Simulation and Study of the Effects of EM Radiations on Cantilever Beams with RF Functionality

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Abstract— The RF functionality in wireless devices is mostly achieved through RF MEMS. These are microelectromechanical systems having resonators that employ cantilever beams to produce radio waves. Our recent work has been in the field of energy scavenging from resonators in RF MEMS through the use of piezoelectric ceramics in cantilevers. In this paper we investigate the role of radiation in functioning of piezoelectric cantilevers and feasibility of the device to produce RF functionality. Weak terahertz electromagnetic radiations are used to irradiate the piezoelectric cantilever.

1. INTRODUCTION

Wireless technology is an indispensable part of modern lifestyle. The exponential increase in the use of wireless transmission in varied forms of gadgetry has posed a grave interest in RF functionality producing circuits and systems [1]. The most prominent and promising solution the wireless transmission and microwaves technology have been through RF MEMS since it produces radio-frequency through resonating cantilevers [2–4].

RF MEMS are Microelectromechanical devices that produce radio waves for wireless transmission and other applications and are quintessential in modern circuitry for providing RF functionality. The MEMS devices are fabricated using SiO_2 and Si_3N_4 along with other insulators. The electrostatic charging in these materials poses a challenge to reliability and performance of MEMS devices [5–8]. Also, the irradiation due to Electromagnetic waves contributes significantly to this phenomenon.

The semiconductor when subjected to irradiations produces electrostatic charge that may get absorbed and hence produce a charging in the device that can alter the dynamic behavior of the device. This effect is profound when the devices are exposed to ionizing radiations.

This paper is a study of the behavior of the cantilever beams under the influence of Electromagnetic Radiation and its effect on the working and efficiency of RF MEMS especially for medical devices where RF MEMS components are used. Also, the sensitivity of RF MEMS devices towards electromagnetic irradiation is studied. Varied irradiations were studied and their effects on the materials were recorded through simulations using multiphysics simulation software. The piezoelectric materials chosen are quartz, Zinc Oxide and Aluminum Nitride. The effect of EM radiations on these structures was observed in terms of increase in leakage current.

2. STUDY DESIGN

MEMS devices that operate on electrostatic principles are sensitive to charge re-distribution in the piezoelectric layer when exposed to EM radiations.

Figure 1 shows a typically clamped resonator generally used RFICs. Figure 2 is the part of resonator which is in the shape of cantilever and was tested for the variation in charge accumulation in the dielectric layer. Different piezoelectric materials like Quartz, Zinc Oxide and Aluminum Nitride were used for testing the structure. The dimensions of the beam were taken to be 40.8 μm × 8 μm × 1 μm.

The characteristics of piezoelectric materials is characterized by the following equations and discussed elsewhere [9]. The frequency of the piezoelectric is given by:

$$f = \frac{v_n^2}{2\pi}\sqrt{\frac{0.236 D_{pw}}{(l-l_m)^3\,(m_c-m_p)}} \tag{1}$$

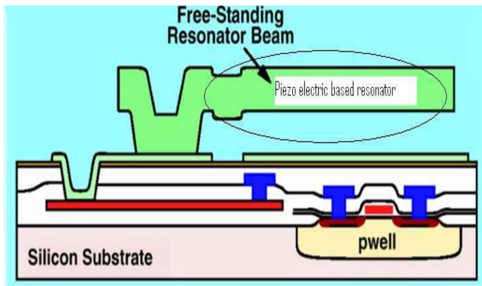


Figure 1. Piezoelectric ceramic based resonator used in RFIC.

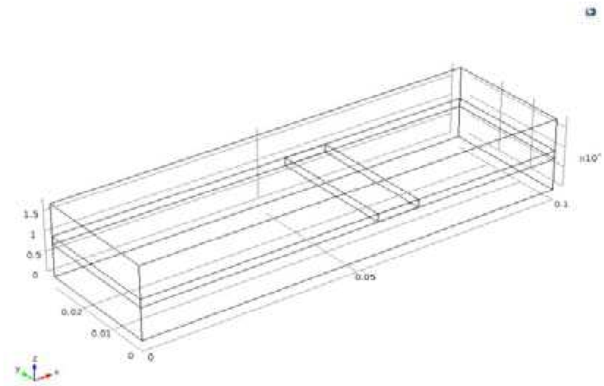


Figure 2. Test structure.

