3D ELECTROSTATIC ENERGY HARVESTER

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ABSTRACT

This paper discusses the design of an electrostatic generator, power supply component of the self-powered microsystem, which is able to provide enough energy to power smart sensor chains or if necessary also other electronic monitoring devices. One of the requirements for this analyzer is the mobility, so designing the power supply expects use of an alternative way of getting electricity to power the device, rather than rely on periodic supply of external energy in the form of charging batteries, etc. In this case the most suitable method to use is so-called energy harvesting – a way how to gather energy. This uses the principle of non-electric conversion of energy into electrical energy in the form of converters.

The present study describes the topology design of such structures of electrostatic generator. Structure is designed and modeled as a three-dimensional silicon based MEMS. Innovative approach involving the achievement of very low resonant frequency of the structure, while the minimum area of the chip, the ability to work in all 3 axes of coordinate system and ability to be tuned to reach desired parameters proves promising directions of possible further development of this issue. The work includes simulation of electro-mechanical and electrical properties of the structure, description of its behavior in different operating modes and phases of activity. Simulation results were compared with measured values of the produced prototype chip. These results can suggest possible modifications to the proposed structure for further optimization and application environment adaptation.

Keywords: MEMS, energy harvesting, generator

1 INTRODUCTION

Due to great progress in the microelectronics there are applications with large demands on the individual components of the application chain. One example is an intelligent wireless sensor network where each node needs to maximize the time that the sensor works and is independent of the energy supply from an external source. Using conventional batteries is not always convenient, because it requires human intervention for their replacement. For this reason it is a major problem to get electricity needed to operate these devices. One way to ensure power is to use other types of energy that are available in the vicinity of the powered device. Most of these devices use (depending on usage field) the heat, light or mechanical energy. In this way, gaining power can meet energy requirements throughout the life of the powered device. The process of obtaining energy from the environment [1,2], converting it into consumable electricity is generally known as energy harvesting. Devices using the principles of gathering energy are usually referred to as energy generators.

2 ENERGY HARVESTER PROPOSE

The main goal is to design the structure topology of the electrostatic generator in standard technologies available on the market. Structure based partly on basic beam structure is designed and modeled as three-dimensional silicon based MEMS. The main task is to optimize the dimensions of the structure due to the available production technology, optimize the geometry of the structure itself with regard to the environment in which the generator will be used and obtaining the excitation energy. Compared to already published proposals we expect to work in all 3 axis of Cartesian system. This makes the system more effective to environment waste energy and makes it possible to use all energy available. Another part of this work is a simulation of electromechanical and electrical properties of the structure, description of its behavior in different operating modes and phases of activity. After verifying the behavior of structures in the simulations the next task is the preparation of the production data in accordance with the design rules specified in the by the manufacturers delivered design kit. The fabricated prototype was characterized, tested on basic functions and these results will be later compared with simulated values.

2.1 Designing the Harvester

The designed power source is using a combination of electrostatic and piezoelectric generator (as required start-up power source) in the form of MEMS structures. Using CoventorWare we designed layout topology and 3D models. For a given structure solving network equations of deformation and mechanical stress were defined. Using the harmonic analysis we obtained response to changes in the structure of the excitation signal. Electrostatic generator [4]uses the forces generated between the opposite charges on the plates of a charged capacitor. Separation of charge Q on the electrodes depends on the potential difference V between them according to equation $Q = CV_{VAR}$. C_{VAR} capacity is a function of geometry (topology) and electrode properties of materials that surround them. When moving a mass m in the range of z(t), as shown in Fig. 1, the capacity changes between C_{MAX} and C_{MIN}. From the mechanical movement extracted energy depends on how the variable capacity is connected to other electronic circuits. There are basically two basic techniques that were used to implement the electrostatic generator - switching or continuous mode.

