

A Numerical Heat Transfer Analysis On An Implantable Phase-Change Actuated Peristaltic Micropump

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Abstract

Advances in protective and restorative biotherapies have created new opportunities to address vestibular disorders, deafness, and noise induced-, sensorineural-, and age-related hearing loss. Controllable and implantable drug delivery micropumps are essential for therapy development in animal models and for future human translation. A peristaltic micropump is developed using a novel direct-write printing fabrication method to build a structure around a commercially available microcatheter. Peristalsis is achieved by sequentially actuating the microtubing at three locations along the tubing, while at each moment two actuators are compressing the tubing. The actuation is provided by expansion and contraction of a thermal phase-change material that is located in three chambers along and adjacent to the tubing, each containing a precision volume of phase-change material. Also, the chambers include resistors to provide heat for melting, and thermistors to monitor the temperature for closed-loop feedback bang-bang control. The micropump is fabricated on the back side of a four-layer printed circuit board (PCB), while the front side the PCB is populated with electronic components needed for controlling the pump with a wireless device.

Here we present a heat transfer analysis of the micropump in order to be able to predict the functionality of the micropump, using COMSOL Multiphysics®. The actual 3D geometry of the micropump is designed in SolidWorks® and then imported to the COMSOL. Then the appropriate boundary conditions are applied on the model. Apparent heat capacity method is employed to be able to model the phase change behavior of the actuation material. A bang-bang controller is applied using events interface to control the temperature of the material in the chambers. It is crucial for the micropump to not to saturate, meaning that when the actuation material is molten in two chambers the other one should not melt due to heat transfer. The feasibility of functioning the micropump without saturation is approved through a transient solution with event interface for closed-loop bang-bang control. Also, it is desired to be able to work with the pump in the highest possible actuation frequency. According to the results, the pump can work in higher frequencies without saturation by changing the geometry of the PCB, such as thinning the Copper layers. Furthermore, it is found that the power consumption can be minimized by changing some elements in the Copper traces, such as thinning the Copper layers and expanding the Copper layer surface area in the chambers to provide more distributed, and thus, more efficient heating. It is essential for any implantable object in the body to not to get more than 2 °C warmer than the body temperature, to avoid irritating the adjacent tissues. It is found in the simulation that the outer surface of the micropump can fulfill this requirement if optimized PCB geometry and appropriate phase-change materials are employed.

Figures used in the abstract

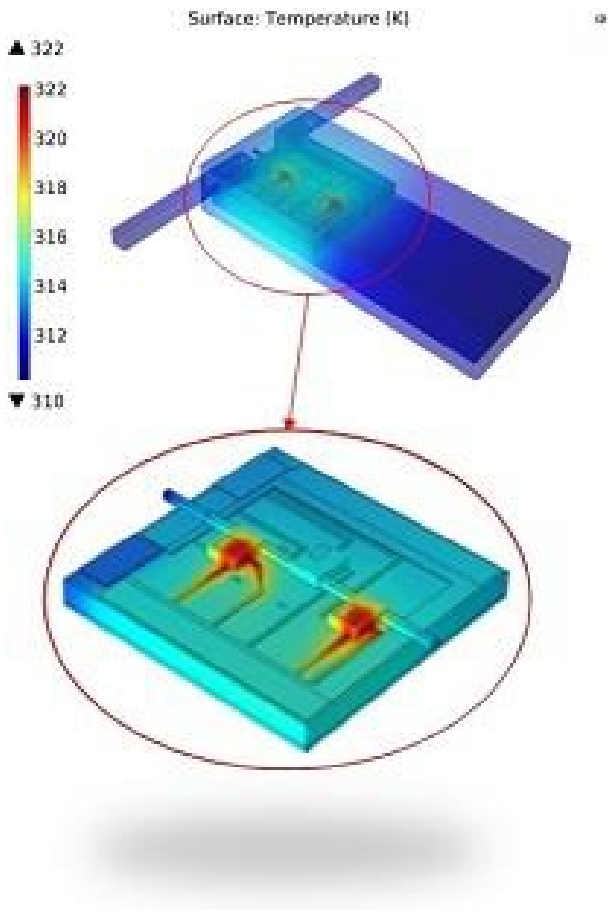


Figure 1 : To evaluate inter-chamber heat transfer and effective insulation, the two exterior chambers were heated to 12 °C above ambient. The middle chamber temperature increased by only 5 °C while the surface temperature of the system increased by < 2 °C, which is a crucial condition for any implantable object.