



Design of MEMS resonator for Reliability and Robustness COMSOL Multiphysics

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ABSTRACT

The variability of design parameters caused by material properties is a major challenge in designing microelectro-mechanical systems (MEMS). The function of MEMSs is significantly influenced by this variability. We consider a thin-film resonator to show how the influence of scattering design parameters affect the behavior of the resonator. Here we used different material properties such as material density, poisson's ratio, young's modulus to analyse the performance of resonator

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Introduction

MEMS resonators are designed for a fixed resonant frequency. Therefore, any shift in the resonant frequency of the final fabricated structure can be a denting factor for its suitability towards a desired application. There are numerous factors which alter the designed resonant frequency of the fabricated resonator such as the metal layer deposited on top of the beam and the residual stresses present in the fabricated structure. With the increasing use of micro engineering techniques (Madou 1997) in producing sensing and actuating devices, it become increasingly significant to consider various after-effects of these techniques if the devices are expected to perform to their specification.

MEMS resonators made of polysilicon have potential application in the areas of RF-MEMS (Senturia 2000), MEMS oscillators (Maluf), resonant sensors (Craighead 2000) such as biological mass detector etc. As a resonator, the most important characteristics is the resonant frequency. Since the MEMS resonators are designed for a fixed resonant frequency, any shift in the resonant frequency of the final fabricated structure can be a denting factor for its suitability towards a desired application. In this paper we are analyzing the effect of design parameters on first resonant frequency.

The properties within a set of realizations of a technical design scatter randomly. Variability, or uncertainty of the design parameters are caused by manufacturing inaccuracy, process instability, environmental influences, human factors, etc. This aspect is considered in the design process.

Design for reliability and robustness of MEMS:

Today's micro electromechanical systems

(MEMS) fulfill a broad range of functions, based on electromechanical, chemical, optical, biological, and thermo-fluidic effects.

Examples are sensors in the automotive industry, surgical devices and implantable biosensors in medicine, optical switches and RF waveguides in telecommunications and navigation applications.

Major hurdles for commercialization are low reliability, robustness, and quality. In optimizing the design of a MEMS that is robust against scattering of material properties, design dimensions, properties of technology steps, or ambient conditions all that properties have to be considered with their distribution functions.

Considering the scattering of the properties is more important in MEMS design, because of the facts that (Tadigadapa and Najafi 2001):

- The scattering of the design and process parameters is relatively large, compared to the dimensions of the system,
- Many materials are poorly characterized.

Resonant frequency of a thin film resonator

The resonator consists of a shuttle and four cantilever beams made up of polysilicon. Almost all surface-micro machined thin films are subject to residual stress.

The most common is likely thermal stress, which accompanies a change in temperature and is due to the difference in the coefficient of thermal expansion between the film and the substrate.

The examples in this section show how to add thermal residual stress to a structural-mechanical model and observe how it changes the structure's resonant frequency.

Here we study the first resonant frequency of the resonator with a 3D COMSOL Multiphysics structural mechanics model. The figure no.1 shows the initial structure of the resonator.

In order to solve the eigen frequencies with the residual stress, the large-deformation analysis is used. In the first step, the residual stress is computed by a linear solver and stored. The second step calculates the eigen frequencies involving the stored linear solution (Eq no 1&2).

The simulation uses the nominal values of the design parameters which are described in the table no.1. In order to find the effect of design parameters and material properties on the performance of resonator, we changed its material and dimensions of the resonator system. We used aluminium, steel and silicon for comparison of performance.

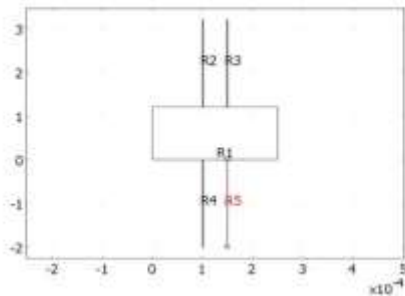


Fig:1 A thinfilm resonator with four cantilever beams.

For a lateral resonator with four cantilever-beam springs, the resonant frequency is

$$f_0 \approx \frac{1}{2\pi} \sqrt{\frac{4Et b^3}{mL^3} + \frac{24\sigma_r t b}{5mL}} \quad (1)$$

where m is the mass of the resonator plate, E is Young's modulus, t is the thickness, L is the length, b is the width, and σ_r

is the residual stress in the cantilevers. The stress is typically a sum of external stresses, the thermal stress, and intrinsic components. Assuming the material is isotropic, the stress is constant through the film thickness, and the stress component in the direction normal to the substrate is zero. The stress-strain

relationship is the $\sigma_r = \left(\frac{E}{1-\nu} \right) \epsilon$ (2) where ν is Poisson's ratio.

A process deposits a thin film onto a thick substrate at a high temperature. When the assembly cools to room temperature, the film and the substrate shrink differently and cause strain in the film.