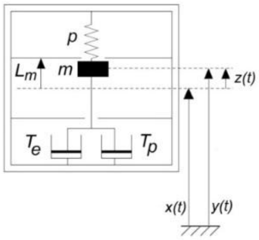

Figure 1: Inertia generator principle

2.2 Switching mode – Constant Charge

In the case of using switching modes there is a switch between the generator and the rest of the circuit which allows time-dependent reconfiguration of the device (charging, discharging). When a pre-charged capacitor at its maximum capacity is disconnected from all external circuitry and the electrodes movement leads to a reduction of its capacity, but also to the generation of work, corresponding to overcome the electrostatic forces acting between the electrodes. This additional energy gained can then be used to power the circuit. The most common way to implement this system is shown in Fig. 2a.

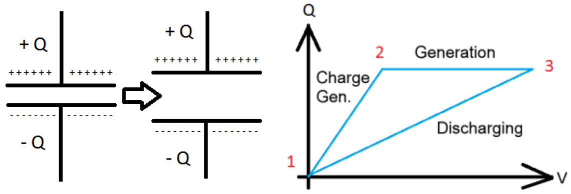

Figure 2a,b: Principle of operation of electrostatic generator in the constant charge mode and its QV characteristics

Two parallel plate electrodes are arranged so that they could move away from each other. This kind of movement, in the case of constant charge on both plates of a capacitor, creates a constant force between these two electrodes. Fig. 2b shows the QV characteristic of the whole working cycle. First, the capacitor is connected to a power source and the electrodes are charged to the low voltage (jump from 1 to 2). Then the capacitor electrodes are disconnected from the source and moved away from each other while maintaining a constant charge on the electrodes (2-3). Finally, the charge is discharged within the third cycle (3-1). The capacity is then increased again and the generator is ready for a new cycle. The area bounded by trajectories connecting points 1 to 3 corresponds to the energy generated.

3 TOPOLOGY DESIGN

The CoventorWare was used to create topology layout of the comb capacitor structure, the 3D model, simulation net, and to provide the electromechanical simulations. CoventorWare is an integrated suite of design and simulation software that has the accuracy, capacity, and speed to address real-world MEMS designs. The suite is filled with MEMS-specific features for accurately and efficiently simulating all types of MEMS, including inertial sensors (accelerometers and gyros), microphones, pressure sensors, resonators, and actuators. The included field solvers provide comprehensive coverage of MEMS-specific multi-physics, such as electrostatics, electro-mechanics, piezoelectric [3], piezoresistive, and damping effects. The goal is to verify the characteristics of the real produces sample with simulated results.

The whole topology can be devided into three main parts (see Fig. 3).

- Movable bomb electrode – part A on picture
- Fixed electrodes – part B on picture
- Spring suspension – part C on picture

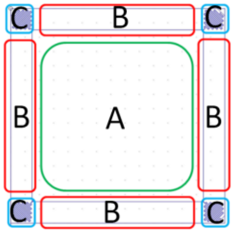

Figure 3: Basic comb structure topology

Fig. 4 shows the 4th designed topology version, which already contains a complete set of both types of electrodes, modified spring suspensions and mechanical stops (highlighted), limiting the amplitude of mechanical displacement in order to avoid possible mechanical damage to the structure and short-circuit between the electrodes.

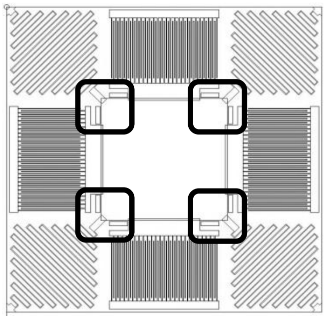

Figure 4: Topology No.4

Fig. 5 shows the 9th version, which spring suspensions are formed by wrapping the periodic structure of the girder type. Thanks to this we achieved such a suspension structure, which is mechanically equivalent to the suspension beam of great length, but on a much smaller effective area. Because of technological reason we changed the position of two contact pads on solid electrodes. Due to the asymmetrical handle of spring suspensions to the moving electrode we obtained very little difference between the 1st and the 2nd modal frequency of the structure. In the case of fine oscillations a smooth transition from one type of conversion mechanism to another occurs which leads to increased efficiency and yield of the conversion cycle. The final 9th topology was sent to production foundry and was modeled for simulations.

