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RESEARCH ARTICLE

A NEW SENSITIVITY-ENHANCING METHOD FOR PIEZOELECTRIC RESONANCE MASS SENSORS THROUGH CANTILIVER CROSS- SECTION MODIFICATION

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ABSTRACT

A resonant cantilever mass sensor can quantitatively detect unknown analytes by measuring the frequency shift, which mainly consists of one piezoelectric or piezoresistive layer, one elastic supporting layer, and one functional layer for absorbing analyte on the cantilever surface. This paper focus on the piezo electric effect as the transduction method which focus on harvesting energy using cantilever beam i.e.resonance based energy harvesting. Furthermore, by optimizing both the cross-section shape and the geometrical ratios of the elastic extension to the piezoelectric layer simultaneously, the overall sensitivity can beincreased by 8.15 times greater than that of the rectangular section cantilever sensor, which has great potential applications in high-resolution mass sensor This paper proposes the increased efficiency which can be obtained by incorporating piezo electric sensors with resonant cantilevers.

INTRODUCTION

In the recent years, much attention has been paid to improving the detection sensitivity and on simplifying the measurement procedure. According to the operating principle of resonant sensors, the mass detection sensitivity $\Delta f/\Delta m$ (resonance frequency shift per unit mass change) is directly bound with the cantilever geometry and configuration and with the properties of the materials composing it. Using this principle, the existing methods are categorized into three main topics: geometrical dimension reduction [1], regulation of high-order vibration, and configuration optimization interface inductance, which reduces the switching harmonics. Piezoelectric generation is a well-researched method of harvesting power from mechanical vibrations.

When the crystal structure of the piezoelectric material is loaded, the micro-structure of the crystal is distorted. In order to maintain electrical equilibrium within the crystal the electrons become mobile and shift, creating a current. This is referred to as the direct piezoelectric effect. Alternatively, the exact opposite phenomenon, the converse piezoelectric effect, can also take place. For micro-generation, the direct piezoelectric effect is used to convert vibration to electricity. The direct piezoelectric effect is used for micro generation and sensing purposed, while the converse piezoelectric effect is used mainly for actuation. Piezoelectric generation is frequency dependant, maximized as the frequency at which the system is driven is at resonance, where the displacement is maximized. Cantilever beams are the most convenient arrangement of piezoelectric material for generating Sensors because it allows for the 31-mode of the piezoelectric material to be accessed easily, maximizing the voltage output of the piezoelectric material, especially in low strain realms. In addition to the cantilever type piezoelectric microgenerator, membrane-based generators are being investigated for both implantable and ambient uses. Generally, a circular membrane of lead zirconate titanate (LZT) is used due to its axis symmetry. In biomedical applications, a circular membrane piezoelectric microgenerator can be tuned to actuate from pressure differences found in the body, such as those generated by breathing, muscle contractions or blood flow. A circular piezoelectric micro generator was designed to be actuated from the pressure difference (40 mmHg) that is produced from a typical human pulse.

It has already been demonstrated that bulk micro machined capacitive MEMS accelerometers are very robust. They even can withstand the firing shocks of 20’000 g when used in

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guided munitions. The limiting factor for many applications is the electronics transforming the capacitive signal into an electrical output. Previous electronics used was not designed for high temperature nor for immunity against radiation effects such as radiation induced upsets SEU/ MBU and large total doses. There are basically two ways of measuring the acceleration with a MEMS sensor: either open or closed loop. In an open loop electronics the capacitance change is the MEMS is measured and amplified. In closed loop electronics the inertial forces are compensated by electrostatic forces [3]. Closed loop system allows reaching better ultimate performance in terms of bias stability, linearity and noise. The price to be paid for these ultimate performances is in terms of power (needs very precise high voltage), size (driven by the power supply requirements) and complexity (analogue and Digital electronics).

Micro Electro Mechanical Systems

The development in electro mechanical technology (MEMS) has opened the door for creation of power systems at unprecedented small scales. This paper also deals with one of the methods to produce power at small scale from waste energy. The micro engines convert the kinetic energy of the heat into mechanical, which is further converted into electrical energy. The waste heat itself can be used as an input to the devices, suppose if the kinetic energy of the heat is insufficient then Rankin's cycle can be introduced in order to produce additional kinetic energy. Also it uses a carbon filter before the exhausted air from the automobile is fed into the wind turbine. All the components can be fabricated in a chip and covered. A heat supply and heat sink are also required in order to form a complete power generation system. Each power plant chip is expected to generate in the range of 1-10 Watts of electrical power.

