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An efficient and effective energy harvesting system using surface micromachined accelerometer

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ABSTRACT

In many of the electronic devices the major role is performed by micro-electro-mechanical systems (MEMS). The electronics field has a vast application where in MEMS contribution to this field is very much greater. The electronics has a greater application in the area of micro-electro-mechanical systems which has greater applications in biomedical, electronics. The capacity, sensitivity in the power and its size helps MEMS for various different applications in different fields. If a device has a greater resonant frequency which can also be used in all frequencies that is at normal frequencies wider bandwidth, then also the MEMS fabrication can be done. A surface micromachined accelerometer is analyzed which can be used for generating energy from the environment. The characteristic feature is analyzed for the surface micromachined accelerometer. A surface micromachined accelerometer is simulate with a geometry of 3 space dimensions with a domain number of 120 whose number of boundaries are 838 which contains 1733 number of edges with 1076 vertices. The surface micromachined accelerator with all these specifications is simulate using COMSOL and the performance has been analyzed for various parameters namely frequency, acceleration and load impedance. The results show that energy has been harvested using the surface micromachined accelerometer.

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1. INTRODUCTION

The smallest mechanical and electromechanical components are used in constructing the micro-electro-mechanical systems. The specification for fabricating a micro-electro-mechanical systems (MEMS) device will be in the range of micron. So, it will be an added advantage for the engineers to fabricate micro electromechanical devices in various fields of the engineering. The MEMS devices will be of many different types. They are being as i) simple MEMS device which consist of no moving elements and ii) complex MEMS device which consist of many moving elements.

The important parameter in considering a MEMS device is that it will be consisting of a mechanical function though there are movable or immovable elements in the fabricated MEMS device. The names used to refer the MEMS device will be varying in different parts of the world. There arises a need in all parts of the world for the MEMS devices in the field of science and technology. So, researchers and inventors in the field of MEMS put forth a various type of microsensors for sensing the various parameters namely pressure, temperature, humidity, moisture, forces, vibration, different radiations, and waves. So, all these microlevel sensors performance is very efficient and effective when compared with macrolevel sensors. The advantages of MEMS fabrication are low cost, more production, and high performance. So, there is an aggressive growth in the field of microsensor than that of the macrosensor. The microsensor has been continuously growing in the various fields of engineering. The massive and ongoing reduction in the size and power consumption of sensors and complementary metal oxide semiconductor (CMOS) circuitry has prompted a concentrated research effort on onboard power sources that potentially replace batteries. The issue with batteries has always been that they need to be charged before they can be used. Sensors and data collecting components in distributed networks, on the other hand, require centralised energy sources to operate. Sensors for structure health monitoring in remote areas, geographically unreachable temperature or humidity sensors, and battery charging or replacement processes can be time-consuming and costly in some applications. Battery replacement in a large-scale sensor network can be difficult and expensive, and it's nearly impossible in dangerous, harsh, and large-terrain deployments. Embedded sensor networks in urban battlefields are one example. In such instances, the focus has logically been on constructing on-site generators that can convert any accessible form of energy.

Ultralow power integrated circuits can now run-on tens of nW to hundreds of W of power, thanks to recent breakthroughs in low-power extremely large-scale integration design. This approach has paved the way for on-chip energy harvesting technologies, which eliminate the need for chemical batteries or complicated microsensor wiring, laying the groundwork for battery-free autonomous sensors and network systems. Using parasitic energy available locally in the environment as a power source is an alternative to using traditional batteries. Industrial machinery, human activities, cars, structures, and environmental sources all produce unused energy, which could be good sources for capturing modest amounts of electricity without impacting the source itself. At the meso-, micro-, and nanoscales, numerous energy harvesting systems based on solar, thermoelectric, electromagnetic, piezoelectric, and capacitive schemes have been presented in recent years. Energy harvesting for sensor and communication networks utilizing a MEMS/thin-film technique and energy harvesting for other electronic devices employing bulk devices are the two categories that can be easily distinguished. The focus of this article is on small-scale power energy harvesting approaches (1–100 W) for self-supported operation of portable or embedded microdevices and systems using the MEMS/thin-film approach. Furthermore, because mechanical vibration energy is abundant and has an infinite life duration, we focus on it as the primary source of electric power generation. "What is the optimum technique for transferring mechanical energy into electrical energy in millimeter 3 dimensions?" is a question that one might pose at this point. When compared to electromagnetics, the piezoelectric mechanism becomes more appealing.