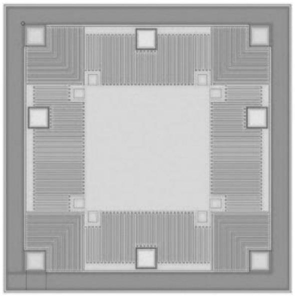

Figure 5: Final 9th topology

3.1 3D Model

A 3D model which has been created for electromechanical simulations in CoventorWare is shown on Fig. 6..

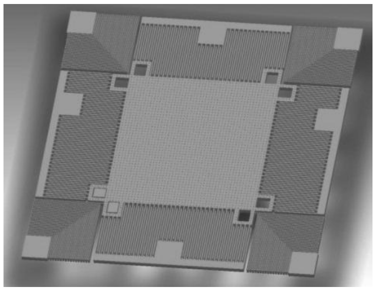

Figure 6: 3D Model of topology No.9 (with 2 stoppers)

4 SIMULATIONS

4.1 Modal Analysis

Modal analysis can be obtained from the natural resonance frequency of the mechanical system in equilibrium. On these frequencies reacts the mechanically undamped (lossless) system to external motion excitation with unlimited deflection. The following figures shows the mechanical simulations performed on the structure in CoventorWare. The Fig. 7-9 show the degree and direction of the deflection structure. For the function generator are important only the first 4 natural frequencies, because in them there is the greatest changes in the position of movable electrode. Other natural frequencies are already showing the effect of several orders of magnitude smaller. The scale of deflection is due to small shifts multiplied by the real and solid electrodes are not shown.

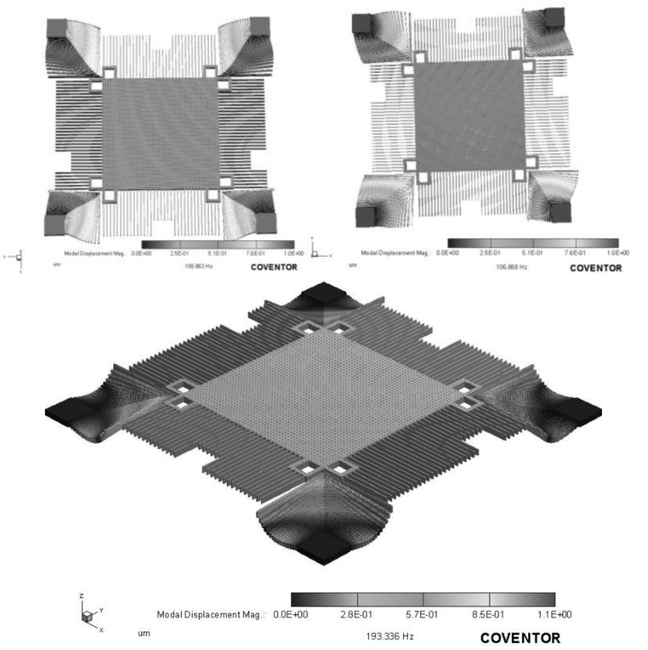

Figure 7,8,9: Modal frequency simulations

Another important aspect is the mechanical stress (Fig. 10) inside the structure caused by mechanical vibrations. The most used method of hanging capacitor structures in published papers is based on the topology of a simple bridge from one side firmly fixed to the frame chip and on the other side connected to the floating electrode. After exposure to mechanical vibration the movable electrode starts to swing. The maximum deflection of the assembly depends on the frequency of oscillation of the mechanical excitation, the total weight, mechanical properties of the material and topology. The weight is generally to reduce the natural frequencies and increases the deflection and internal stress.

