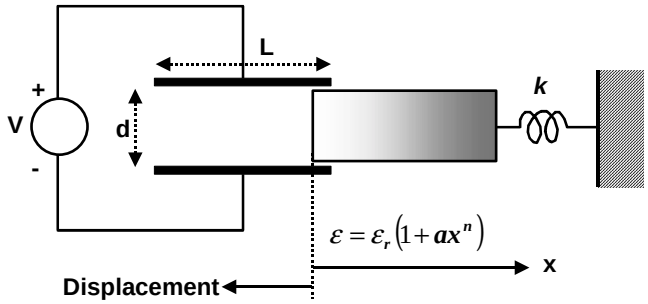
ε_0	Free-space permeativity	8.854×10^{-12}	F/m
μ_0	Free-space permeability	$4\pi \times 10^{-7}$	Henry/m

1) Design a comb drive actuator on a SOI (silico-on-insulator) substrate. Assume the silicon layer is 5 μm thick, and design rule is 1 μm (i.e., the minimum linewidth and spacing are both 1 μm).
   a) Estimate the force you can generate at 10 V bias for the comb drive with 100 fingers (i.e., 100 fingers on moveable comb, and 100 fingers on fixed comb, both with minimum finger width and spacing).
   b) What is the total spring constant of the folded flexure springs with a beam length of 200 μm for each section? Note there are a pair of springs to keep the comb drive symmetric.
   c) What voltage is needed to achieve a displacement of 10 μm?

2) This problem is regarding scaling of electrostatic and electromagnetic actuators. Assume uniform scaling, i.e., the width, thickness, length, and spacing of the actuator, spring, and displacement are scaled proportionally.
   a) If the dimension of the DMD is scaled down by 10 times, how does the operating voltage (pull-in voltage) scale?
   b) If the dimension of an electromagnetic scanner with N turns of coils in a fixed magnetic field (shown below) is scaled down by 10 times, how does the operating current scale for the same scan angle?



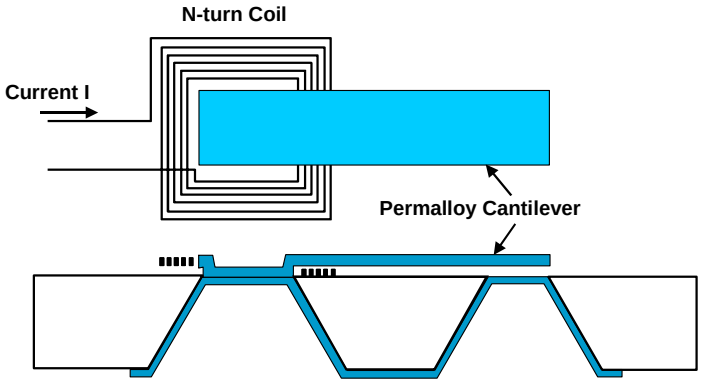
3) Consider the following electrostatic actuator:



A dielectric material with *non-uniform* dielectric constant, $\varepsilon = \varepsilon_r(1+ax^n)$, where *n* is a parameter, is placed in between a parallel plate capacitor with an area of A and a gap spacing of d. The dielectric material is able to move laterally into the capacitor and is supported by a spring. Ignore the friction between the dielectric slab and the capacitor.

a) Derive the expression for electrostatic force of this actuator.
b) Find the range of parameter *n* for which the actuator will exhibit pull-in phenomena.

4) Consider the magnetic relay shown in the following:



It consists of a permalloy core with permeability μ_{core} = 1000 and a N-turn coil. The permalloy cantilever is 10 μm thick, 100 μm wide, and 1000 μm long. Bulk micromachining and electroplating is used to create return part of the permalloy core. The area of the exposed permalloy in the air gap at the tip of the cantilever is A_{gap} = 10 μm x 10 μm. The air gap spacing is 10 μm. The Young's modulus of the permalloy is 100 GPa.

a) Construct the effective lumped circuit for the actuator.
b) Find the expression for magnetic force of the actuator.
c) For N = 100, find the current required to bend the permalloy cantilever to contact.