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# Thermal Energy Harvesting for Application at MEMS Scale

Springer

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# Preface

In most sources of low-temperature waste heat, the heat is dissipated to the atmosphere due to a lack of cost-effective solutions that can efficiently convert the heat into useable electrical energy. The ability to capture this thermal energy could increase the efficiency of existing processes and machinery, supply isolated sensors, allow for extended portable electronic power supply, and much more. The aim of this Springer Brief is to summarize a very broad range of thermal energy harvesting methods, and describe the potential of applying these methods to low-cost, batch process manufactured, micro electromechanical systems (MEMS). The brief will focus on the functionality of the device, rather than the MEMS production methods. An additional motivation for the production of this Springer Brief is the rapid growth of the MEMS market, which grew to $11 billion in 2012 and is expected to double by 2018 [1].

Chapter 1 defines waste heat and gives examples of the sources. It also presents the concept of the Carnot limiting efficiency, and defines high- and low-grade heat energy. The chapter proceeds to outline the reasoning for the potential use of MEMS for thermal energy harvesting, and compares micro to macro-scale electromechanical systems.

The most familiar form of thermal energy conversion is the combustion heat engine. Chapter 2 describes a subset of these engines that can be used for thermal energy harvesting. These processes convert a thermal difference into mechanical motion and include four common external combustion thermodynamic cycles: Stirling, Brayton, Ericsson, and Rankine. Each cycle is described in terms of thermodynamics, and theoretical and practical design. Each cycle is then assessed against the likelihood that a practical MEMS-scale device could be manufactured to match the cycle, giving examples when available.

In Chap. 3, less common thermomechanical heat engines are described. These engines also convert thermal differences into mechanical energy, but use a variety of different mechanisms. They include the two main types of thermoacoustic processes, which use a gas phase working fluid; shape memory alloys and thermomagnetic generators, which use solid material phase change properties; and hydride heat engines, which use chemical properties of solids to store hydrogen. The key details of each mechanism are described and the practicality of designing a device at MEMS scale is discussed.

Chapter 4 outlines technologies that can convert thermally generated mechanical energy into electrical energy. The discussion includes operating temperature ranges, feasibility of scaling, and production with MEMS batch processes. This chapter focuses on maximum operating temperatures and factors that limit this.

Chapter 5 details a range of devices and technologies that can convert thermal energy directly into electrical energy. These devices use a range of techniques and physical properties of materials to perform this conversion, but mostly have no moving parts in the traditional sense. The chapter explains each technique, outlines examples of use at MEMS scale, and describes the advantages and disadvantages of each technique for use at MEMS scale. The performance or potential performance of each technique is outlined where possible. Several proprietary devices are included for the sake of completeness, although little information about these devices is publically available.

Since the best solution is dependent on the specific application, it is left to the reader to decide which will be the best solutions or technologies for future research. However, this will likely depend on the availability of new materials, and a willingness to explore low-temperature heat sources.

## Reference

1. Yole Développement (2013) MEMS Trends—April 2013

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