Simulation based on Comsol Multiphysics for analyzing the effect of different heat dissipation methods on the thermal effect of microchip

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Abstract. Nowadays, with the flourishing development of microchip technology, the computational speed of the microchip is rising and its size is gradually shrinking. However, the heat will cause deformation of the circuit board, microchip life decline and other problems, so heat dissipation has always been a key issue restricting the development of microchips. This paper qualitatively analyses the heat production during microchip running and gives a reasonable heat dissipation solution. In this paper, A simplified model of the circuit board, including electrodes, silkscreen circuits, and microchip, was constructed, and the thickness was simplified to emphasize the temperature as well as the deformation variations of the board. the effects of ventilation conditions and the use of heat sink on the maximum temperature of the microchip and the deformation of the circuit board are tested by simulation experiments using Comsol Multiphysics with multi-physical field coupling. Increasing the heat convection exchange between the microchip and the environment, increasing the heat sink can increase the efficiency of chip heat dissipation and decrease the deformation and temperature of the microchip. This paper analyzes different heat dissipation schemes at the data level and provides a methodology for a practical analysis.

Keywords: Circuit Board Heat Dissipation, Multiple Physical Field Coupling, Heat Sink, Heat Convection.

1 Introduction

In the contemporary era of technological advancement, the microchip stands as a cornerstone of electronic innovation. The rapid evolution of microchip technology, characterized by an exponential increase in computational speed and a concurrent reduction in physical size, has been pivotal in propelling the digital revolution forward. However, this progress does not come without its challenges. One of the most significant hurdles in the ongoing development and optimization of microchips is managing the heat they generate during operation. Excessive heat not only threatens the integrity and longevity of the microchips themselves but also poses a risk to the entire electronic device by potentially causing deformation of the circuit board and a decline in overall performance and reliability [1].

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The pursuit of efficient heat dissipation strategies in microelectronics has been well documented in the literature. The impact of packaging technologies on cooling systems under three dimensions discussed in related articles, as well as related articles exploring a variety of cooling technologies ranging from conventional heat sinks to advanced liquid cooling systems, evaluating their effectiveness and applicability in different scenarios [2, 3]. These studies provide an important context for current research, highlighting the ongoing efforts and challenges in thermal management in microelectronics.

Comsol Multiphysics is a powerful software designed for modeling and simulating complex physical phenomena across various disciplines, including electromagnetics, structural mechanics, fluid dynamics, heat transfer, and chemical reactions. It provides a user-friendly interface for engineers, scientists, and researchers to build and solve multiphysics models, allowing them to explore the interactions between different physical phenomena in a single environment.

Through reviewing the literature, it can be found that the research in the field of microelectronics on the deformation of circuit boards when circuits heat up and the effects of ventilation conditions and heat sinks on reducing the maximum temperature reached by the microchip and preventing the deformation of circuit boards is basically at a blank stage, so this study would like to build a basic model to explore and analyze this problem.

Considering the limited capacity, this paper addresses the pressing challenge of heat dissipation in microchip technology by proposing a simplified model of a circuit board, inclusive of its critical components such as electrodes, silkscreen circuits, and the microchip itself. By focusing on a model that simplifies the physical dimensions to highlight the impact of temperature and deformation, this research aims to shed light on the thermal dynamics within electronic devices. Utilizing Comsol Multiphysics, the study investigates the effects of ventilation conditions and the incorporation of heat sinks on mitigating the maximum temperature reached by microchips and preventing the deformation of circuit boards.

This article begins with basic information about PCB circuits. It then describes the modeling process, including parameters, circuit design, heat sink design, and physical field coupling process. Finally, the experimental results are analyzed and discussed.

2 Method and Experiment

2.1 Model Interpretation

First, it need to clarify the different part of this model to tell you why build this model.

When talking about the circuit boards, PCB, namely Printed Circuit Board just can't be ignored. Printed Circuit Board is like an interstate highway for electrical signals, which is an insulating material, with layers of metal wires linking the conductors at different locations (see Fig. 1). The circuit board is composed of a variety of materials, mainly divided into two categories of organic and inorganic materials.

Organic substrates are composed of multi-layer paper layers impregnated with phenolic resins or non-woven or glass cloth layers impregnated with epoxy resins, polyimide, cyanate esters, BT resins and so on [4]. Inorganic substrates mainly include ceramic and metal materials, such as aluminum, soft iron, Nichrome.

