CHAPTER 6
TEMPERATURE PROFILE ANALYSIS

Temperature is an important parameter to be analysed, as high temperature could lead to bubble formation or even it could cause damage to the cell’s viability. This chapter deals with analysing the temperature in the designed electrothermal microgripper, particularly focused on the gripper jaws, as this jaws are going to be in contact with the manipulated biological cells. In addition, the importance of incorporating the heatsink with the microgripper is explicitly explained, which indeed helps in reducing the temperature at the gripper jaws enormously.

6.1 INTRODUCTION

Heatsink is a heat exchanger that transmits the heat from the device (electrothermal gripper, in our case) to the external surrounding medium. The medium can be the surrounding air or a coolant liquid. This heatsink is a metallic part that dissipates the heat from the device to the environment, thereby reducing the excessive heat generated and thus regulating the temperature at an optimal range. These devices are used in various applications (like CPU, FET, GPU, refrigerator, air conditioning, etc.) that have electronic components and the heat generated should be regulated, as overheating damages the device performance. The metallic heatsink transfers the heat from the electronic devices to the surrounding air by means of thermal conduction. To transfer the heat to the heatsink, small amount of a chemical compound or thermal paste is used. In most of the cases, the
The heatsink is integrated with the cooling fan that aids in pushing the hot air from
the device at higher temperature and allows the cool air in.

Heat transfer characteristics are the most important concern for the
development of micro electromechanical system. Ionescu & Neagu (2017)
implemented the basic micro heater model for modelling the heat exchange
characteristics using Comsol software. Different microheater shapes like
octagonal, circular, square and rhombic were investigated for total enthalpy
distributions, total internal energy, effective volumetric heat capacity and
temperature gradient. Kosar & Peles (2006) analysed the heat transfer and
pressure drop of deionized water over the 243 μm long micro fins. They
developed 1800 μm broad and 1 cm stretch of a microchannel. The micro fins
of size 99.5 μm diameter are developed within the microchannel. The
deonized water is made to flow through the inlet and passes the micro fins
where the heat is dissipated and left the outlet with low temperature.

Lopez Walle et al. (2009) developed the submerge ice microgripper
for biological manipulation applications. This system equips thermal
actuation principle based on peltier effect and performs the modelling using
an electrical analogy. This system is specifically focused to manipulate the
biological molecules of sizes below 100 μm. The input voltage increases the
temperature in the actuator that gets transported to the gripper arm, which is
going to be submerged in the aqueous solution to grip the biological cells. To
reduce the temperature in the ice microgripper, the heat sinks were
incorporated in between them, which dissipate the heat to the surrounding
fluid and thus reducing the temperature in the end effector.

In this chapter, detailed reviews of heat sink principles were
discussed. Then, the microgripper with and without heat sink integration is
designed and analysed the temperature profile computationally.
6.2 HEATSINK PRINCIPLE

Heat sink dissipates the heat from a higher heat gradient to the surrounding fluid as in the Figure 6.1. To understand the heat sink principle, one must think about Fourier’s law of thermal conduction. According to the law heat will always flow from a higher temperature gradient to the lower one when it prevails in a body. This is accomplished by convection, radiation and conduction.

![Figure 6.1 Principle of Heat sink](image)

(i) **Convection** Heat always flows from higher temperature layer to the lower one, which is termed as convection and it can be either forced or natural. Forced convection utilizes the fan to push the hot air from the device and allows the cool air to flow in. This is the most used method and helps in fast cooling. Natural convection, which is a slow cooling process, does not equip any external fan to cool down and the cooling process occurs naturally. The fins on the heat sink should be positioned in such a way that, the hot air travels in parallel to the direction of the fin. If the fins are placed in perpendicular direction to the flow of air, this ends up with reduced cooling operation, which is not at all required here.
(ii) **Conduction:** Conduction refers to transfer of heat from heat originating device to the heat sink through direct contact. The important criteria for having good conduction are choosing the appropriate material for the heat sink. Among different metals, copper and aluminium is having good thermal conduction property. But, as far as the material is concerned, the weight of the metal should be taken into the picture because heavier metal may induce stress on the working device. Hence, the material should be chosen in such a way that its reduced weight. When comparing aluminium with copper, aluminium is having low weight with appreciable thermal conducting property, hence it is preferred. Thus, in most cases, aluminium is chosen as the appropriate material for heat sink in real time applications. The rate of heat transfer by conduction \( q_c \), is comparable to the cross sectional area and it’s the product of temperature gradient through which the heat is conducted.