Key requirements for high performance and high reliability in harsh environments are a stable mechanical sensor that is a MEMS device and its associated die attach technology. For the MEMS sensor a proven capacitive accelerometer design is used as illustrated in Fig.1. It is based on a proof mass suspended by a spring and detecting acceleration in the out of plane direction. It has already shown that excellent performance can be reached with this approach [2]. An out of plane acceleration will deflect the proof mass and change the capacitances between the middle and the top and bottom plate respectively. A new die attach technology was developed that is robust in high repetitive but has still minimal die attach stress.

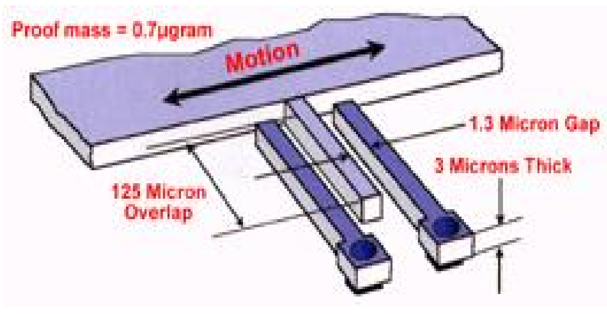

Fig1 Cantilever Cross Section

The second key element is the design of the electronics for operation over in all environmental conditions, i.e. over the full temperature range and under radiation. In a first phase an ASIC was designed for industrial applications, including operation at high temperature (175°C).

Mems Technology

MEMS described as an enabling manufacturing technology as opposed to an industry. Because many of the processes employed for MEMS manufacturing originated in the semiconductor industry, silicon is typically utilized for MEMS substrates. However, non-silicon materials such as glass, quartz, ceramic, plastic and metal substrates are also emerging in micro fabrication. The process technologies normally employed in silicon MEMS manufacturing include: surface micromachining, bulk micromachining and high aspect ratio micromachining.

Bulk micromachining refers to processing in which the silicon substrate acts as the mechanical constituent of the devices. Applications of bulk micromachining include pressure sensors, ink jet nozzles and many high precision acceleration sensors.

Surface micromachining incorporates processes in which thin films on the substrate surface act as the mechanical constituent while the substrate acts solely as support. Air bag acceleration sensors are an example of surface micromachining.

Non-traditional lithographic processing for the fabrication of tall, high aspect features are generally referred to as HARMS (high aspect ratio micromachining). HARMS processes include high intensity exposure (using x-rays as a source) and deep vertical etching of substrates.

Accelerometer Manufacturing & Testing

Prototypes of the accelerometers and the ASIC in a non-rad hardened version where manufactured.

Complete accelerometer with the MEMS (left) and the ASIC (right) in a hermetically sealed ceramics housing. A new die attach technology was applied to make them very robust. This technology is already applied in the existing

Calibres RS9000 product family. Shock test were performed on the RS9010 devices to qualify the technology. Two tests were performed, one with multiple shocks of low amplitude and one with multiple shocks of high amplitude. The low amplitude shock test consisted of 20 shocks with 740g. These test were performed at -30, 20, 80°C. The measured bias shift was < 44 ppmFS. This die attach technology is also applied for the new generation of accelerometers The high shock test consisted of 90 shocks of 6000g, 0.15 ms. Tests were performed on 13 samples. No sample failed. Figure 4 shows the variation of bias during these tests. The maximum observed bias shift was 1250 ppmFS and the sensitivity shift > 400 ppm. As a comparison, devices with the previous die attach technology would generally fail under these conditions.

Resonant Cantiiver With Piezo Plate

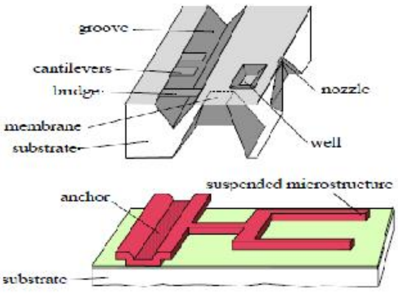

Fig2 Resonant Cantilever Cross Section

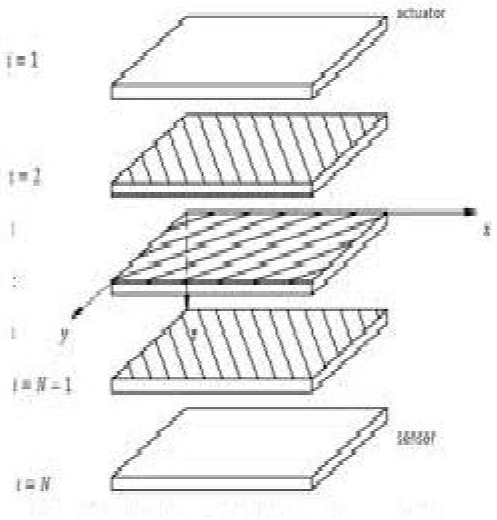

Fig3 Piezo Plate

Piezoelectric Plate

A piezoelectric plate is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical charge. Piezoelectricity, also called the piezoelectric effect, is the ability of certain materials to generate an AC (alternating current) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both. The most common piezoelectric material is quartz. Certain ceramics, Rochelle salts, and various other solids also exhibit this effect.