A predominant growth has been achieved in the field of MEMS so that the inventors and achievers in that field has contributed more in microactuators which consist of a control unit for scrutinizing the flow of gas and liquid; for modulating light beams an optical switch has been developed by the inventors in the field of MEMS. In order to display micromirror has been created; for developing pressure in the fluid micro pumps are developed; for developing airstreams or airfoils microflaps are invented; though these micro actuators are very very small they can develop the same effect as that of a macroscale component. The various techniques have been analyzed and the highlights are put forth here which has been listed is being as: Lee [1] developed a linearized model which is used for testing the stability. The gate driving voltage is increased which is helpful in reducing the power loss is achieved by self-boosting technique which in turn will reduce the capacitor’s quality factor. Jiang *et al.* [2] explained the double sampling method which is correlated with the chopper stabilization is used for designing a capacitive accelerometer CMOS. Using this method, the accelerometer is designed which will have reduced flicker noise. In this paper an accelerometer with low noise and low power is designed.

Terzioglu *et al*. [3] the capacitive accelerometer has been designed using feedback system with the actuation method. A dynamic force across the patellofemoral joint is measured using a little implant. The author suggests that the forces in the knee can be measured by this sensor. The biomechanics in the knee, pain in the anterior side of the knee can be understood with the help of the sensor. The difficulties can be reduced by analyzing this sensor [4]. The author has put forth a system with which an efficient practical energy harvesting from human vocal folds vibrations. This power level is very large enough to satisfy the power requirements for future biomedical implants [5]. Agarwal and Guo [6] has developed a micromachined accelerometer with a greater resolution where in a silicon-on-insulator (SOI) microelectromechanical foundry method has been implemented which finds its application in the field of seismic. A new method of electromagnetic (EM) radiation has been developed by the author in which there is a reduced absorption which in turn will produce a lower amount of thermal heating [7].

A neural technology is used for recording the neural happenings where in an advanced modulation scheme namely four-level frequency-shift keying (FSK) modulation method is analyzed and it is used for data transfer from neural area to the outside environment in higher order [8]. According to the author it provides a more efficient way of approach where in the dissipation of power is greatly reduced [9]. In order to have more efficient and effective method for the estimation of perfect intraocular pressure (IOP) reading the automated algorithms have been developed for optimization of optical and mechanical methods [10]. The author has implemented a resonant accelerometer in MEMS with the help of electrostatic softening effect [11]. It provides a new and effective method which increases the tuning sensitivity of the MEMS accelerometer.

2. METHOD

In the emerging scientist development area fabricating a MEMS device is a great challenge. There are many different methods for fabricating the MEMS device. The most famous and efficient technology in fabricating a MEMS device is surface micromachining [12], [13]. The micromachining can be differentiated with the different methods in which the fabrication of MEMS device is performed. It mainly depends on the type of materials used in doing the fabrication and also the combinations of the etching materials that has been used in doing so. The different steps involved in MEMS fabrication are: i) Depositing a thin film device and patterning; ii) The temporary layer is removed; iii) The mechanical structural layer will be removed; and iv) The structural layer is allowed to move in.

The fabrication is explained with an example. It is shown in the Figure 1. The steps involved here are as shown in: i) The deposition is carried on with the help of oxide and it is patterned; ii) This is known as sacrificial layer as it is a temporary one; iii) A polysilicon layer has been deposited as a thin film layer it has been patterned; iv) The above layer is known as the structural mechanical layer; v) The important procedure is that the sacrificial layer which is a temporary one will be removed at this juncture; and vi) Since all the temporary layers are removed the polysilicon layer is very easy to move now like a cantilever.