\[
q_c = -kA \frac{dT}{dx}
\]

(iii) **Radiation:** Like convection and conduction, the heat sink must radiate as much as heat, to the surrounding fluid for better operation. To boost up the radiation, the surface area and emissivity of the heat sink should be made larger. Even though large surface area radiates much heat, it may lead to loss due to convection. Hence, the surface area should be balanced to have highly cooling effect. Emissivity is the measure of how effectively the surface transfers the heat to the air. But, increasing the emissivity does not affect the conduction or convection in any manner.
Considering the above defined principles, the heat sink should be designed for reducing the overheating problem. This is very much important in our scenario, as we are focusing on manipulating the biological cells, which should be manipulated at reduced temperatures, as high temperature could lead to bubble formation and affects the liveliness of the targeted cells.

### 6.3 DESIGN OF ELECTROTHERMAL GRIPPER WITH HEATSINK

The electrothermal microgripper is designed with an objective to manipulate the biological cell with precisely controlled force. If the force is larger, it will damage the cells, also temperature also plays an important role, and it needs to be measured. Since high temperature could lead to bubble formation and ending up damaging the cells. It also makes it difficult to form a coating of SU-8 over aluminium, as aluminium is not a biocompatible metal. Hence, the gripper should be designed, in such a way; its temperature is at an optimal level. The microgripper integrated with the heat sink is given below in Figure. 6.2 and their corresponding dimensions were listed out in Table 6.1.

![Electrothermal Microgripper](image)

(a)

**Figure 6.2 (Continued)**
The heat sink is integrated with the microgripper in the arm that connects the actuator with the gripping arms. This is because, as the voltage is applied to the actuating contact pad, high temperature rise occurs at the centre shuttle and this high temperature is transferred to the gripping arms by heat conducting principle. Though aluminium helps in transferring the heat to the surrounding air, not much heat can be dissipated into the air as the surface area between the air and the device is very less that result in low emissivity. Hence, the heat sinks are developed between the contact pad and the gripping arms.

Table 6.1 Dimensions of the heatsink

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dimension (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of heat sink fin (hs_L)</td>
<td>40</td>
</tr>
<tr>
<td>Width of heat sink fin (hs_W)</td>
<td>4</td>
</tr>
<tr>
<td>Depth of heat sink fin (hs_D)</td>
<td>10</td>
</tr>
<tr>
<td>Distance between fins in the gripper arm (hs_D)</td>
<td>4</td>
</tr>
<tr>
<td>Distance between fins in the arm connecting shuttle and gripper arm (hs_D1)</td>
<td>10</td>
</tr>
</tbody>
</table>
arms. As the device is symmetrically designed, that is the separation distance, the length, breadth, thickness of the device in both the halves are identical. Hence, when the heat sink is positioned on either side of the arms, it will tend to reduce the heat in an even manner on both the sides. Again, the material used for heat sink is aluminium due to its good thermal conductivity, low weight, easy to fabricate, etc. The fins of the heatsink are designed in a way that it is in line with the direction of heat-dissipated airflow that permits the hot air to flow to the surrounding air without any hindrance and this ultimately enhances the cooling of the device. Not only in the arm, that connects the contact pad and gripping arm, the heat sink is also integrated in the gripping arm just below the gripper jaws. This additionally dissipates the heat to the surrounding air and greatly reduces the temperature in the gripper jaws, where the target cells are going to be in contact. This heat sink and its fins in the gripper arm are developed in the same manner as specified above (heat sink between the contact pad and the gripper arm) with the same aluminium material.

