Modeling of Microcantilever based Nuclear Microbatteries

B.G. Sheeparamatti [*] , J.S. Kadadevarmath [**], and R.B. Sheeparamatti [***]

[*]Basaveshwar Engineering College, Bagalkot, India, sheepar@yahoo.com
[**]Karnataka University Dharwad, India, jagadish_sk59@rediffmail.com
[***]Basaveshwar Engineering College, Bagalkot, India, rajeshwari_sheepar@yahoo.co.in

ABSTRACT

Microcantilevers are extremely versatile and are used as sensors, actuators and in many other microsystems. In this work, simulink model of a microcantilever based actuator, which can be driven by nuclear radiation, is developed. This actuator can be used as micro-battery or micro-generator.

Microcantilever tip portion is exposed to nuclear radiation from lower side and becomes charged because of emission of electrons from the radioactive element. Thus an electrostatic attraction is created between base and the cantilever tip, which gradually bends at the tip and discharges the electrons. Now, electrostatic attraction disappears for a moment and then, the process repeats and thus the cantilever sets into oscillations. The piezoelectric plate on the microcantilever produces electric pulses, and can be used to generate electricity. The mechanical equivalent of the microcantilever is developed. In the electrical model, the force-voltage (or mass-inductance) analogy is considered. The transfer function obtained is used to derive the system performance. The model developed is subjected to different input conditions and the output is observed. The results of the analytical model are compared with the model developed in ANSYS/Multiphysics.

Such microcantilevers offer an attractive power source for MEMS based actuators, which require high power density or long life.

Keywords: microcantilevers, microbatteries, mathematical modeling, microgenerators.

1 INTRODUCTION

Microcantilevers are extremely versatile and are being used as sensors, actuators and in many other microsystems. In this work, mathematical/simulink model of a microcantilever based actuator, which can be driven by nuclear radiation, is developed. This actuator can be used as micro-battery or micro-generator. These microbatteries may not replace chemical batteries but definitely they make a considerable change in power supply for small electronic gadgets.

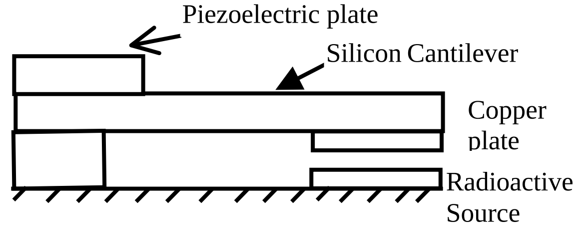

Figure 1: Microbattery

The main idea behind the microbattery is, microcantilever tip portion is exposed to nuclear radiation from lower side as shown in Fig 1[1]. Thereby its lower surface becomes negatively charged because of emission of electrons from the radioactive element underneath. Thus there is an electrostatic attraction between base and the cantilever tip. Once, sufficient number of electrons are collected, gradually the cantilever bends and discharges the electrons either by physical contact / tunneling / gas breakdown. Now electrostatic attraction disappears for a moment and then, the process repeats and thus the cantilever sets into oscillations. This recurring mechanical deformation of the piezoelectric plate kept on the microcantilever produces a series of electric pulses. These pulses can be rectified and smoothed to provide electricity.

2 THEORY

Considering the oscillating microcantilever as a system of single degree of freedom formed by a body of mass m and spring of stiffness k, and a dashpot, equation of vibration is developed. Similarly the mechanical equivalent of the microcantilever is also developed as shown in Fig. 2. In the electrical model, the force-voltage (or mass-inductance) analogy is considered as shown in Fig. 3. Laplace transform of the derived equations are taken for solving and easy analysis of such MEMS systems. The Laplace transform can be used to directly write the transfer function of the electrical equivalent. The transfer function obtained is used to derive the system performance. The model developed is subjected to different input conditions and the output is observed. The results of the analytical model are compared with the model developed in ANSYS/Multiphysics, as the ANSYS/Multiphysics is the finite element (FE) software, which is suited for performing the myriad of physics simulations required for MEMS.

Such microcantilevers offer an attractive power source for MEMS based actuators, which require high power density or long life.