This study chose glass as the component of the PCB in the simulation experiment due to the complexity of the PCB board material and the limitation of the simulation. This assumption is sufficient to characterize the deformation of the PCB. This is because it is underneath the insulating soldermask and the deformation mainly comes from here.

The silkscreen circuit is on the PCB, the wires connecting the various electrical components, are generally Nichrome wires and are attached to the glass layer. Its width is on the scale of micrometers. Due to the complexity of silkscreen on a single microchip, to simplify the model, this study have integrated it as a thin silk-screened layer with a sufficiently large width but a constant height, which makes it easier to characterize the sum of the heat dissipation capacities of all the wires [5].

As for the electrodes, since they are not the main heat generating part, this study set them up as electrode sheets of silver material, in the same thin layer as the silkscreen.
For the microchip, which is also the main part of the heat generation, this study decided to consider only the resistive heat effect since the simulation cannot model the real calculation process of a real microchip. Its material is iron.

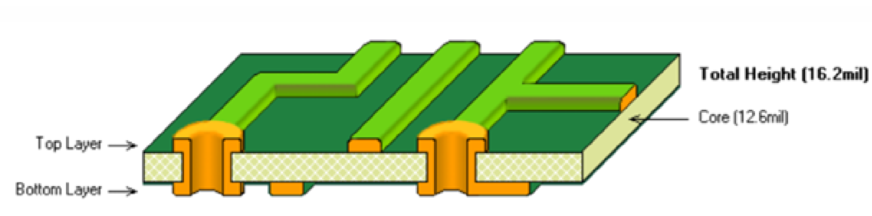


Fig. 1 Simple PCBs, including layers of different materials and silkscreen circuits. (Photo credited: Original)

When exposing a hot or cold part to air, heat is transferred between the part and the air by convection. Natural convection occurs due to changes in natural flotation caused by changes in air temperature, or air can be forced through a fan [6]. It is assumed that heat is transferred to the outside air space by natural convection, as expressed in Equation 1 below.

$$q = h(T_{ext} - T) \tag{1}$$

T_{ext} means outside air temperature, and h means heat transfer coefficient. This equation characterizes the rate of heat exchange between an object and air, with h increasing as the air flow rate increases and decreasing as the air flow rate decreases.

2.2 Model Building

Basic Model. In order to cope with the ease of use of the parameters, they are placed at the global parameters, and the parameters used are shown in Table 1 below.

Table 1. Relevant parameters and explanations

name	value	discription
V_in	*12 V*	Input voltage
T_air	*293.15 K*	Air temperature
h_air	*5 W/(m²·K)*	Heat transfer coefficient, air
d_layer	*8um*	Layer thickness
Sigma_iron	*1E7 S/m*	Electric conductivity of iron
Sigma_ Nichrome	*5.7E7 S/m*	Electric conductivity of Nichrome
Sigma_ silver	*6.3E7 S/m*	Electric conductivity of silver

The next step is the creation of the model geometry. First creating a rectangle as a PCB (glass material) with a length of 80mm, a width of 130mm and a thickness of 2mm (see Fig. 2).

After creating the PCB, select the work plane to adjust to the appropriate location to create the circuit, draw electrodes, silkscreen circuits, microchip in the appropriate location (see Fig. 2).

Create materials. Create corresponding materials for the different locations, which are silver for the electrodes, Nichrome for the silkscreen circuit, and iron for the microchip. The required parameters related to the corresponding materials are shown in Table 2 below, and Data from Wikipedia.

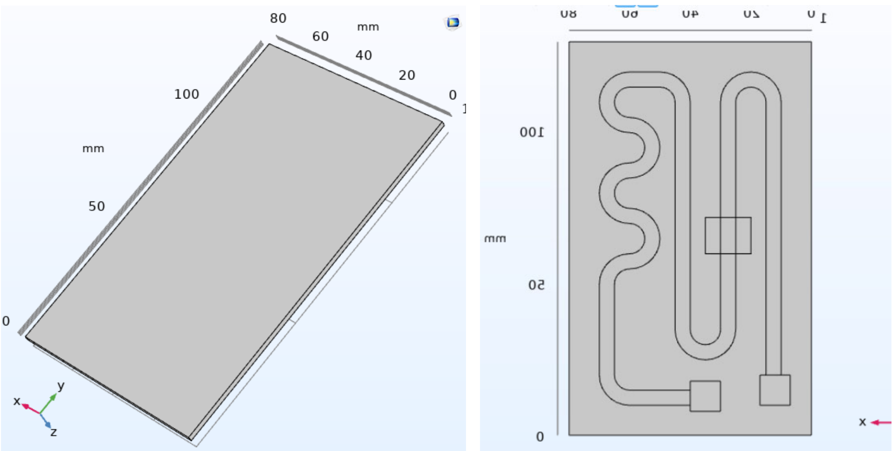


Fig. 2 Model geometry and related circuit (Photo credited: Original)

