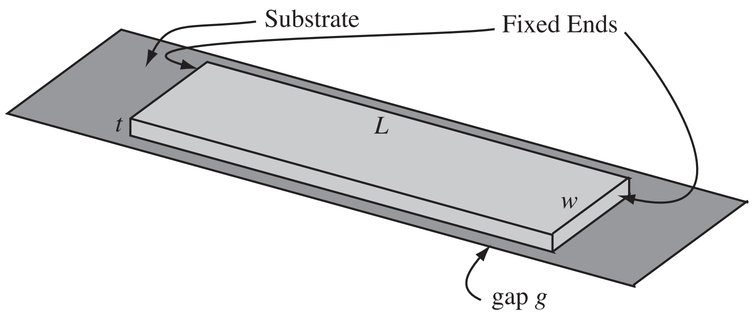
ECCE 550/ME 550 Simulation Lab 5:
MATLAB Simulation of an Electrostatic Switch

1 Introduction

For this lab, we will use MATLAB to model the pull-in behavior of an electrostatic switch. The switch is also being fabricated in labs 5 and 6 in the clean room. The next modeling lab will model the same switch in ANSYS, allowing you to compare both models to test data from the fabrication labs.

The figure below shows the basic geometry to be modeled. A metal fixed-fixed beam of length L, width w, and thickness t is suspended above the substrate with a gap g. Electrostatic force is applied to the beam using a voltage difference between the beam and the substrate. The goal for this lab is to develop a finite difference model in MATLAB that will allow prediction of the pull-in voltage for this beam.



2 Procedure

The deflection of a beam may be modeled using the differential equation

$$EI\frac{\mathrm{d}^4y}{\mathrm{d}x^4} - P\frac{\mathrm{d}^2y}{\mathrm{d}x^2} = f_e(x, y) \tag{1}$$

where EI is the beam's flexural rigidity, y is its deflection, x is a coordinate along its length, P is an axial force acting to put the beam in tension or compression, and f_e is a distributed load (force per unit length). This equation may be solved using any of several methods for solution to differential equations. On the course web site is a MATLAB script which solves this equation for a MEMS beam, assuming an electrostatic force. The script allows you to change the beam's dimensions, as well as the residual stress and applied voltage, and the material properties (Young's modulus and the Poisson ratio). Note that the electrostatic force is a function of the deflection y, so that the equation is a nonlinear differential equation. The code supplied solves it in an iterative fashion, by using each iteration's deflection profile to predict the electrostatic force for the next iteration.

However, the script assumes the presence of a MATLAB function called `electf` which calculates the electrostatic force as a function of deflection. You will need to write this function. It should accept the following arguments, in order:

1. a vector containing deflections at different points along the beam (in microns)
2. a scalar giving the value of the initial gap g (in microns)
3. a scalar giving the beam's width w (in microns)
4. a scalar giving the applied voltage V (in Volts).

The function should return a vector the same size as the input vector, which contains the value of the distributed force corresponding to each deflection, in units of μN/μm.

After you write this function, you should be able to calculate the beam's deflection in response to an applied voltage. You should also modify the code to allow you to find the total capacitance of the beam as a function of its deflection (you can assume that you can integrate along the beam using the parallel plate equation).

3 Deliverables

Model the beam with the dimensions and properties shown in Table 1, which are representative dimensions for the switches you will be fabricating, and properties for aluminum, the switch material. Find the deflection for the beam assuming a voltage of 5 V for a residual stress of -1, 0, 1, 10, and 50 MPa. (Note that compressive residual stress is negative, while tension is positive.) Why does the deflection change in each case? Report the capacitance in each case also.

You should also use your model to find the pull-in voltage of the beam (to the nearest hundredth of a volt) for each of the residual stress cases listed above. For this step, you can either develop an automated routine to find pull-in voltage, or you can simply guess and check until you narrow it down. Notice that the pull-in voltage changes significantly in response to different residual stress. This will allow us to estimate the residual stress in the film by measuring the pull-in voltage. You should also find the maximum deflection of the beam before pull-in for one of the cases above. Is it what you expect (one third of the gap)? Can you explain why or why not? Also, find the capacitance just before pull-in. Is it significantly different than the rest-state capacitance?

Prepare a short memo report (about one page) answering the above questions, and giving the results for each test above.

Table 1: Beam Parameters.

Parameter	*Value*	*Parameter*	*Value*
L	200 μm	w	40 μm
t	0.5 μm	g	2 μm
E	69 GPa	ν	0.33