Design And Simulation of MEMS Based Double Ended Tuning Fork Strain Gauge

Supriya M Biradar[1], Preethi M S[2], Nishanth N[3], Rakshitha V S[4], Mr.G Narayanaswamy[5]
[1, 2, 3, 4] Dept of Electronics and Communication
[5]Assosciate Professor, Dept of Electronics and Communication
[1, 2, 3, 4, 5] VidyaVikas Institute of Engineering and Technology, Mysore, India.

Abstract- *Strain gauges have been extensively used for detecting strain in various applications. Double ended tuning fork strain gauges present better performance characteristics than standard foil gauges, including higher sensitivity, smaller size and higher resolution. This study focuses on the design of a MEMS Double ended tuning fork and the evaluation of its performance through the comparision of analytical and computational model outcomes. The analytical model predicts the sensitivity and frequency of the gauge using the beam equation while the finite element computational model is set up using COMSOL.*

Keywords- Strain gauge, DETF, tuning fork, MEMS.

I. INTRODUCTION

A Strain gauge (sometimes referred to as a Strain gage) is a sensor whose resistance varies with applied force; It converts force, pressure, tension, weight, etc. ,into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur.

The strain gauge is one of the most important sensor of the electrical measurement technique applied to the measurement of mechanical quantities. As their name indicates, they are used for the measurement of strain. As a technical term "strain" consists of tensile and compressive strain, distinguished by a positive or negative sign. Thus, strain gauges can be used to pick up expansion as well as contraction.In civil engineering and the biomedical field, strain gauges are used to measure deformation sustained by various objects. Typically, foil gauges are used, but they have low sensitivity. MEMS-based gauges, like the double-ended tuning fork (DETF) strain gauge, offer better performance. There are applications that requires a high sensitivity gauge. Depending on the specific setting, there may be additional requirements such as high temperature operation, high temperature oreutectic bonding and high fracture toughness. MEMS-based strain sensors have been demonstrated to be more sensitive than metal or semiconductor gauges, be able to withstand high temperatures during operation or bonding. To optimize the design of a new DETF strain gauge, we used the COMSOL Multiphysics software and compared the results to an analytical model.

Double ended tuning fork strain gauge

The geometry of double ended tuning fork strain gauge consists of beams and anchors.The beams are connected on each end with the base, which is of the same material and usually much stiffer than the beams. The whole structure is suspended by the anchors, which connect the double-ended tuning fork to the substrate. The device layer will be monocrystalline silicon, thus, the density used is 2230Kg/m^3 and the Young's modulus (E) will be 150 GPa.The model uses comb drive structures which are often used as linearactuators, which utilize electrostatic forces that act between two electrically conductive combs. The measured frequency of a double ended tuning fork (DETF) is dependent on applied strain.

II. LITERATURE SURVEY

1. Optical strain gauge

Author: Diaz-Carrillo ,S. Salaverria,Guemes J A
Published in: 2018

This paper states that optical strain gauges can survive in harsh environments, but The tool used to measure the optical gauges are bulky, preventing their use in confined spaces.

2. Capacitive strain gauge

Author:Kirankumar, B balavada, G Sheeparamatti
Publishedin:2015

This paper states that capacitive strain gauge has high sensitivity and the power consumption is less.But these gauges are more sensitive to electromagnetic interference.

3. Piezoresistive and Piezoelectric strain gauge

Author: Li Cao,Tae Song Kim and Dennis

Published in: 2011

This paper of piezoresistive and piezoelectric strain gauges are quiet small in size but they suffer from high temperature sensitivities and there is non linear strain measurements.

4. Metal foil strain gauge

Author: David Richard Myers

Published in: 2010

This paper states that these metal foil gauges are very compliant relative to the component which they are measuring. Since the measurement is resistive based, temperature increases cause thermal noise. They suffer from poor sensitivity compared to other strain gauges.

Motivation

- Micro size sensors and actuators: Integration with electronics on single chip (system or lab on chip)
- Decreased cost of production: bulk processing
- Many new features and products previously unthought can be possible.
- Combination of MEMS with other branches:Example optical MEMS, Bio-MEMS futuristic devices.

Problem statement

- The primary drawbacks to capacitive sensors is the sensitivity.This can be improved by increasing the size of the gauge but this is also problematic because large area gauges are typically less shock resistance.
- Optical strain gauges are highly sensitive but since they are bulky it becomes less shock resistant.