Table 2 Relevant parameters for different materials

material	PCB	Silver	Nichrome	iron

CTE(1/K)	0.55e-6	18.9e-6	10e-6	10e-6
C_ρ(J/(kg·K))	703	230	20	460
ρ(kg/m³)	2203	10500	9000	7860
κ(W/(m·K))	1.38	420	15	80
E(Pa)	73.1	83e9	213e9	208e9
ν	0.17	0.37	0.33	0.30

Next is the parameterization of the section on solid mechanics. For the full domain selection, which makes it the object of study, the initial value is set to zero since the degree of deformation of the microchip at the stationary (non-operational) state is zero. All boundaries are considered free and the silkscreen layer is treated as a thin layer and approximated as a thin film for simulation purposes.

The solid heat transfer part remains the same for the whole solid treatment, the initial temperature of the microchip is room temperature, the adiabatic approximation is made for the four thin edges and the same thermal convection coefficients are set on the upper and lower surfaces, note that the coefficients here are experimental variables that can be adjusted in the subsequent experimental process.

For the current part, the silkscreen circuit is set up as a conductive shell as a whole, and the positive and negative poles of the silver electrodes are set up separately, and the circuit boundary is set up as an insulation. For the junction of different materials, the continuity condition is set.

The next step is the coupling operation of the multiphysics field. The solid heat transfer field is coupled with the solid deformation as well as the current field, respectively, to obtain both the results of the coupled multiphysics fields [7].

Meshing the model, because Comsol Multiphysics simulation is based on the finite element method, it is not possible to fully compute all parts of the object (infinitesimal division). Therefore, the purpose of meshing is to obtain more correct results with the simplest possible computation.

After completing the above steps, simulate the heat generation and deformation of the microchip during operation in general. Heat sinks are categorized as "passive heat sinks" in the field of electronic engineering design. With good thermal conductivity, lightweight, easy to process metal (mostly aluminum or copper, silver is too expensive, generally do not use) attached to the surface of the heat, to compound the heat exchange mode to dissipate heat. The realistic heat sink is shown in Fig. 3 below.

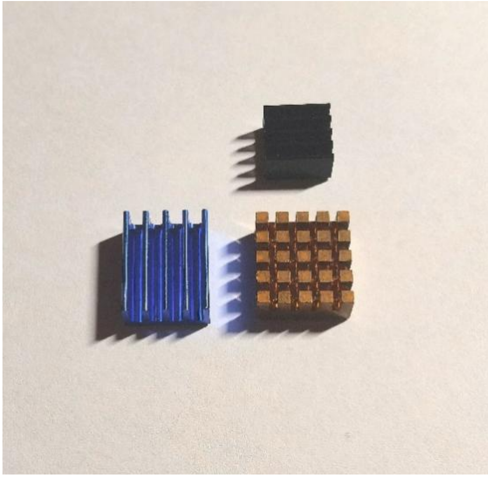
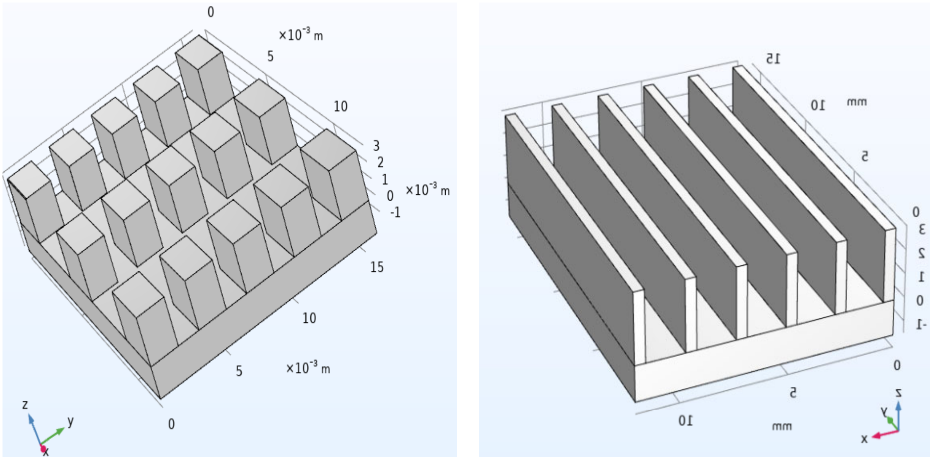