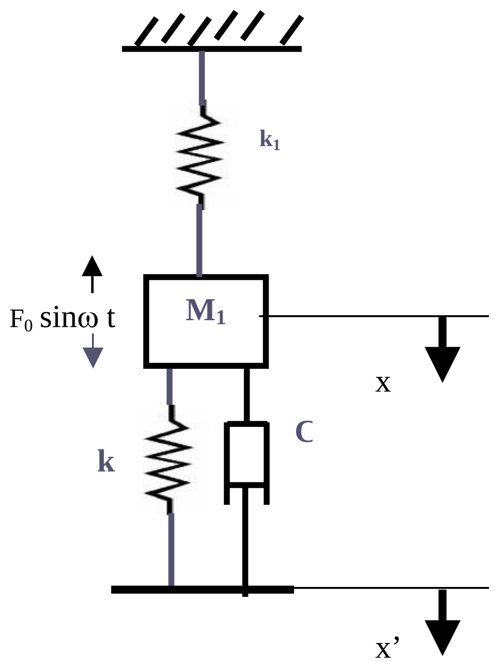

Figure 2 : Equivalent mechanical system

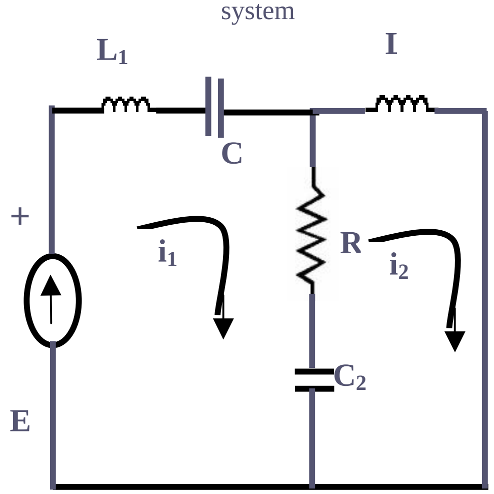

Figure 3 : Equivalent electrical circuit for a damped dynamic vibrating microcantilever with radioactive *stimulus*

3 SIMULINK MODEL

Assuming the silicon cantilever has negligible inertia, and the electrostatic force because of radiating particles leads to continuous oscillations. The capacitance between cantilever and base is given by equation 1, refer Figure 4.

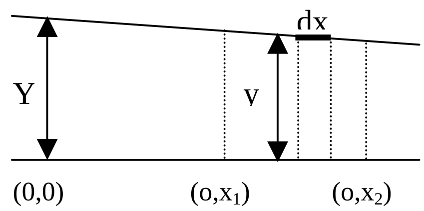

Figure 4: Cantilever Model

$$c = \frac{\omega \varepsilon_0}{a}\left[\log \frac{(y/a - x_1)}{(y/a - x_2)}\right] \quad (1)$$

The spring force of the cantilever exactly balances the electrostatic attraction force on the cantilever, which is shown in equation 2.

$$k(Y - y_0) = QE \quad (2)$$

where k is the spring constant, Y is the initial distance, and y_0 is the changed distance.

Assuming a uniform electric field, the capacitor can be modeled as a parallel plate capacitor C and the change on it is given by equation 3, below.

$$Q = CV = \frac{\varepsilon_0 AV}{y} \quad (3)$$

The MATLAB/Simulink tool enables one to model, simulate and analyze such dynamic systems. In this case a graphical model of the microbattery is created using Simulink model editor. The model depicts the time dependent mathematical relationships among the system inputs, states and outputs. Then using Simulink, the behavior of the system over a specified time can be simulated. The simulink model of the microbattery developed is shown in the Fig. 5. The result of the simulink model is shown in the Fig. 6. The microcantilever is also developed in ANSYS/ Multiphysics software and the output in the form of resonance frequency is shown in the Fig. 7.

4 RESULTS AND CONCLUSIONS

The simulink output showing distance (gap) versus time for an initial distance of 32 microns with a period up to 400 seconds[2]. Figure 6 shows the simulink output of the model. Similarly the ANSYS was used to create the