III. METHODOLOGY

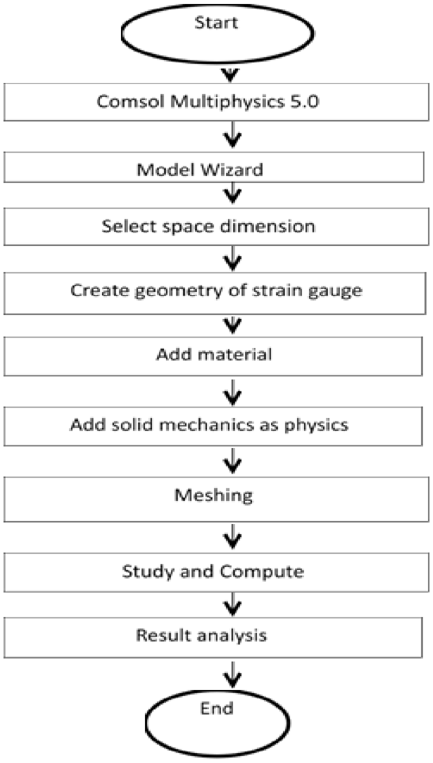


Fig 1: Flow chart of the proposed work

Fig 1 shows the flow chart of the proposed work started with creating a 3D model of DETF strain gauge using COMSOL Multiphysics 5.0.Once the model is ready, the strain applied on the model is computed.

Implementation

The model of the DETF strain gauge model has been created using COMSOL 5.0. The 3D geometry consists off the DETF itself as well as the electrostatic comb drive.Firstlywe have to build comb drive structure.These comb drive structure are often used as linear actuators which utilize the electrostatic force between two electrically conductive combs. Comb drive structure is shown in the figure 3.1

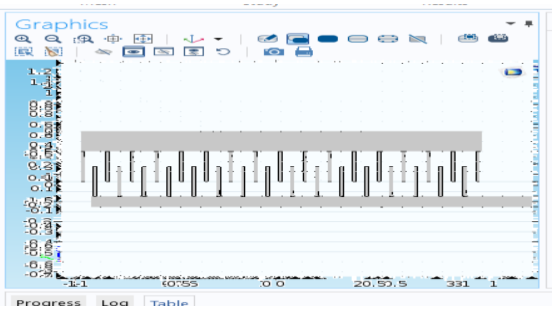


Fig 3.1 comb drive structure

The model used beams and anchors to support geometry. The device is made from a mono-crystalline silicon layer. The material of the device was modeled as linear elastic material. The model uses the silicon oxide as the material. The final model of double ended tuning fork strain gauge is shown in the figure 3.2

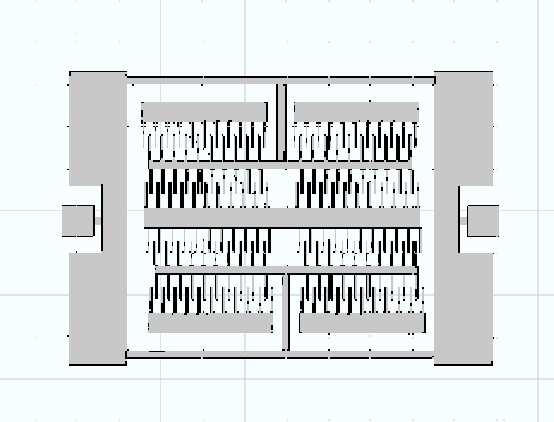


Fig 3.2 : Double ended tuning fork strain gauge

The model uses the solid mechanics node and an eigenfrequency analysis A study was performed to calculate the frequency of the DETF strain gauge. The force applied is 100[N].The model is meshedusing free triangular mesh. The mesh is shown in the figure 3.3