where, $v_n = 1.87$

$$m = \rho_p t_p + t_s \rho_s \tag{2}$$

$$m_c = 0.236mw\left(l - l_m\right) + mw\frac{l_m}{2} \tag{3}$$

$$D_p = \frac{\left(E_p^2 t_p^4 + E_x^2 t_x^4 + 2E_p E_x t_p t_x \left(2t_p^2 + 2t_x^2 + 3t_p t_x\right)\right)}{12(E_p t_p + E_x t_x)} \tag{4}$$

The energy of the piezoelectric is given by:

$$q = \frac{-3d_{31} s_s s_p t_s (t_s + t_p) l^2 F}{B} \tag{5}$$

where,

$$s_s = \frac{1}{E_s}, \quad s_p = \frac{1}{E_p}, \quad s_h = s_s t_p + s_p t_s \tag{6}$$

$$B = s_s^2 t_p^4 + 4s_s s_p t_s t_p^3 + 6s_s s_p t_s^2 t_p^2 + 4s_s s_p t_p t_s^3 + s_p t_s^4 \tag{7}$$

The voltage generated by the piezoelectric is given by:

$$V = \frac{-3d_{31} s_s s_p t_s t_p (t_s + t_p) l F}{\epsilon_{33}^T w B \left(1 + \left(\frac{3s_p^2 s_s t_p t_s^2 (t_p + t_s)^2}{s_h B} - 1\right) K_{31}^2\right)} \tag{8}$$

where E_p Young's modulus of piezoelectric material is, E_s is Young's modulus of substrate, l_m is length of proof mass, $l = l_b$ is length of the beam, $w = w_b = w_m$ is the width of beam, t_p is the thickness of piezoelectric material, t_s is thickness of substrate, m_p is proof mass, ρ_p is the density of piezoelectric material, ρ_s is density of substrate material, ϵ_{33}^T is permittivity in the direction of the applied electric field, d_{31} is the piezoelectric constant and K_{31} = coupling factor for longitudinal oscillation.

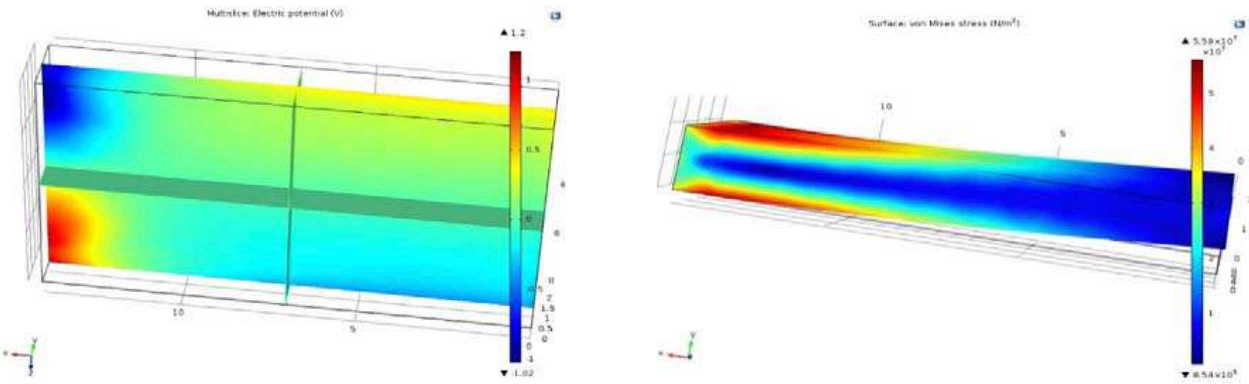
3. RESULTS AND DISCUSSIONS

Energetic particles and photons cause damage by transferring energy to the materials they penetrate. The energy loss mechanisms are complex, but the type of damage can be classified in two consequences: a) atomic displacement (i.e., moving atoms due to the collisions) and b) ionization (i.e., creating electron-hole pairs).

Figures 3(a) and (b) show voltage distribution and displacement produced across the whole test structure.