Fig. 3 Heat sinks of different types and shapes (Photo credited: Original)

This experiment designed two kinds of heatsinks to test their help in cooling the microchip, they are both made of copper, as shown in Fig. 4 below.



(A) (B)

Fig. 4 Simulation modeling of two different designs of heat sinks (A) and (B) (Photo credited: Original)

Note that due to the simplification of the model, our microchip shell is electrically conductive (which it wouldn't be in real life), so it needed to add a thin insulating layer to the bottom of the heat sink, or change the conductivity of the entire heat sink to zero [8].

2.3 Experimental Step

After completing the modeling of the PCB circuit as well as the heat sink, start the experimental testing.

1) Import the heat sink into the main program and adjust the position so that it sits on top of the microchip (see in Fig. 5)

2) Recheck the boundary conditions and the settings of the other parameters.

Simulation to get results.

Change the parameters and repeat the experiment.

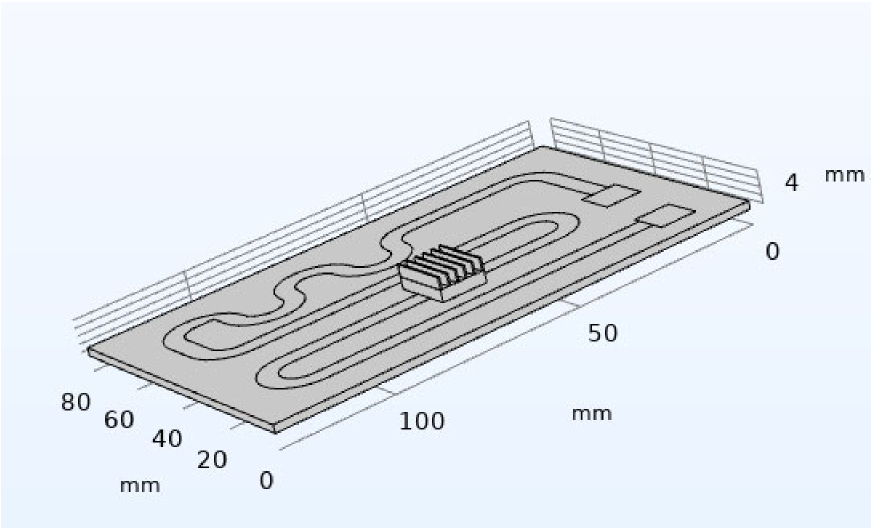


Fig. 5 Placement of heat sinks on the PCB to form a combined model (Photo credited: Original)

3 Results

When running the simulation without any imposed conditions, can get the following results (see in Fig. 6).

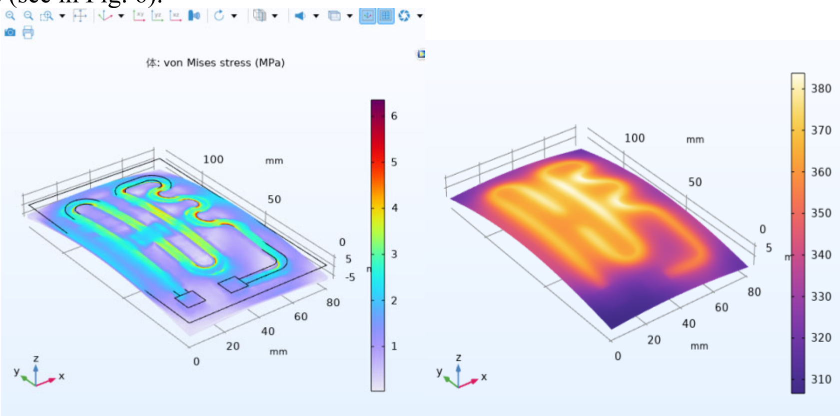
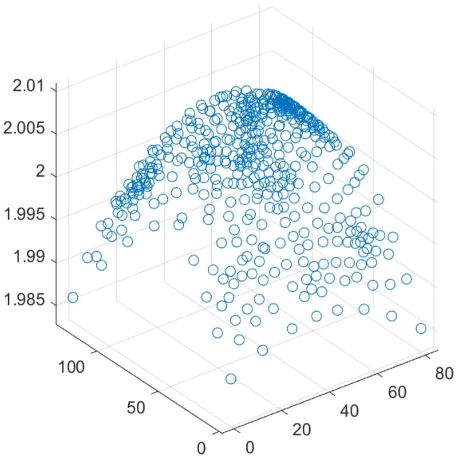