As the thickness of the deposition film can be limited for the structural and sacrificial layer. In the direction the dimension can be controlled horizontally which is shown in Figure 1. The photolithography and etching process is used mainly for maintain better fidelity which is maintained by the tolerance [14], [15] in the structural layer. The advantages of surface micromachining are a greater amount of structure can be fabricated. A wide variety of sacrificial and etchant methods can be used simultaneously. Because of all these features it is very easily compatible with the MEMS and microelectronics. Low pressure chemical vapor deposition (LPCVD) is used for deposition in designing the surface micromachined accelerometer the wafer technology enables single sided hence it is known as a simple method for fabricating a MEMS. Therefore, the integration density is greater and the cost for fabricating a bulk micromachining is very much lesser.

The deposited thin films [16] are not known commonly and have to be calculated which the major disadvantage is in the surface micromachining. Hence a residual stress has to be reduced in the structural layer which enhances a frequent increase in annealing to a greater temperature. There are a lot of difficulties faced by these films in reproducing the properties mechanically [17]–[20]. The structural area can be released with a greater difficulty because of the capillary forces there arises a problem of stiction effect which is major problem in surface micromachining. So it can be controlled with the help of anti-stiction material coated in the layer [21]–[25]. The main drawback in the existing method is that power not harvested from the environment.

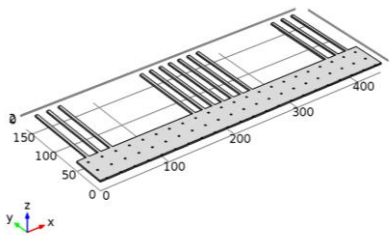

Figure 1. Micromachined accelerometer

3. RESULTS AND DISCUSSION

The popular method of surface micromachining and the material used is very important in fabricating a MEMS device. The sacrificial layer is built using a phosphosilicate glass (PSG) layer and the doping material used is polysilicon. The sacrificial layer is removed using the popular hydrofluoric acid which acts as an etchant. For fabricating the analog devices which are integrated with the MEMS accelerometer can be used as an airbag in crash avoidance management. The detection circuit has been correlated with the help of microstructures which uses sensors for mechanical devices are known as surface micromachined capacitive accelerometer which is shown in Figure 2. There exists perpendicularity between the substrate and the sensing axes. There will be a translator for conversion of mechanical displacement into its equivalent signals which will be an electrical one. The microchips are produced with the help of crystalline silicon which is easily available from the levels of impurity in the silicon is very lesser than that has been required for other applications there are different steps involved in purifying the silicon to the semiconductor level. They are as shown in: i) Chemical purification: in which semiconductor level silicon is produced as hyperpure silicon; ii) Recrystallization: the monocrytalline silicon is grown in this process which enables us to get a better silicon form; and iii) Wafer cutting: the final process of having a wafer is achieved by cutting the cylindrical boules. The Figure 1 shows a MEMS device constructed using the polysilicon material for deploying micro machined accelerometer.

There is another different method where the metal surface layer can be used for structural layer and the sacrificial layer can be developed with the help of polymer. The removal is done with the help of the etchant O_2 plasma. The reason for using a metal layer here is that the temperature required for depositing a sacrificial layer the structural layer can be reduced to a greater extent which will not lower the value of any of the materials that has been present in the base layer which is nothing but the substrate made up of silicon. So, it is an added advantage where in the electronics circuits are integrated with the MEMS devices. Here the removal of the sacrificial layer is performed by a non-immersion method. Since the non-immersion technology is carried out the problems raised due to stiction is cleared. The Texas instruments digital light processor (DLP) device makes use of the same method of removing the sacrificial layer without immersion which finds its application in the field of projection environment. The geometric statistics are listed in Table 1 which is as shown in. The material properties are listed in Table 2 which uses those properties for the analysis purpose. The main properties considered are density, Young's modulus and poison's ratio. The simulation of a capacitive actuated surface micromachined accelerometer using the electromechanics interface is performed and the various parameters are analyzed. The energy can be harvested from the resources which are available naturally and this is one of the alternatives for emerging system in case of the MEMS. Thus, in the proposed method of surface micromachined accelerometer power can be harvested from the environment and various analysis has been performed and the simulation is performed for getting the various analysis which shows that energy can be harvested in more quantity which is shown in the result. The various parameters are analyzed which shows a clear indication that surface micromachined accelerometer is very suitable for maintaining greater energy for performing its various functions. The discussion can be made in several sub-sections.