A piezoelectric transducer comprises a "crystal" sandwiched between two metal plates. When a sound wave strikes one or both of the plates, the plates vibrate. The crystal picks up this vibration, which it translates into a weak AC voltage. Therefore, an AC voltage arises between the two metal plates, with a waveform similar to that of the sound waves. Conversely, if an AC signal is applied to the plates, it causes the crystal to vibrate in sync with the signal voltage. As a result, the metal plates vibrate also, producing an acoustic disturbance.

Principle of Operation

Depending on how a piezoelectric material is cut, three main modes of operation can be distinguished: transverse, longitudinal, and shear.

Super Capacitor

Super capacitors also called ultra-capacitors and electric double layer capacitors (EDLC) are capacitors with capacitance. Super capacitors are not as volumetrically values greater than any other capacitor type available today. Capacitance values reaching up to 400 Farads in a single standard case size are available. Super capacitors have the highest capacitive density available today with densities so high that these capacitors can be used to applications normally reserved for batteriesefficient and are more expensive than batteries but they do have other advantages over batteries making the preferred choice in applications requiring a large amount of energy storage to be stored and delivered in bursts repeatedly.

Advantages

- Power density
- Recycle ability
- Environmentally friendly
- Safe
- Light weight

The most significant advantage super capacitors have over batteries is their ability to be charged and discharged continuously without degrading like batteries do. This is why batteries and super capacitors are used in conjunction with each other. The super capacitors will supply power to the system when there are surges or energy bursts since super capacitors can be charged and discharged quickly while the batteries can supply the bulk energy since they can store and deliver larger amount energy over a longer slower period of time.

Super capacitor construction

What makes' super capacitors different from other capacitors types are the electrodes used in these capacitors. Super capacitors are based on a carbon (nanotube) technology. The carbon technology used in these capacitors creates a very large surface area with an extremely small separation distance. Capacitors consist of 2 metal electrodes separated by a dielectric material. The dielectric not only separates the electrodes but also has electrical properties that affect the performance of a capacitor. Super capacitors do not have a traditional dielectric material like ceramic, polymer films or aluminium oxide to separate the electrodes but instead have a physical barrier made from activated carbon that when an electrical charge is applied to the material a double electric field is generated which acts like a dielectric. The thickness of the electric double layer is as thin as a molecule. The surface area of the activated carbon layer is extremely large yielding several thousands of square meters per gram. This large surface area allows for the absorption of a large amount of ions. The charging/discharging occurs in an ion absorption layer formed on the electrodes of activated carbon. The activated carbon fibre electrodes are impregnated with an electrolyte where positive and negative charges are formed between the electrodes and the impregnate. The electric double layer formed becomes an insulator until a large enough voltage is applied and current begins to flow. The magnitude of voltage where charges begin to flow is where the electrolyte begins to break down. This is called the decomposition voltage.

The double layers formed on the activated carbon surfaces can be illustrated as a series of parallel RC circuits. As shown below the capacitor is made up of a series of RC circuits where R1, R2 …Rn are the internal resistances and C1, C2..., Cn are the electrostatic capacitances of the activated carbons. When voltage is applied current flows through each of the RC circuits. The amount of time required to charge the capacitor is dependent on the CxR values of each RC circuit. Obviously the larger the CxR the longer it will take to charge the capacitor.

