Department of Electrical Engineering and Computer Science
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6.777 Design and Fabrication of Microelectromechanical Devices

Spring Term 2001

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DESIGN PROBLEM: Waste-Heat Energy Scavenger

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Problem Statement

Power generation and supply to MEMS devices are important constraints in enabling a number of MEMS applications. On-chip fuel processing offers an exciting opportunity to realize small power sources with very high energy storage densities. The power density of a fuel processing device increases with increasing temperatures, as the chemical reaction rates increase and a larger fuel quantity can be processed in a given volume. Therefore, on chip fuel processing must take place at elevated temperatures, with heat management (heat exchange, heat recovery, insulation) as the critical design consideration.

Even the best fuel processing schemes result in overall efficiencies of 30-40%. This implies that majority of the fuel heat content is dissipated to the environment, often in the form of low temperature gas streams. If the heat from these process streams could be forced to travel through a thermoelectric generation device on the way to the environment, additional electrical energy would be recovered, improving the overall device efficiency. A MEMS thermal-waste generator could also be used to generate power in other applications, such as remote sensing near a heat source or perhaps power recovery from heat dissipation by a laptop processor.

The goal of this project is to design a thermoelectric generator which converts waste heat from a gas stream into useful electricity.

Design Specifications

This generator is to convert low-grade thermal energy of a gas feed stream (100-200°C , ~100 sccm) to electricity using the thermoelectric effect. The objective is to maximize usable electrical power output while minimizing gas pressure drop (the device will vent to the atmosphere).

The thermal-waste generator should consist of several components. A fluidic structure must be realized to accept a gas feed stream, intimately contact this gas stream with the thermoelectric element, and then vent the gas to the environment. The thermoelectric element (for example, a thermopile) and associated power-conditioning circuitry must be designed to achieve high efficiency at the operating temperatures. Ideally, this circuitry should be in a form that can be monolithically integrated with the rest of the device, but a hybrid design is also acceptable. The device must be packaged such that it has simple and reliable fluidic connections and can readily dissipate processed heat to the environment.

Overview

The design process is described below in terms of several distinct tasks. However, it will be quickly recognized that all these tasks interact. The goal of the team is to delegate tasks and provide communication between tasks so that the final merged device design meets the requirements.

First-Order Device Concept

The design team should rapidly familiarize itself with thermoelectric generation principles and heat transport principles. Lumped models and engineering calculations should be used to achieve a first-pass design.

System Partitioning and Circuits

You will need to identify a power-conditioning circuit, and decide between monolithic and hybrid integration of the power-conditioning system.

Device and Packaging Fabrication

Selection of thermoelectric materials, device layout,the device packaging scheme and the associated device fabrication process are tightly coupled with one another. One of the primary envisioned challenges in the device design is how to achieve a thermal gradient across the solid state thermopile as opposed to the gas phase itself. That is, the resistance to thermal flow will need to be higher in the thermocouple than in the gas. You are not constrained by traditional silicon micromachining techniques, though these may prove most advantageous.

Second-order Issues

You may need to support your design with steady-state numerical modeling of the device in order to make a good estimate of overall thermal power to electrical power conversion.

Integrate the design

Iterate to ensure that the device design, process flow, energy-conversion mechanism, packaging and power-conditioning electronics are compatible with each other and meet the system specifications.