Fig. 6 The picture on the left characterizes the pressure exerted on the PCB. The picture on the right characterizes the degree of deformation of the upper surface with the temperature distribution at different locations. (Photo credited: Original)

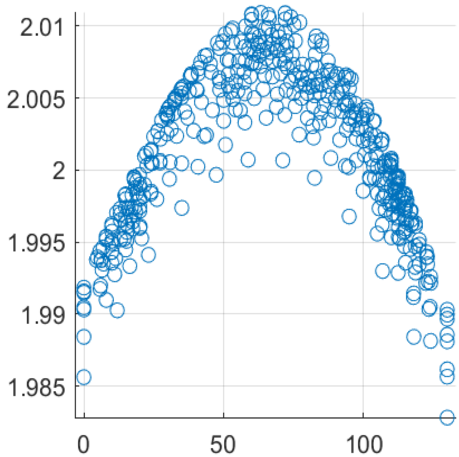
Based on the picture results, it can be performed a preliminary qualitative analysis. When the circuit is energized to generate heat, due to the physical effect of "thermal expansion and contraction", the center of the PCB will bend upwards. This is because the silkscreen circuit is located on the upper surface, heat production leads to the upper and lower surfaces of the temperature difference, the upper layer of the degree of expansion is greater than the degree of expansion of the lower layer, so the upper layer of the center of the surface area increases, showing upward protruding tendency, and vice versa around the PCB shows a downward trend. Theoretical analysis of the simulation results are consistent with the actual.

At the same time, note that the temperature of the microchip is less than the wire temperature when the heat generated by the microchip's operation is not taken into account, which is mainly due to the characteristic of the material.

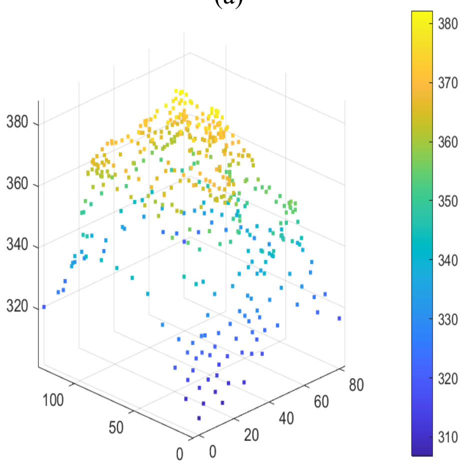
Of course, since the image output of PCB deformation and heat generation does not provide exact numerical information, needed to export the data and plot it with a plotting software (Matlab) to provide a more visual result. (see in Fig. 7).

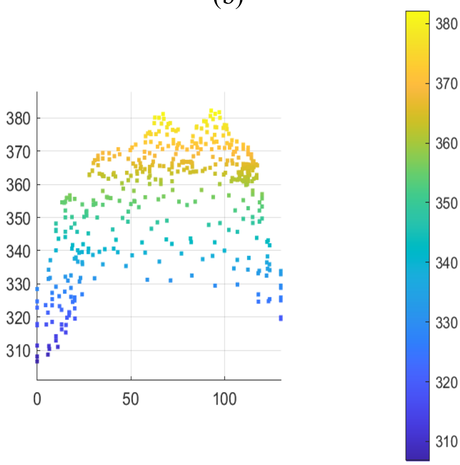


(a)



(b)



