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A MICROMIRROR SOLAR CELL AS AN ELECTROSTATIC MEMS POWER SUPPLY

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ABSTRACT

An innovative creation of electrical power and increase the possibility of a novel, alternate, avenue for the utilization of solar power, which has the potential to be both cost effective and highly efficient. The approach converts solar energy into electrical energy via a MEMS device that utilizes spectrum insensitive thermal absorption combined with power generation via the piezoelectric effect. By harvesting thermal and quantum components of solar energy converted into mechanical energy that converted into electrical energy. This device can be used to power wireless micro sensors or as micro battery charger, while arrays of this device can be used for small scale generation.

(*keywords:MEMSs power source, piezoelectric power, thermal power*)

1. INTRODUCTION

Understanding energy harvesting system performance requires simulation of the combined mechanical and electrical parts of the system under realistic and representative vibration conditions. In this paper, we use numerical simulation to investigate several piezoelectric energy harvesting systems driven by either sinusoidal or random, broadband vibrations. The systems consist of a unimorph cantilever type design combined with a variety of power conditioning circuits and stopper models.

Since the power requirements for MEMS devices can be quite different from that for general electrical circuitry, additional external, power connections or extra voltage conversion circuitry are needed. In addition, for autonomous operation, such as free- moving micro robotic systems and space-based MEMS, a self-contained on-board power supply is desirable. A direct on-board power supply and an energy coupling method by using magnetic fields have been introduced previously. Solar cells are also attractive as power sources for MEMS since they are easily integrated, and can therefore be fabricated easily as a self-contained on-board power supply.

Due to current technological constraints, solar energy provides an untapped resource for use on the ground. Additionally, space assets suffer from extremely high overhead costs in order to use solar power at today's required efficiencies. If all solar energy that strikes the surface of the earth could be utilized, it would provide 6,000 times the current global consumption of primary energy, yet as of 2006 solar power represented less than 1% of electricity production from renewable sources.

The cause of this low percentage of use is due to the current cost of using solar power at reasonable efficiencies.

Numerous efforts are underway to attempt to resolve this issue. Current avenues of solar research include photovoltaic, solar thermal devices, photosynthetic, photo (electro) chemical, thermal, and thermo chemical processes. The most prevalent of these technologies, photovoltaic, suffers from the requirement of making efficient use of its semiconductor band gap. This requirement inevitably leads to low efficiencies in the production of energy. In order to maximize this efficiency, the most advanced photovoltaic cells use different layered materials to maximize the band gap energies for absorption. These multi-junction cells are cost prohibitive and still provide nominal beginning-of-life useful efficiencies of less than 30%.

Energy harvested from vibration is becoming an attractive power source for low-power microelectronics and micro electromechanical systems (MEMS). For vibration energy harvesters, three different transduction mechanisms that can be implemented in a MEMS device are in common use. These are the piezoelectric, electrostatic, and electromagnetic transduction mechanisms. In this paper, we investigate piezoelectric energy harvesting systems. When evaluating the performance of energy harvesters, it is common to simulate and test devices with a resistor as the load on the output terminals. This allows the performance of the device itself to be quantified without any dependence on the implementation details of the power conversion electronics. In addition, certain conversion circuits, such as the buck-boost converter, can be represented as a constant, resistive load to the MEMS. In some cases, electrostatic generators without internal bias, the power conversion circuitry is such an integral part of the system that MEMS and electronics cannot be evaluated separately. In other cases, the conversion electronics affect the electromechanical transduction strongly to boost system performance and thereby have a considerable impact on the proof mass dynamics. Notable examples are the nonlinear power conversion circuit principles for piezoelectric devices: synchronous electric charge extraction (SECE) and synchronized switch harvesting on inductor (SSHI).

Simulation models for energy harvesters coupled to these conversion circuits are therefore of great interest. The simulations can be done with ideal switches to study the merits of the conversion principles isolated from performance of particular switching circuit implementations. Displacement limitation of the proof mass caused by design restrictions is inevitable, at least for microscale devices. If a design is optimized for the lower part of its input vibration operating range such that mechanical stoppers are not hit under these conditions, they will be hit at the higher end or under overload conditions. If not, it would mean that the device could have been made smaller without any sacrifice in performance. Some kind of mechanical stoppers must be included in simulations for large-amplitude vibrations. By demonstrating theoretically and experimentally that the strongly nonlinear effect of stoppers can be used to increase the bandwidth of the harvesting system.

Both in simulation and experiments, sinusoidal vibration is the most frequently used waveform. A sinusoidal excitation is attractive because of its simplicity in theory and experiment and it is used for both linear and nonlinear systems. It models vibrations that are much more narrow banded than the harvester. Ambient vibrations in many cases contain a broad band of frequency components. The behavior of energy harvesting systems subject to broadband vibrations is less well known than the sinusoidal case. We have therefore advocated the use of Gaussian white noise for characterizing energy harvester performance. This case is the opposite extreme to a sinusoidal vibration and in some respects it is simpler because only one parameter determines this noise. It represents situations where the bandwidth of the vibration signal exceeds that of the harvester in a more realistic way.

