Design and Analysis of an Integrated Mems Harvester for Low Power Devices

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Abstract
This paper introduces a hybrid energy harvester generating electric power from both ambient heat and vibration. Harvesting energy from vibration was realized by piezoelectric effect Phenomena in Lead Zirconate Titanate (PZT) crystals, whereas the energy generation from heat was supplied by making use of Seebeck effect of n-type and p-type Bi2Te3 thermocouples. The industrial software Comsol Multi physics is used for the simulation. A total voltage of 17.024V was generated from the thermoelectric part and .4 V from the piezoelectric part of the device. Total power produced from the chip is predicted to be 1.91nW.

Keywords: Energy Harvesting, Micro Power Generation, Piezoelectric, Vibration, Thermoelectric

1. Introduction
Nowadays energy harvesting from single source microgenerators is not even sufficient to meet the power requirement of low-power devices. Thus, hybrid solutions utilizing multiple ambient energy sources in a single chip can be an option to overcome the low power issue.

Thermoelectric energy harvesting is a favorable option since ambient heat is always present in various environments such as mobile systems, industrial machines, and many components in a car. Several thick-film and thin-film thermo electric generators were previously introduced in literature1-3. High figure of merit thermoelectric materials offer the best thermoelectric efficiency in most of the cases. However, the implementation of these materials to micro devices requires complicated and high-cost fabrication steps. At this point, metals having a high thermoelectric power factor are often used as thermocouple materials1.

Energy harvesting from vibration is a commonly used technique due to its high energy density and abundance of vibration in nature. Piezoelectric, electrostatic, and electromagnetic energy conversion mechanisms are the methods used for energy harvesting from vibration4. Among these piezoelectric energy harvesters have high electromechanical coupling effect, require no external voltage sources, are compatible with MEMS technology, and have received much attention accordingly4-7. In order to extract the maximum power from the environment, the resonant frequency of such device has to match the dominant frequency in the surroundings, whereas the frequencies of ambient available vibration sources are relatively low (normally less than 200 Hz)8.

2. Concept and Design
The template is used to hybrid harvester consists of two systems monolithically integrated on a single base.

• Thermoelectric system.
• Piezoelectric system.
Micros TEG consist of two different materials with relatively high seebeck coefficient value. Primarily it consists of:

- N-type Bismuth Telluride.
- P-type Bismuth Telluride.
- Junction material (here Copper).

The output voltage of the energy harvesting thermoelectric generator can be expressed as

\[ V_{out} = n \left( \alpha_1 - \alpha_2 \right) (T_h - T_c) \]

where

- \( n \) = No of thermocouples in the TEG,
- \( \alpha_1 \) = Seebeck coefficients of p-type Bi2Te3 V/ C,
- \( \alpha_2 \) = Seebeck coefficients of n-type Bi2Te3 V/ C,
- \( T_h \) = Temperature of the hot junction, °C (or)/ K,
- \( T_c \) = Temperature of the cold junction. °C (or)/ K.

Piezoelectric harvester consists of two layers:

- Lead Zirconate Titanate (PZT-5A).
- Structured steel.

Piezoelectric harvester consists of n and p-type Bismuth Telluride material sandwiched between the copper junctions. The PZT harvester is located at the right side. When temperature is applied at the base and vibrational load at the tip of the Cantilever beam. Both the structures begin to generate electric potential based on the harvesting technique.

![Figure 1. Structure of the thermoelectric module.](image)

![Figure 2. Structure of the piezoelectric module.](image)

Power output of the system at resonance is

\[ P_{\text{max}} = \frac{m \omega^3 Y^2}{4\zeta} \]

where

- \( m \) = seismic mass at the beam end, Kg.
- \( \omega \) = Natural frequency of the system, Hz.
- \( Y \) = Amplitude of vibration, µm.
- \( \zeta \) = Damping ratio.

### 3. Structure and Dimensions

The harvester consists of n and p-type Bismuth Telluride material sandwiched between the copper junctions. The PZT harvester is located at the right side. When temperature is applied at the base and vibrational load at the tip of the Cantilever beam. Both the structures begin to generate electric potential based on the harvesting technique.

![Figure 3. Schematic view of a Hybrid micro power generator.](image)

The initial dimensions of the hybrid energy harvester are given in the Table 1.

| Geometric Dimensions | Values (µm) | Material Selection |
|----------------------|------------|-------------------|
| Thermoelectric materials | 3000 | n-type and p-type Bi2Te3 |
| Heat source | 500 | Aluminium |
| Thermal contact pads | 700 | Copper |
| Ceramic contacts | 500 | Silicon carbide |
| Heat sink layer | 500 | SiO2 coating |
| Electrical insulation | 500 | Parylene-C |
| Piezo electric materials | 4000 | Lead Zirconate titanate (PZT5A) |
| Proof mass | 300 | Silicon |

### 4. FEM Simulation

Simulation of the device has been done using the COMSOL Multiphysics tool. The heat transfer in solids, electric currents and piezoelectric devices physics has been used to model the design.

This is done mainly in 3 steps..
For thermoelectric, specify the temperature gradients.

Figure 5. Setting up the physics.

For piezoelectric, apply load and specify boundary conditions as given in Table 2.

Table 2. Boundary conditions

| Boundary Condition | Value       | Location     |
|--------------------|-------------|--------------|
| 1. Displacement    | Fixed       |              |
| 2. Electrical      | Ground      |              |
| 3. Electrical      | Zero charge or Symmetry | |
| 4. Load            | Pressure    |              |

Figure 6. Thermoelectric results (temperature distribution).

Figure 7. Thermoelectric results (electric potential).

Figure 8. Piezoelectric results (displacement).

Figure 9. Piezoelectric results (electric potential).
5. Results summary and Conclusion

Table 3. Simulation and Analysis

|                         | Maximum       |
|-------------------------|---------------|
| Displacement(mm)        | 0.8           |
| Strain(unit less)       | 3.825e-4      |
| Stress (MPa)            | 28            |
| Electric potential(V)   | 18            |
| Electric field norm(V/m)| 3.27e5        |

- Piezoelectric (Static analysis).
- Thermoelectric (Static analysis).

5.1 Electric Potential

Maximum = 0.024 V  
Minimum = 1.57e-4 V  

A multisource energy harvester, using multiple energy sources (heat and vibration) to produce electrical energy was introduced. The simulation and initial test results were obtained for the device. A total voltage of 18.024 V was generated from the device. Although energy developed is very low, power level for this particular device can be increased significantly increased by increasing the PZT cantilever number, or by using high Seebeck coefficient materials and/or by optimizing the layer thickness for better thermal and vibration based harvesting.

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