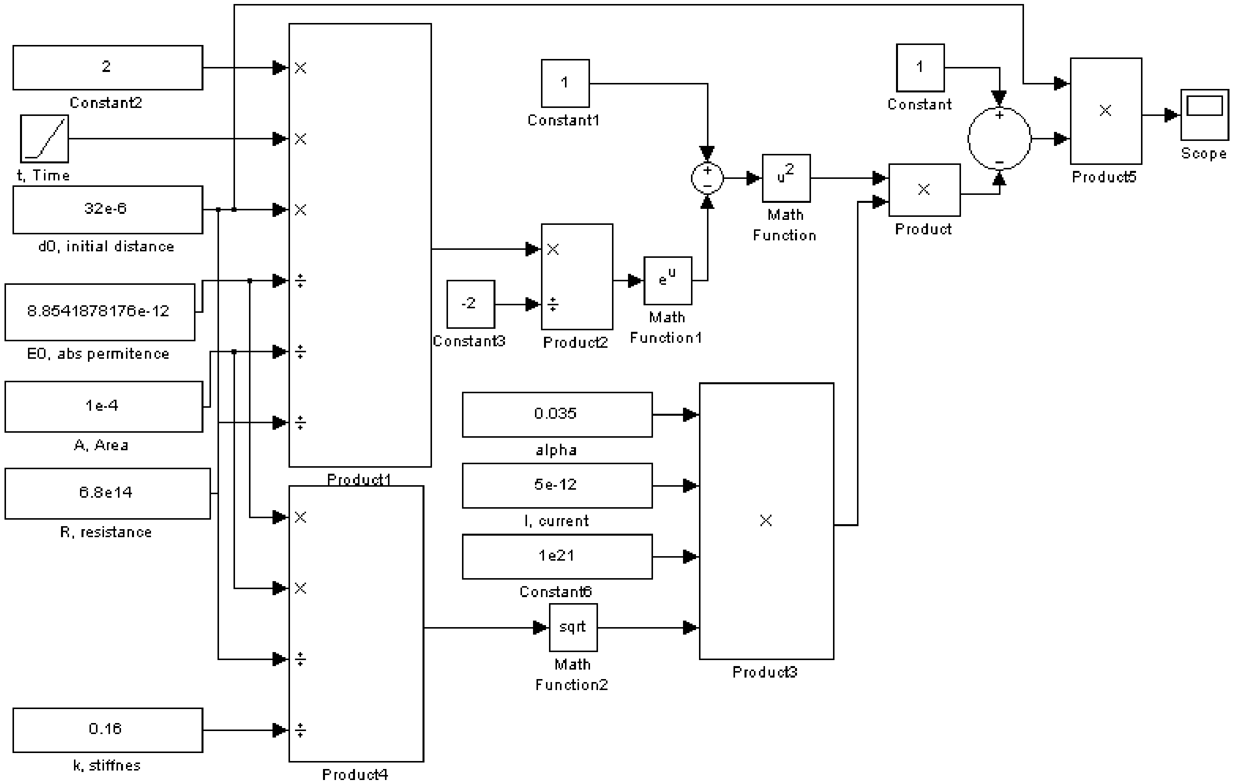

Figure 5 : Simulink model of the Microbattery

cantilever to find the critical oscillating frequencies. The result is shown in Figure 7. Harmonic analysis is carried out with excitation force of F sin ωt where F is in few fractions of micronewtons. In the frequency analysis, the ranges of frequencies considered are, from zero to 1 MHz. It is observed that at about 70 KHz and 430 KHz, maximum amplitudes (resonance) are obtained for a silicon cantilever of 100 micron long, 20 micron wide and 0.5 micron thick. This indicates that it is possible to simulate the behavior of silicon cantilever of the nuclear microbattery referred in this work.

The nuclear powered oscillators may become effective power sources for future personal electronic gadgets. The electrical equivalents, simulink models and ANSYS models developed in this work will help in understanding the microcantilever based nuclear microbatteries. These results help the people working on fabrication of such radiation based microcantilevers. The theoretical results and their analysis developed in this work will be much useful to the people working on design, testing and fabrication of microcantilever based actuators.

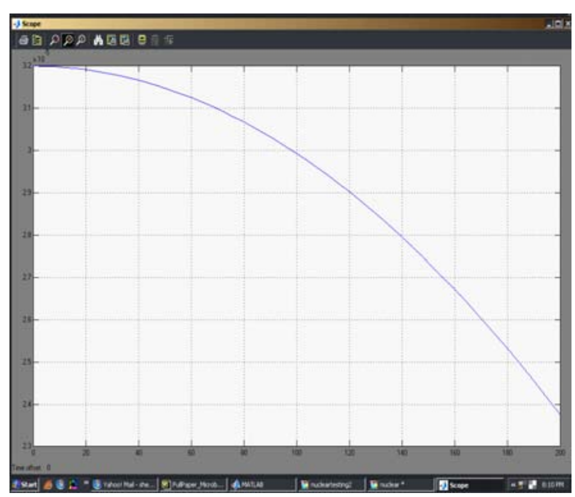

Figure 6 Simulink Output of the Microbattery

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8505-1 Vol. 3

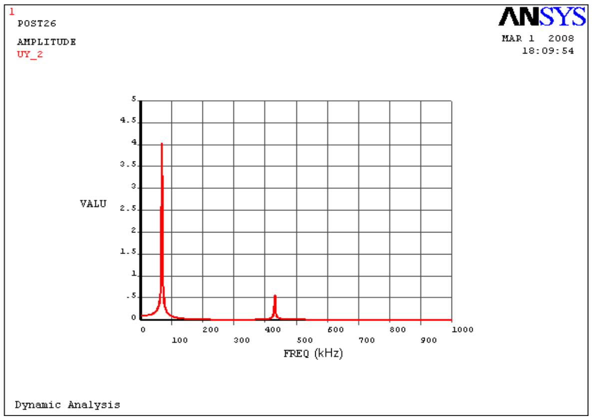

Figure 7 ANSYS/Multiphysics Output

REFERENCES

[1] Amit Lal, James Blanchard, “The Daintiest Dynamos”, IEEE Spectrum, 36-41,September 2004

[2] Hui Li, Amit Lal, James Blanchard, Douglas Henderson, “Self-reciprocating radioisotope-powered cantilever”, Journal of Applied Physics, Vol.92, Number 2, 1122-1127, 15 July 2002