2. OPERATION OF MEMS SOLAR CELL

The series interconnected array of Silicon/Graphene solar cells was bonded and packaged on a standard flat-pack carrier with a prototype MEMS device, a micro machined movable Si mirror suspended at its center by flexible polyimide supports . The movable Si/Graphene mirror is directly driven by the cell array output. The electrostatic drive voltage from the array is placed between the movable plate and the underlying metallic surface (ground) of the flat-pack carrier. A polyamide (Kapton) tape has been placed underneath the MEMS the to prevent electrical shorting between the mirror plate and the bottom ground. The deflection of the tip of the Si mirror was measured by focusing on the tip of the mirror using a Nikon MM-li Measure scope and measuring the deflection of the microscope head necessary to keep the deflecting tip in focus.

The fabrication of the solar device will follow standard MEMS fabrication processes and is illustrated in. First, a wafer (the substrate) will be utilized with which to grow the device on. Due to the bimaterial being on the bottom of the device, a sacrificial layer will first be deposited. After the sacrificial layer, a layer of Al will be deposited and then etched to create the alternating bottom legs of the bimaterial. The anchor holes will be etched in the sacrificial layer after that. Next, the piezoelectric material will be deposited. As stated previously, numerous methods for growth exist for both AlN and SiC on both Si and SiC. However, in this case the growth will be occurring on top of a sacrificial layer. It must be noted that the polytype of SiC grown will be dependent on the material it is grown on. For instance, in order to grow SiC on a Si substrate , single crystal 3C-SiC must be used due to the dissimilarity in crystalline structure of SiC (6H) with Si. After the piezoelectric layer is successfully deposited, it will be etched into the form of the solar MEMS device. Finally, the sacrificial layer will be removed creating the freestanding solar MEMS device on top of the substrate.

3. PIEZOELECTRIC EFFECT

This section aims at qualitatively exposing the general principles that lie behind three energy harvesting processes from the piezoelectric effect. The first one is the widely used standard energy harvesting interface that simply consists in directly connecting the piezoelement to a diode bridge rectifier connected to a storage capacitor and the load. The second includes a digital switch in series with the piezoelement and the rectifier, and performs a nonlinear treatment in order to increase the energy output of the micro generator.

The final conversion from mechanical to electrical energy involves utilization of the piezoelectric effect. Discovered in 1880, this effect can produce a 1000 V/cm field from a strain in piezoelectric materials such as quartz crystal. This effect is maximized in piezoelectric materials below the Curie point (and normally above 0 ℃) and varies for each material. The actual cause of the piezoelectric effect is the displacement of ionic charges within the crystal caused by the alteration of the spacing between the centers of charge sites in each domain cell. This effect occurs solely in noncentro symmetric groups and is strongly orientation dependent. For the purpose of this thesis, since no electric field is being utilized to create the piezoelectric effect, the second term on the right can be left out and the equation reduces to . D can be solved for by noting that the deformation directly related to the strain and therefore the stress via the constitutive relation given by Hooke’s law. The output voltage, V, is then related to the z component of D, where t is the thickness of the piezoelectric material in the z direction and ε is the permittivity of the material. Note that the principal polarization direction is the only term utilized in this final equation since the contributions from components in other directions are negligible for piezoelectric materials polarized in the z direction.

4. CURRENT GENERATION

Due to the rapid rate of charge leakage that occurs in strained piezoelectric materials, generation of a continuous current for power utilization requires the voltage to oscillate. In order to achieve this, a heat sink is placed near the maximal displacement of the MEMS device. The heat sink will lower the temperature of the MEMS device via thermal contact conduction until the MEMS device retracts a certain distance away from the heat sink. In general and in accordance with Fourier's law, the heat removed during this process is given by *QhTA.*

where Q is the heat flow, h is the thermal contact conductivity, A is the cross-sectional area, and ΔT is the temperature gradient in the direction of flow. However, it must be noted that this is a generalized approximation and not necessarily accurate due to the difficulties of accurately modeling the contact points between two solids. There are multiple competing analysis efforts that exist for thermal contact conductance and it is an active area of research. The heat removal that occurs every time the device contacts the substrate will reduce the deformation of the device. The constant heat flux will then force the device back into contact with the substrate. This process will continue causing the MEMS device to reach an oscillatory motion and generate a continuous pulsating current.