Table 1 shows the dielectric constant chosen for different piezoelectric materials in the analysis.

Figures 4(a)–(c) show the charge distribution and electric field variation in the test structure with ZnO as piezoelectric material and with radiations between 1.50–240 THz range.

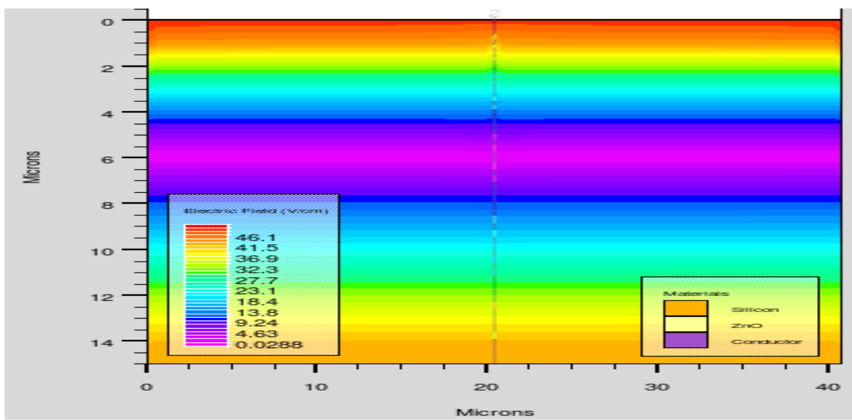


(a) (b)

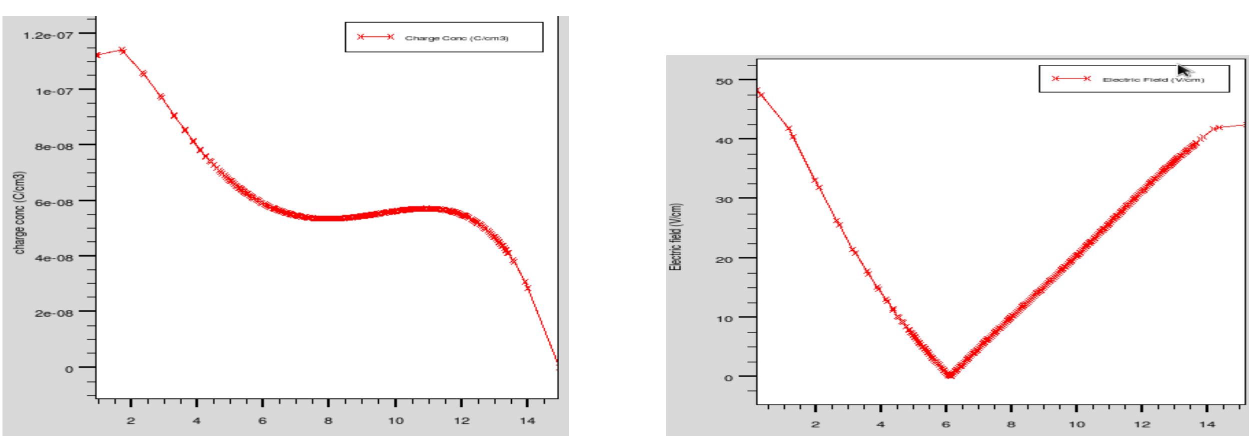
Figure 3. (a) Voltage distribution across the whole structure. (b) Displacement.

Table 1.

Piezoelectric material	Dielectric constant
Quartz	5
ZnO	10.8
AlN	9.14

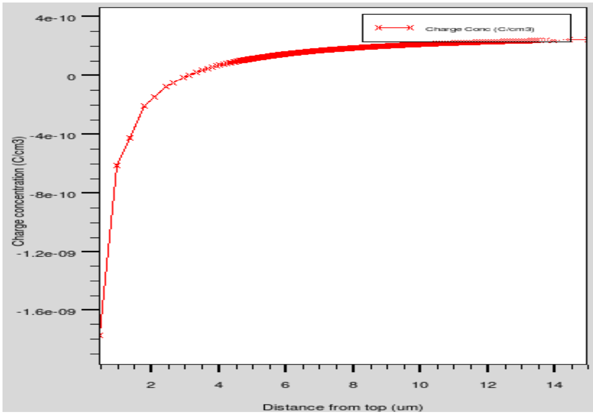


(a)