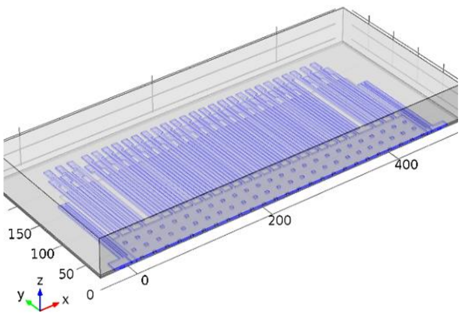

Figure 2. Si-polycrystalline silicon

Table 1. Geometry statistics

Description	Value
Space dimension	3
Number of domains	120
Number of boundaries	838
Number of edges	1733
Number of vertices	1076

Table 2. Material properties

Name	Value	Unit
Relative permittivity	4.5	1
Density	2320 [kg/m^3]	kg/m³
Young's modulus	160e9 [Pa]	Pa
Poisson's ratio	0.22	1

3.1. Acceleration versus output power

The software used for simulation is COMSOL. COMSOL is slow if the computations are complex. It also needs more power and greater memory. It has been a challenging issue, as the software is following finite element approach. Though it has certain limitations the software has many advantages and very easy for setting up solutions for complex problems with greater efficient solution. With the help of COMSOL the various parameters are studied and graphs are plotted. The relationship between capacitance and voltage is analyzed. The acceleration and capacitance have been calculated and plotted graphically. The graphs are plotted for various parameters and the capacitance is observed. The graphs show that energy can be harvested more from the surrounding so that various applications can be performed. The Figure 3 explains in detail how the output is varying whenever there is a change in the acceleration. If the acceleration is increased then the output power will be increased which in turn will increase the efficiency of the device.

3.2. Dynamic viscosity versus pressure

The behaviour of the surface micromachined cpacitive MEMS accelerometer is analyzed in terms of its dynamic viscosity and pressure. If the viscosity is varied in accordance with the pressure then the performance is analysed graphically. Even if the viscosity is getting varied the pressure is also getting varied in accordance with the variable. It has been shown in the Figure 4 which helps to understand the behaviour of the accelerometer.

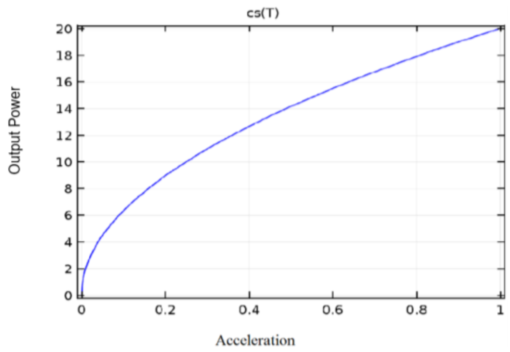

Figure 3. Acceleration versus output power

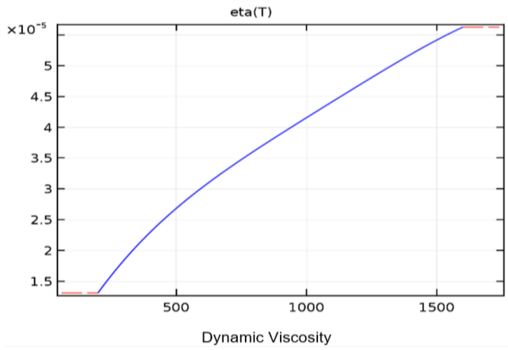

Figure 4. Dynamic viscosity versus pressure

3.3. Heat capacity versus pressure

The another important parameter namely pressure has been analyzed for the accelerometer and the graph has been plotted. Figure 5 clearly shows the variation of haet capacity with that of the presuure. If the heat capacity is increased then the pressure is increased linearly which is indicated in the graph. This gives us a clear idea of the behaviour the heat capacity versus the pressure so that the behaviour of the surface micromachined MEMS can be well studied with the help of the graph which help us to analyze the performance behaviour.