5. Bimetalic effect

The thermal energy absorbed by the power generator element can be converted to mechanical energy via the thermal bimetallic effect. This process involves portions of the structure having two material layers, each having a different coefficient of thermal expansion, and tightly joined along their longitudinal axis. These materials serve as a single mechanical element such that when a thermal flux is applied, the element deforms. The beam bends toward the material with the lower coefficient of thermal expansion for a given temperature change. The deformation solely depends on the materials used and the thickness ratio. The amount of deformation is given by

$$\theta = \frac{6(\Delta\alpha)(\Delta T)L}{t1\left(\frac{(1+\lambda\xi)(1+\xi^3\lambda)+3\lambda\xi(\xi+1)^2}{\lambda\xi^2(\xi+1)}\right)}$$

where θ is the deformation vis-a-vis the free-end slope, Δα is the difference in the thermal expansion coefficients of the materials, is the temperature difference, L is the length of the element, is the thickness of the layer with the higher thermal expansion coefficient, is the ratio of Young's moduli between the two materials, and is the thickness ratio between the two materials. It can be seen from Equation that, to maximize the absorption, the two layers have to have materials with as large a difference in coefficients of thermal expansion as possible. $T\Delta\ 1t\ \lambda\xi$

6. Design:

The initial design placed the Al material toward the incident heat flux with the alternating legs placed so as to lower the center pad with legs toward the heat sink. Long cross legs were placed in order to minimize the shear stresses on the center pad. This design was not effective as the innermost legs displacement was greater than the center pad. This indicated the strong possibility that the center pad may never touch the substrate. Additionally, due to the torque created by the innermost bimaterial legs attachment to the center pad, the center pad's deformation was not uniform as can be seen by figure.

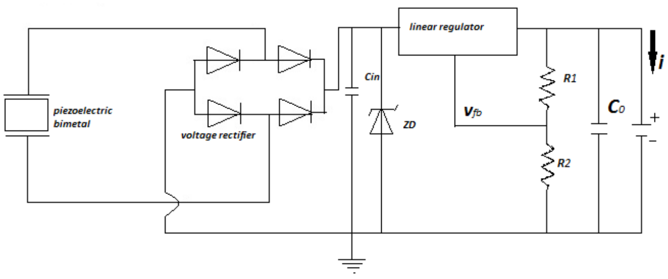

Figure 6.1: Electrical Equivalent circuit

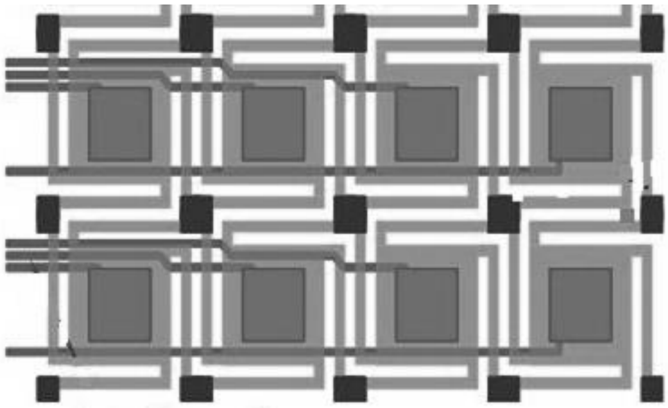

Figure 6.2: Micro mirror solar Cell array structure model

7. Working principle:

When the sunlight falls on the piezoelectric material the electron flows towards the holes those electrons are captured and the material gets heated, the change in temperature of the material creates thermal mechanical effect due to bimetallic this causes piezoelectric effect. The vibrations created on material by the mechanical effect induce more electrons form the material. Due to the rapid rate of charge leakage that occurs in strained piezoelectric materials, generation of a continuous current for power utilization requires the voltage to oscillate. In order to achieve this, a heat sink is placed near the maximal displacement of the MEMS device. The heat sink will lower the temperature of the MEMS device via thermal contact conduction until the MEMS device retracts a certain distance away from the heat sink. In general and in accordance with Fourier's law, the heat removed during this process is given by:

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8. Current generation efficiency:

A basic estimation of the current can be modeled by placing a connection between the ends of the MEMS device and completing the circuit. The current density generated in a non-optimized time-dependent COMSOL model utilizing a metal connection with 24.5 Ω of resistance at a time of 1 second. Utilizing the basic equation P=RI2, the instantaneous power output is 4.14 x 10–9 W. The model designed in Figure 6.2 is expected to have a larger power output due to the optimized design. The total possible efficiency of the Solar MEMS device is the product of the maximum thermal-mechanical and piezoelectric efficiencies.

$$\eta o=\eta t*\eta p$$

Here the two various maximal efficiencies can be achieved as thermal efficiencies and piezoelectric efficiencies.

Conclusion

The two maximal efficiencies display the dichotomy of the physics within the proposed solar MEMS device. The efficiencies were found given maximal work for the thermal-mechanical efficiency and oscillation at the resonant frequency for the optimized piezoelectric efficiency. The gross estimate of the total efficiency is approximately 0.001%. Although this is extremely low, it should be noted that the calculation of both efficiencies can only provide gross estimations of the total efficiency and that the total efficiency may very well be greater than current single junction solar cells. Due to the innate complexity of the MEMS device, experimental results are required in order to attain actual efficiencies. However, these analytical results do point to the limiting factor in the efficiency being the thermal-mechanical efficiency. Further data analysis via actual experimental study must be conducted in order to validate these analytical results.

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