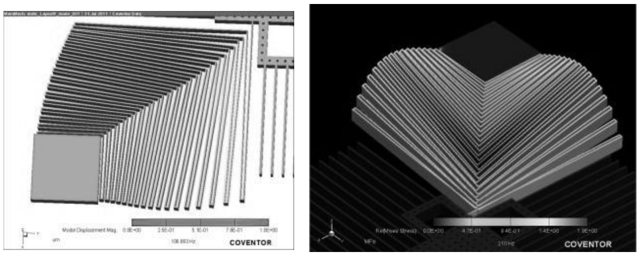

Figure 10: Mechanical excitation and internal stress

4.2 Harmonic Analysis

Using harmonic analysis, we find the dynamic response of the system with harmonically variable load. Fig. 11 shows the statistical study of the mechanical response of structure to random excitation of periodic oscillations in all three axes. The vertical axis shows the excitation in X, Y and Z. The horizontal axis shows frequency in Hz. On frequencies around 100 Hz (1st and 2nd modal frequency) the structure shows a movement in both directions X and Y. Thus, there are local maxima of both curves X (blue) and Y (red). The 3rd modal frequency of 193 Hz has a major move in the Z axis, suggesting a local maximum of the green curve. The 4th modal frequency at which the structure exhibits rotational motion around the Z axis is seen in the local maxima of both curves X and Y. The 5th modal frequency at 305 Hz shows again movement mainly in the Z axis. The local minima at the 4th and 5th modal frequencies are equivalent to the standing wave due to movement around the axis or point of symmetry, which is located within the housing structure.

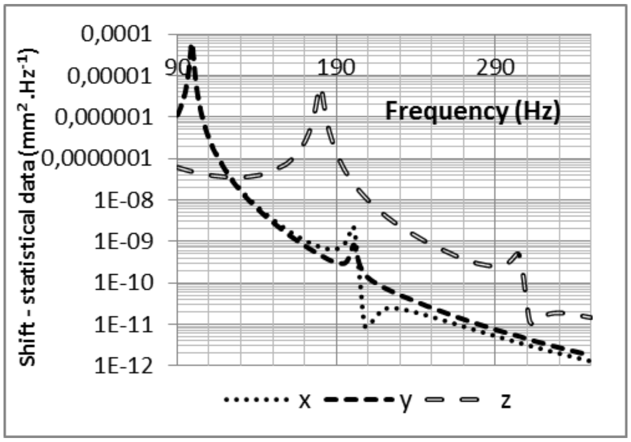

Figure 11: Randon vibrations excitation in all three axis with a constant statistical distribution from 90 Hz to 350 Hz. Acceleration 3500 (mm.s^{-2})2.Hz^{-1}

5 FABRICATION

The proposed generator was produced by SOI HARM 60µm Tronics® technology. Fig. 12a,b show details of the laboratory sample.

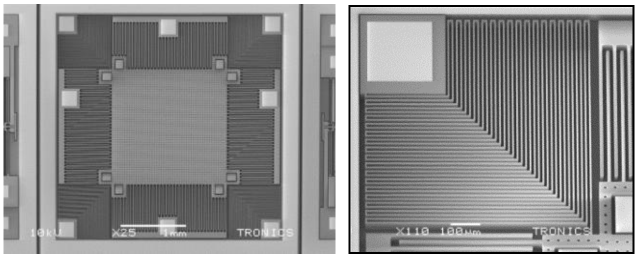

Figure 12a,b: Real sample

5.1 Parameter evaluation

A measurement chain for modal frequencies can be seen on Fig. 13. We use capacitance bridge with periodic signal excitation. The generator is placed on a vibration table KCF ES02 with KCF PA5100 signal generator.

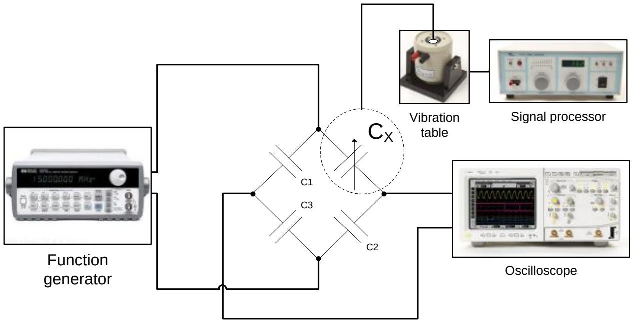

Figure 13: Measurement chain

6 CONCLUSIONS

The proposed generator is able to work in all 3 axis, has very low modal frequencies (about 108 Hz), in-build stops-structures again damage of the electrodes and very small dimensions. These properties make it possible to use this generator in embedded systems. It is proposed to be used in combination with piezoelectric source which acts as start-up source.

Acknowledgments

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