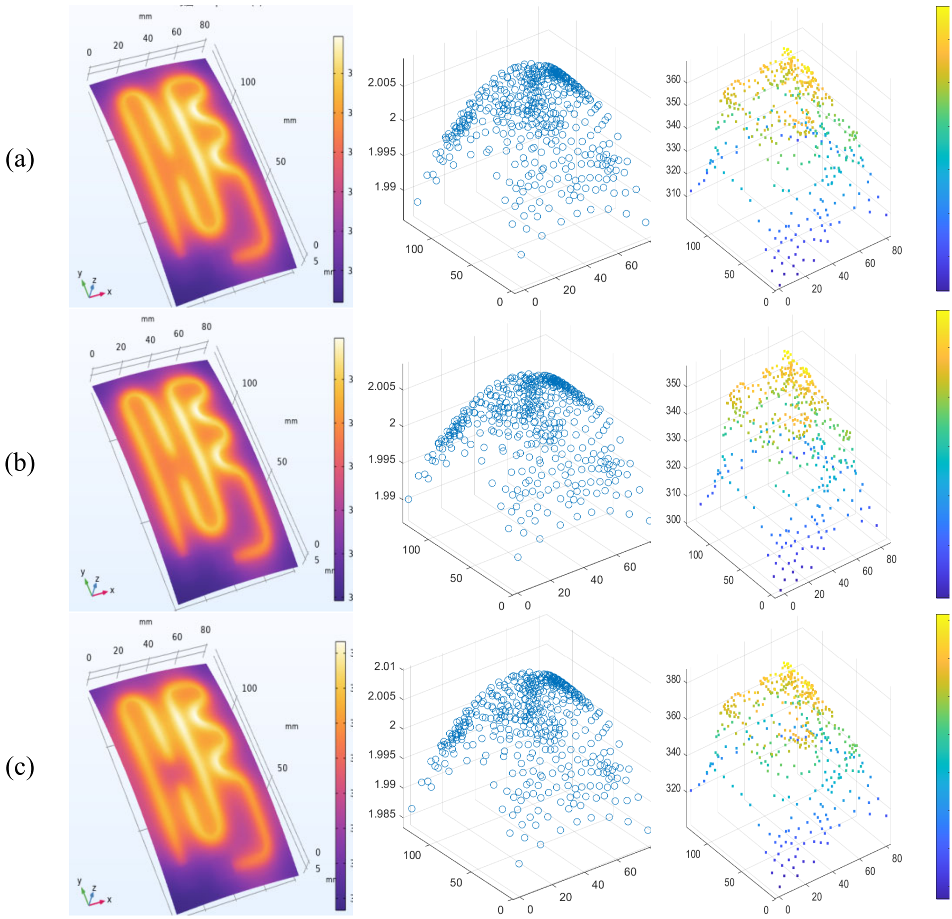


(c) (d)

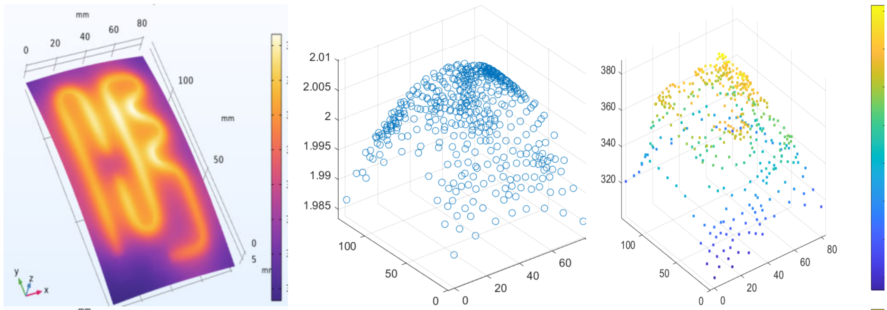
Fig. 7 Data Output Result Figure (a):Degree of deformation map (b): Degree of deformation map (yz-view) (c): Upper surface temperature distribution (d): Upper surface temperature distribution (yz view) (Photo credited: Original)

Based on the data points can visualize the results more intuitively and can find the PCB deformation and temperature maxima. The maximum PCB temperature is 382.17 K, The maximum PCB deformation is 10.90 μm, The maximum microchip temperature is 366.32K.

Now the model is modified by changing the parameter h to 12.5 W/(m²·K) or 15 W/(m²·K) and adding a heat sink to conduct the experiment again and the results are shown below (see in Fig. 8).