The strain comes from $\epsilon = \Delta\alpha\Delta T$ where $\Delta\alpha$ is the difference between the thermal-expansion coefficients, and ΔT is the difference between the deposition temperature and the normal operating temperature assembly cools to room temperature, the film and the substrate shrink differently and cause strain in the film. The strain comes from $\epsilon = \Delta\alpha\Delta T$ where $\Delta\alpha$ is the difference between the thermal-expansion coefficients, and ΔT is the difference between the deposition temperature and the normal operating temperature.

Here the material used is polysilicon (Gad-el-Hak 2002).The width of the cantilever has been changed to 10 micrometer. This affects the first resonance frequency than any other design parameter.

The reliability and robustness of this kind of resonator is characterized by resonant frequency greater than or equal to 18 KHz. When this condition is not satisfied, our resonator system does not meet the required application for which it has been designed.

So to make our resonator more reliable and robust, the resonant frequency must be greater than 18KHz.We made changes in dimensions and material properties and found that width and material density affect the resonant frequency than any other parameter. Other parameters do not play an important role. The design parameters are given in the table no. 1.

The table no.2 describes the design parameters that are used for the comparison of the performance of resonator.

The first resonant frequency 42 KHz obtained for polysilicon for modified width is shown in the figure no.2.

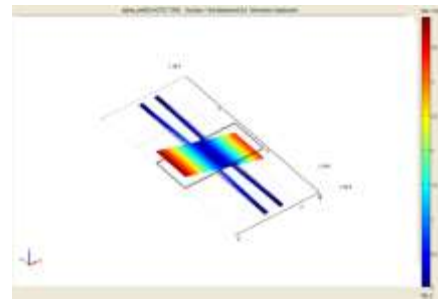


Fig no.2 The first resonant frequency for polysilicon

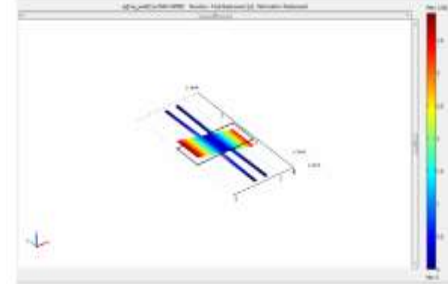


Fig no.3 The resonant frequency for Al

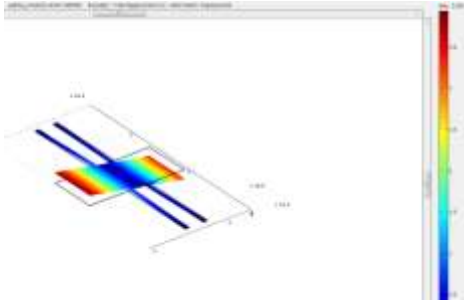


Fig no.4 The first resonant frequency for silicon

The obtained resonant frequency for Al,Si,Si3N4 and polysilicon are 18 KHz,43 KHz,50KHz,42KHz respectively.The figure no.3 shows the first resonant frequency for steel as 25KHz.The figure no.4 indicates the obtained resonant frequency for silicon as 43 KHz,When we use silicon nitride,it has less tensile stress.but it has worst electrical properties.Among these comparison of different materials,polysilicon is best suited for MEMS applications.Because of the presence of fine granular structure,it makes flexible.Though the metals are used for contacts,polysilicon is best for this applications.Thus the increased width and polysilicon as material is best suited to increase the reliability and robustness of the MEMS resonator.

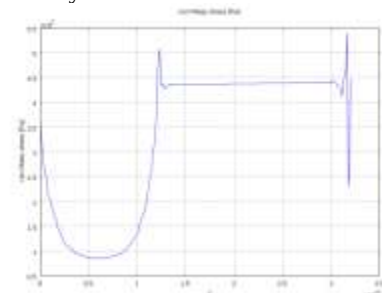


Fig no.5 The plot showing the decrease in stress

Conclusions

Thus the analysis of different paramaters and their effect on resonant frequency has been analysed. The increase in width of the cantilever increases the first resonant frequency by 42KHz..This reduces the stress effect to a certain extent (fig no.5).This resonator with resonant frequency 42 KHz is used in

gyroscope for testing the reliability under fatigue and stress conditions.

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Table: 1 Design parameters of polysilicon

Design parameters	Value
Young's modulus E (GPa)	155
Density rho (kg/m ³)	2330
Residual stress sigma (MPa)	50
Poisson's ratio	0.23
Deposition Temperature T1 (K)	605
Shuttle Length Ls (μm)	250
Shuttle Width Ws (μm)	120
Cantilevers Length Lc(μm)	200
Cantilevers Width Wc (μm)	10

Table: 2 Comparison of design parameters

Design parameters	Si	Si ₃ N ₄	Al
Young's modulus E (GPa)	170	250	70
Density rho (kg/m ³)	2329	3100	2700
Poisson's ratio	0.28	0.23	0.35