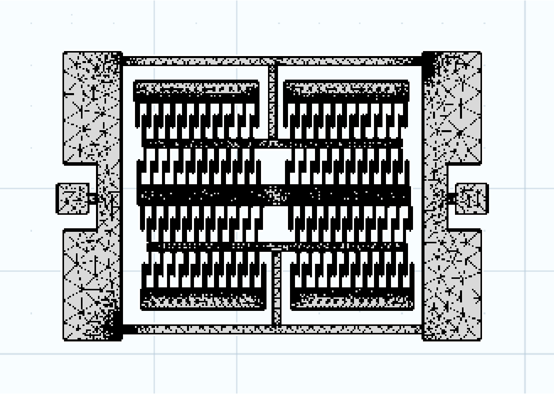
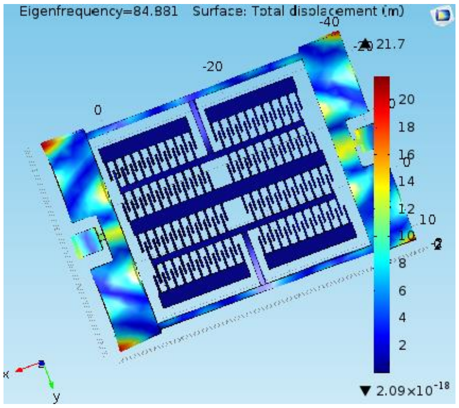


Fig 3.3: Structured mesh of the model geometry

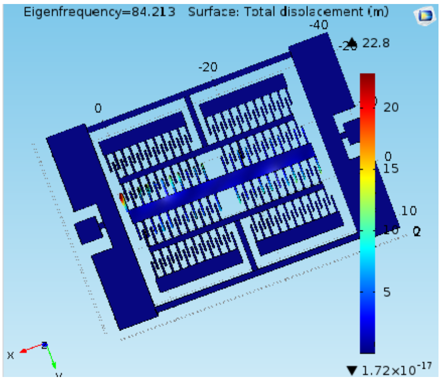
The first step of the study was to perform a static analysis according to the applied load and the second is the modal analysis to estimate the frequency. Fixed constraint condition was applied at the bottom of the anchors and the bottom of the stationary combs. The boundary conditions were applied at the bottom of the device and at the comb fingers. In order to analyze the sensitivity of the sensor, all the degrees of freedom were removed from one of the anchors and a boundary force was applied to the free anchor. The force was applied to the longitudinal direction of the device effectively being a tensile force.

IV. RESULTS AND ANALYSIS

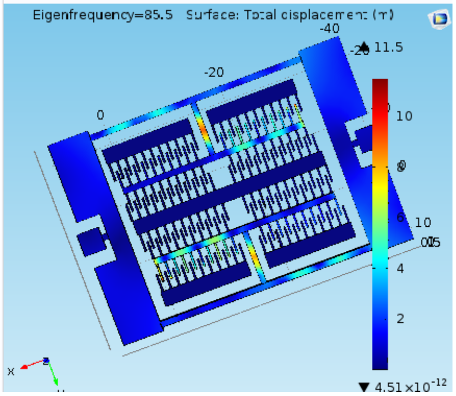
The frequency analysis is conducted in order to obtain the maximum amplitude at the resonant frequency in the range 80KHz-88KHz. The unstretched resonant frequency of the gauge predicted by the beam theory was found to be 87.220 kHz and the resonant frequency of the first mode estimated by COMSOL was 84.881 kHz. In this setting, there is no tensile force applied on the beam. The frequency response of the model is shown in the figure



Frequency 1: 84.881KHz



Frequency 2: 84.213KHz



Frequency 3: 85.5KHz

The derived expression for frequency sensitivity of the sensor is givenby

$$\frac{\partial f_r}{\partial \varepsilon} = \frac{128Ebh}{105\pi L\left(M_{act}+\frac{128L\rho bh}{315}\right)\sqrt{\frac{\frac{256Eb^3h}{15L^3}}{M_{act}+\frac{128L\rho bh}{315}}}}$$

The internal strain term εint and the input strain ε term are assumed zero. The sensitivity of the beams to strain greatly depends on their physical dimensions. The sensitivity of the gauge is 47.5 Hz/με as per the computed model.

V. CONCLUSION

This study shows a high sensitivity DETF strain gauge capable of resolving strain as high as 1000ue.By manipulating the dimensions of the gauge it was possible to achieve the high sensitivity without structurally compromising the rest of device. Although the sensitivity of the gauge is higher than other gauges presented in the literature, the strain losses from the substrate and the anchor structure of the DETF have tobe further analyzed. This will provide a more accurate estimation of the gauge output under experimental testing.

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