(d)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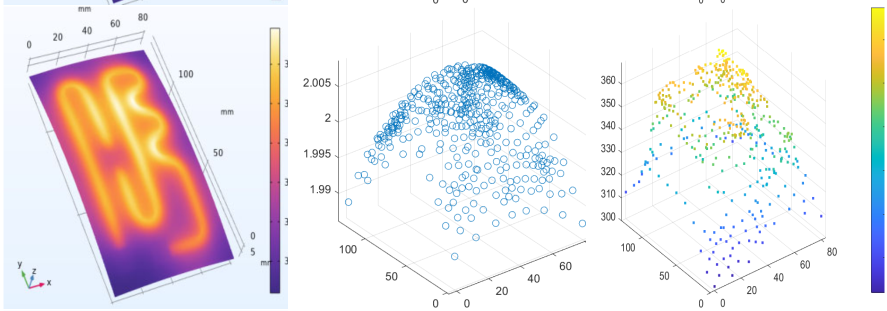
(e)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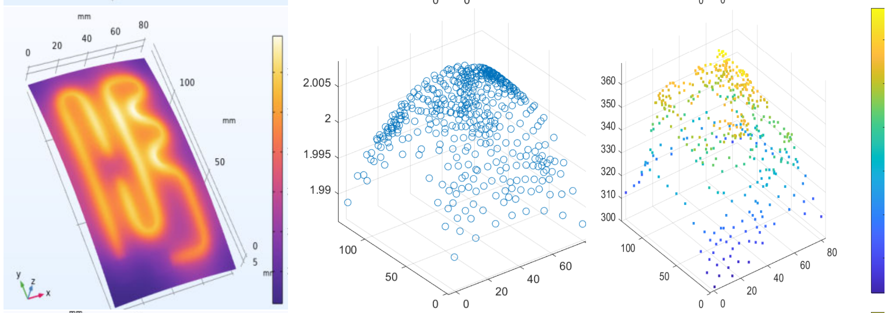
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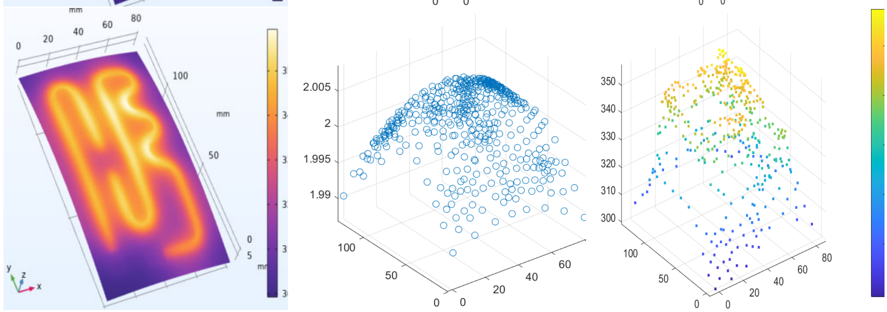
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(h)

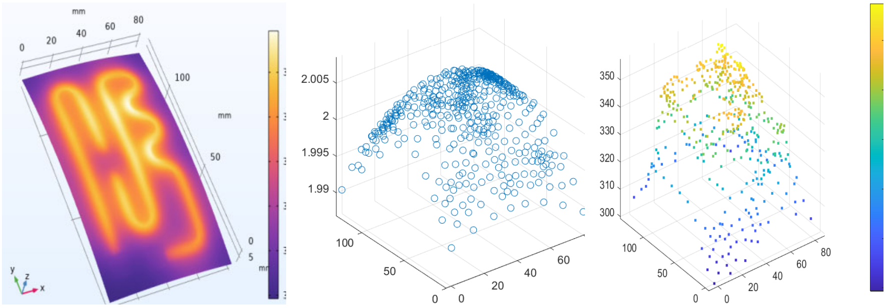

Fig. 8 (a) $h = 12.5W/(m^2{\cdot}K)$ no heat sink (b) $h = 15.0W/(m^2{\cdot}K)$ no heat sink (c) $h = 10.0W/(m^2{\cdot}K)$ heat sink A (d) $h = 10.0W/(m^2{\cdot}K)$ heat sink B (e) $h = 12.5W/(m^2{\cdot}K)$ heat sink A (f) $h = 12.5W/(m^2{\cdot}K)$ heat sink B (g)$h = 15.0W/(m^2{\cdot}K)$ heat sink A (h)$h = 15.0W/(m^2{\cdot}K)$ heat sink B (Photo credited: Original)

The data for the cases under different parameters are shown in the Table 3 below.