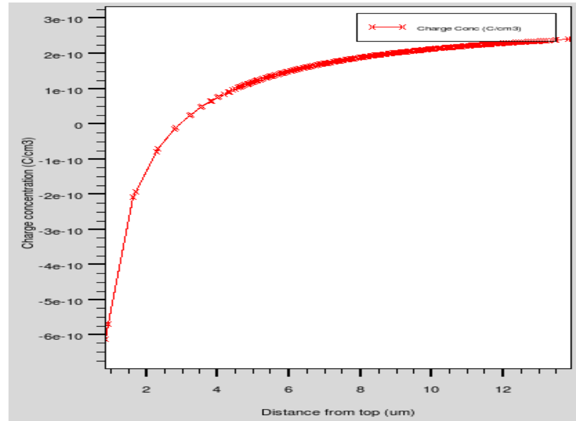


(b) (c)

Figure 4. (a) Charge distribution inside the ZnO based test structure. (b) Variation of charge concentration inside the structure. (c) Electric field variation inside the structure.

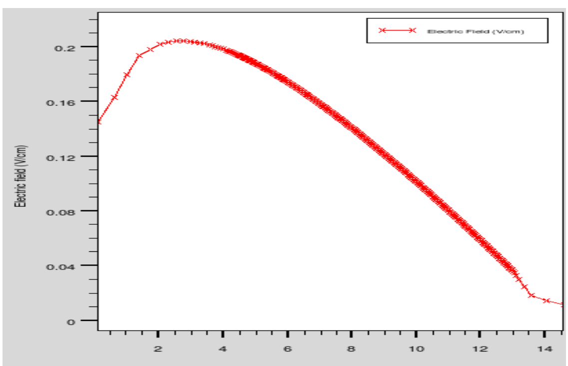


(a)

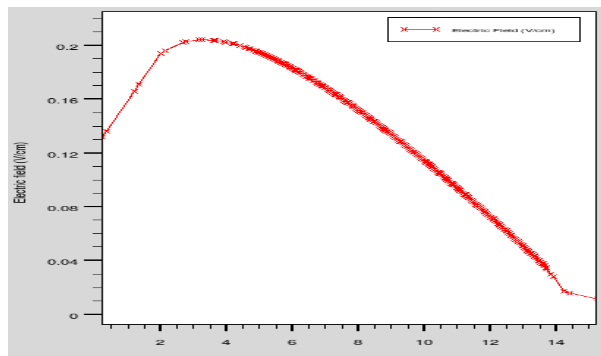


(b)

Figure 5. (a) Charge concentration with strain and radiation simultaneously (ZnO). (b) Charge concentration with strain and radiation simultaneously (AlN).



(a)



(b)

Figure 6. (a) Electric field with strain and radiation simultaneously (ZnO). (b) Electric field with strain and radiation simultaneously (AlN).

In the next simulation cycle the test structure strain as well as radiation was applied. The results obtained for charge concentration are shown in Figure 5.

Figure 6 shows the variation in electric field when strain and radiation both are applied.

Higher electric field was observed with ZnO followed by AlN and Quartz. It was observed that the behavior of the RF MEMS devices changes drastically with the change in type of different piezoelectric materials used. In the present case Zinc Oxide, Aluminum Nitride (AlN) and Quartz was used. Photon with sufficient energy can give rise to losses. It can be concluded that electric field rises because of radiation exposure. This is due to increase in charge concentration/trapping inside insulator as number of electron hole pairs are created because of non-ionizing radiation loss or displacement damage.

4. CONCLUSIONS

The paper investigates the role of radiation in functioning of piezoelectric cantilever and feasibility of the device to produce RF MEMS functionality. It was observed that behavior of piezoelectric materials changes drastically when exposed to radiations. Weak THz electromagnetic radiation is used to irradiate the piezoelectric cantilever made up of ZnO, AlN and Quartz. It was observed that electric field inside the piezoelectric material increases on radiation exposure which may affect the voltage produced when used for energy harvesting purpose.

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