3.4. Micro-electro-mechanical systems accelerometer

The Figure 6 explains the arrangement of the MEMS accelerometer for the surface micromaching process. It helps to analyze the alignment of mems accelerometer which will be used for energy harvesting. The acceleration is varied and its corresponding output power is observed which is indicated the figure. The analysis clearly tells the behaviour of the MEMS when various acceleration is given how the various output power is generated.

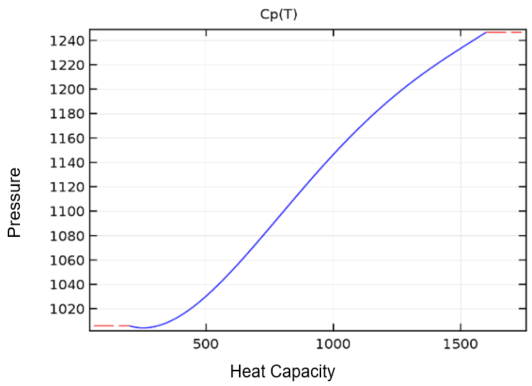

Figure 5. Heat capacity versus pressure

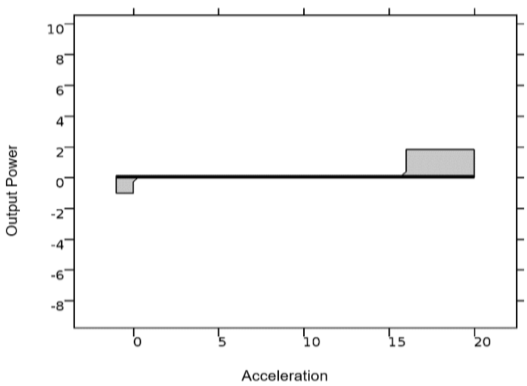

Figure 6. MEMS

3.5. Relationship between acceleration and power

The relationship between acceelration voltage and power is studied with reference to the acceleration and the performance has been plotted with the help of graphical representation and it is shown in the Figure 7. The relationship between the acceleration voltage and power is linear which can be used for different energy harvesting applications. The analysis clearly shows the dependance of acceleration voltage with the power. This gives us a good observation for knowing the relationship between different tyoes of acceleration and power.

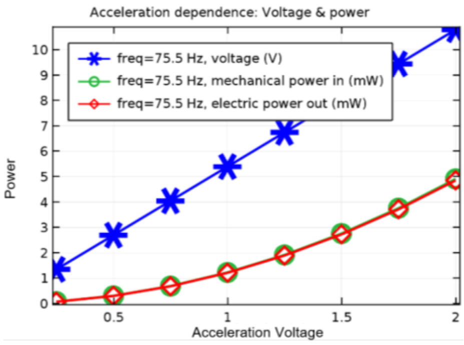

Figure 7. Relationship between acceleration and voltage and power

4. CONCLUSION

The output shows the characteristics of energy harvesting. A simple piezoelectric energy harvesting which uses a cantilever arrangement is analyzed. It will be the basis of the harvesting principle which generates energy from the environment. The MEMS energy harvester is tested by applying acceleration sinusoidally and the output is obtained. This research work focuses on the idea of the behavior of energy harvesters. The output is obtained for various parameters namely frequency, acceleration, and load impedance. It clearly shows the analysis of the energy harvesting. The characteristic feature is analyses for the surface micromachined accelerometer. A surface micromachined accelerometer is simulate with a geometry of 3 space dimensions with a domain number of 120 whose number of boundaries are 838 which contains 1733 number of edges with 1076 vertices. The surface micromachined accelerator with all these specifications is simulate using COMSOL and the performance has been analyzed for various parameters namely frequency, acceleration and load impedance. The results show that energy has been harvested using the surface micromachined accelerometer.

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