Table 3 Basic information of PCB

	maximum PCB temperature/ K	maximum PCB deformation/ μm	maximum microchip temperature/ K
(a)	*365.64*	9.01	349.91
(b)	*355.64*	7.72	342.16
(c)	*379.66*	10.31	354.97
(d)	*378.64*	10.01	351.91
(e)	*365.37*	8.60	343.10
(f)	*365.33*	8.53	341.94
(g)	*355.48*	7.41	334.90
(h)	*355.45*	7.36	334.00

Comparing each group of data with the basic data it can be seen that all groups can reduce the maximum temperature and the maximum degree of deformation of the PCB. the maximum temperature of the microchip is also significantly reduced. It can be calculated the percentage reduction in the maximum value of these three dependent variables for each group, shown in the Table 4 below.

Table 4 Percentage reduction in three dependent variables

	Percentage reduction in maximum temperature change of PCB	Percentage reduction in maximum deformation change of PCB	Percentage reduction in maximum temperature change of microchip
(a)	18.57%	17.34%	22.43%
(b)	29.80%	29.17%	33.02%
(c)	2.82%	5.41%	15.51%
(d)	3.97%	8.17%	19.69%

(e)	18.87%	21.10%	31.73%
(f)	18.92%	21.74%	33.32%
(g)	29.98%	32.02%	42.94%
(h)	30.02%	32.48%	44.17%

Comparison of the data shows that increasing the amount of ambient heat flux coefficient can effectively reduce the maximum temperature of PCB, while adding the heat sink can effectively reduce the maximum temperature of the microchip. The optimal combination of reducing the maximum PCB deformation, the maximum temperature and the maximum temperature of the microchip are $h = 15.0W/(m^2 \cdot K)$+heat sink B.

To summarize, either increase the ambient heat flux coefficient or add heat sinks can effectively reduce the adverse effects on the microchip due to thermal effects, which can ensure the normal running of the microchip function and life extension.

COMSOL simulation can accurately simulate multiphysics processes in multiphysics fields, which can provide useful information for engineering design and materials research.

4 Discussion

Simulation experiment is a kind of experimental way to simulate the experimental results by using software modeling without actually doing the test in reality. Based on this characteristic, it can improve the efficiency of analysis, and improve the efficiency of work. However, it is undeniable that even if your model is built more accurately, there will be some deviation from reality, so it can only be used as a reference tool for realistic experiments.

This experiment has several advantages:

1) A simpler model was used to simulate the heat production of the microchip and the components were quantitatively analyzed using derived data points.
2) It provides a feasible way to analyze the microchip heat dissipation problem and helps the development of the microchip heat dissipation industry.

The experiment has the following points that can be improved:

1) The oversimplification of the model, e.g., considering only a single primary material for the PCB, the simplification of the silkscreen circuitry, the microchip package is oversimplified and the absence of the microchip computational process all reduce the reliability of the experiment [9]. The next step is to take these aspects into account and add them to the model.
2) Actual experimental operations should be performed and analyzed in comparison with simulation results. Next experiments should be carried out in reality.
3) Multi-simulation software can be used to simulate the results jointly to make the results more reliable [10].

Overall, this experiment basically accomplished the set goals and gave relatively reliable results, but there is still a lot of space for improvement, and I hope that this project is the beginning of my career in the field of electrical engineering, and I will continue to conduct research on this path.

5 Conclusion

Based on this experiment, the following conclusions can be drawn: Microchip circuits located on the PCB generate a lot of heat during running, causing the microchip temperature rise and deformation. The maximum PCB temperature is 382.17K, The maximum PCB deformation is 10.90 μm, The maximum microchip temperature is 366.32K. Excessive temperatures can impair performance as well as shorten the life of the microchip. Increasing the amount of ambient heat flux coefficient can effectively reduce the maximum temperature of PCB, while increasing the heat sink can effectively reduce the maximum temperature of the microchip. All groups showed a positive effect in reducing the maximum temperature and deformation of. The optimal combination of reducing the maximum PCB deformation, the maximum temperature and the maximum temperature of the microchip are $h = 15.0W/(m^2{\cdot}K)$+heat sink B, which can reduce 30.02% in maximum temperature change of PCB, 32.48% in maximum deformation change of PCB and 44.17% in maximum temperature change of microchip. Although increasing ambient heat flux coefficient and adding heat sinks have been decrease the temperature and the deformation, the microchip system still has a large degree of temperature increase and deformation. More effective means need to be added to further reduce the temperature.

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