6.4 COMPUTATIONAL ANALYSIS OF HEATSINK

As the microgripper is designed for biological cell manipulation, the temperature profile becomes an important criterion to be framed. The designed electrothermal microgripper is computationally analysed for obtaining the temperature profile in COMSOL multiphysics software. First, the gripper without heat sink is analysed and then the gripper with heat sink is analysed in order to acquire the comparison among the temperature profile of both the structures. This highlights the advantages of using the heat sink. The prime intention of the proposed microgripper is to manipulate the biological cells with sizes ranging from 10 - 55 μm, as the initial opening of microgripper is fixed to 60 μm. The microgripper without heat sink with predefined dimensions made of aluminium alloy AL6061N is designed in
COMSOL. The temperature in the contact pads was set to 293 K (20°C) as shown in Figure. 6.3. The voltage is applied to the contact pads and finite element analysis is performed to study the response of the device.

Due to joule heating and thermal expansion principle, the actuator beams expand and pushes the centre shuttle which in turn pushes the gripper arms. This action increases the temperature in the centre shuttle which gets transferred to the entire gripper device. The computational results of temperature are given below in Figure. 6.4. For the input voltage, 0.12 V, the displacement of the gripper jaw achieved is 25.5 μm and the temperature in the gripper’s centre shuttle is raised from 293 K to 569 K. This rise in temperature is due to the material’s thermal expansion property (coefficient of thermal expansion $= 23.1 \times 10^{-6}$ K$^{-1}$ and thermal conductivity $= 235$ W/m.K). The temperature at the gripper jaw is observed to be 525.69 K (233°C), which is very much higher than the room temperature. This eliminates the possibility of coating SU-8 over the designed gripper, as the softening point of SU-8 is 210°C (483 K). Also, this high temperature bubbles will be formed in the analyte solution, which makes the manipulation process difficult. This hurdle
is overcome by incorporating the heat sink with the microgripper, which enables the microgripper for biomanipulation applications.

![Temperature profile of microgripper without heatsink](image)

**Figure 6.4 Temperature profile of microgripper without heatsink**

The microgripper with heat sinks, developed in both the gripper arms and in the arms connecting the centre shuttle and gripper arm is designed and analysis is obtained with the help of COMSOL software. The dimensions of the heat sink are already specified in the table 6.1. The same input parameters, as in microgripper without heat sink, were applied and the computational analysis is carried out. The corresponding result achieved is pictorially represented below in Figure. 6.5. From Figure. 6.5, the existence of high temperature is observed in the centre shuttle, same as in gripper without heat sink, and the temperature gets reduced in the gripper jaws due to dissipation action to the surrounding air. With heat sinks, the temperature gets additionally dissipated through the heat sink and further gets reduced at the gripper jaw. For 0.12 V, the temperature in the gripper jaw is 449 K (176 °C)
which is lower than the gripper without heat sink (525.69 K), which is particularly represented in Figure. 6.6.

Figure 6.5 Temperature profile of microgripper with heatsink

Figure 6.6 Temperature profile in the jaw of microgripper (a) without heat sink and (b) with heat sink

Figure. 6.6 (a) & (b) represent the temperature in the gripper jaw without and with heat sink configuration respectively. From Figure. 6.6, we
can observe the change in color intensity in the Figure. 6.6(a) when compared to Figure.6.6(b) (from pale yellow to dark yellow) due to the heat dissipation action. Also, this result were observed in the range of input voltages from 0 to 0.2 V and is plotted as given in the Figure. 6.7. The reduction in temperature in the gripper jaw with and without heat sink is clearly observed from this figure. For 0.125 V, the temperature in the gripper jaw with the heat sink arrangement is 449 K which is lower than the softening point of SU-8 (483 K). This makes the coating of SU-8 possible, which in turn extends the gripping application in the field of biomedical manipulation.

![Figure 6.7 Temperature vs Applied voltage with and without heatsink](image)

**Figure 6.7 Temperature vs Applied voltage with and without heatsink**

### 6.5 SUMMARY

In this chapter, the temperature in the designed electrothermal microgripper is analysed. In addition, the importance of incorporating the heatsink with the microgripper is explicitly explained briefly. This chapter particularly focussed on analysing the temperature in the gripper jaws, as this jaws are going to be in contact with the manipulated biological cells. Temperature in the gripper jaws, with and without heating incorporation, were analysed and compared to identify the effectiveness. For 0.125 V, the
temperature of the gripper jaw without heatsink is 525.69 K, whereas temperature with the heatsink is 449 K which is very much lower when compared with the results that obtained without heatsink.