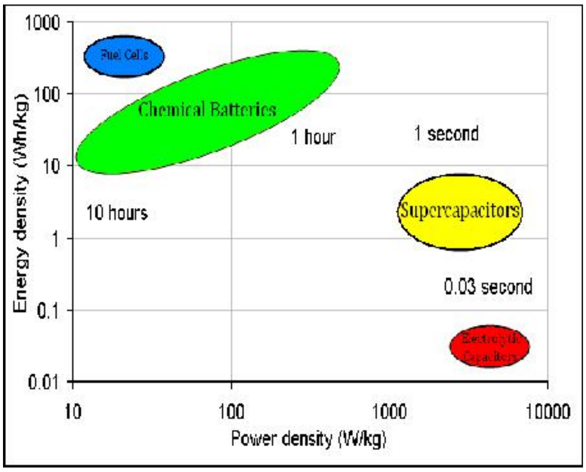

Fig4 comparison of Battery and SuperCapacitor

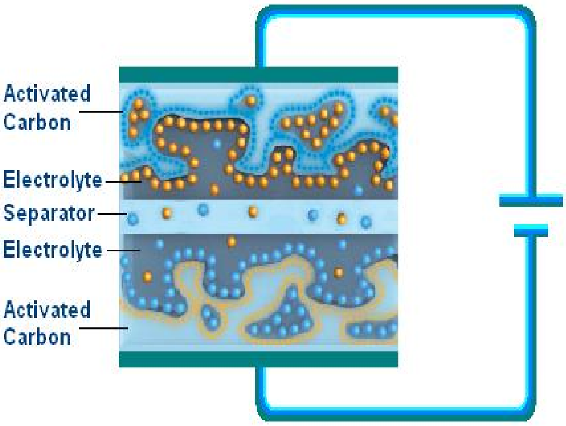

Fig5 Internal Structure of Battery

Simulation Analysis

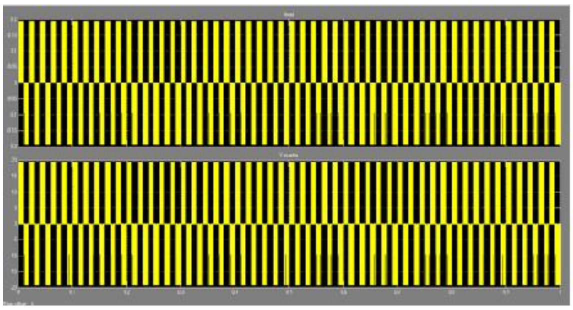

Fig.6a With super capacitor

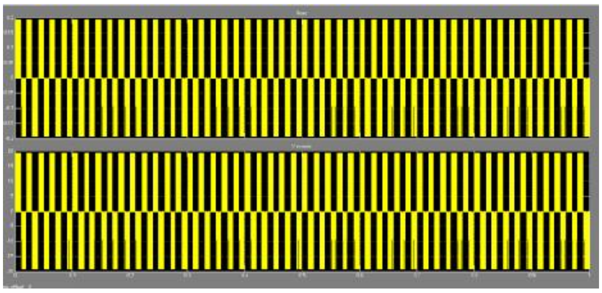

Fig.6b With supercapacitor

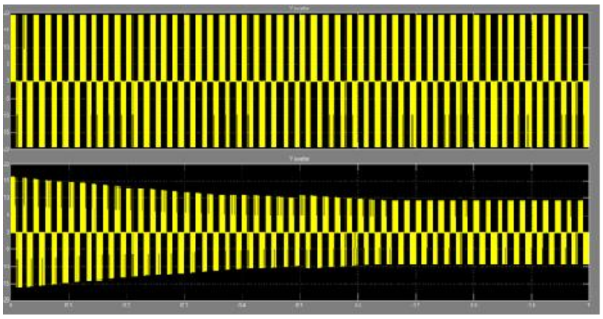

Fig6c Comparison of output voltage with super capacitor and normal capacitor

Performance Evaluation

Type	Experimental result(kHz/g)	Theoretical result(kHz/g)
Grooved cantilever	37.5	38.1
Rectangular section	17.9	18.2

Fig6a represents the output of normal capacitor. It is observed that there is a voltage drop. In fig6b.it is observed that a continuous output without any dead time is obtained. Therefore the proposed system can offer a higher output with minimum dead time and instant charging using super capacitor.

CONCLUSION

As validated previously, besides the geometric dimension, the cross-section shape plays an important role in determining the mass detection sensitivity. Meanwhile, once the total length and cross-section shape are fixed, the mass resolution can also be improved by changing the geometric ratios of the non-piezoelectric part to the piezoelectric part, including the thickness ratio (t2/t1) and the length ratio (l2/l1). show the sensitivity variations of the two kinds of mass sensors against the thickness ratio (t2/t1) and the length ratio (l2/l1), in which the parameters (t2/t1) and (l2/l1) represent the geometric factors of the non-piezoelectric extension to the piezoelectric layer. In Fig. 8, it can be seen that the detection sensitivities for both cantilever sensors can be increased by decreasing the thickness ratio for any length ratios. Moreover, there exists an optimum value at the point of length ratio equal to 1.7 for the grooved-cantilever sensor to achieve the highest resolution.

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