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Analysis on heat transfer characteristics of integrated circuit silicon chip package based on finite element model

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Abstract: *The heating problem of components in integrated circuits has become an important factor affecting the service life and reliability of chips and the whole circuit. In recent years, the study of thermal effects in circuit design and packaging process has become an important topic. In this article, we use comsol software model for integrated circuits, close to the surface of the voltage regulator on simulation circuit boards silicon chips and heat condition of components, each part drawing three dimensional temperature distribution, by changing the voltage regulator for heating power, analysis of the voltage regulator in a certain position in different heating situations on the circuit chip as the core of the influence of the temperature of the parts, Finally, the safe operating range of integrated circuit is obtained without affecting the life of each device. In the simulation process, the thermal thin approximation and grid processing are used, and the temperature distribution map obtained is smooth and continuous, and the circuit structure is fully simulated, which can provide guidance and suggestions for real IC packaging.*

Keywords: *Heat Transfer; COMSOL; encapsulation; finite element mesh; temperature field*

1. Introduction

In recent years, the integrated circuit industry has developed rapidly, and the integration degree of circuit components has been continuously improved. However, in the use of integrated circuits, there are unavoidable heating problems due to resistive elements. In the increasingly dense electronic system, it is difficult for these heat sources to keep a long distance from the heat sensitive integrated circuit chip to absolutely avoid interference. More heat is conducted through the circuit board, connector, etc., resulting in an increase in the working temperature of the chip, which has a certain impact on the working performance of the chip and reduces its service life. Therefore, thermal interference has become a key factor affecting circuit reliability.

At present, many scholars at home and abroad on the thermal effect of chip packaging and related thermal stress has been a lot of research results. Haidong Shen et al. explored the influence of modeling methods on thermal analysis in the process of chip packaging, analyzed and evaluated on the basis of double thermal resistance model and "lumped parameter method" modeling, and compared the temperature of the chip[1]. Wang Hongwei from Nanjing Institute of Technology aimed at the problem of thermal failure of typical plastic square flat package PQFP in the process of work. He used vertical two-dimensional finite element numerical simulation analysis model to study the stress distribution of the package[2]. Savidis et al. conducted an experimental study on the thermal coupling phenomenon in 3D integrated circuits by means of wafer vertical bonding, and put forward some suggestions to reduce the thermal effect in integrated circuits [3]. Many studies on this kind of packaging at home and abroad are experimental results. The finite element simulation mainly focuses on the analysis of the thermal stress between the components under the condition of alternating temperature field. However, most studies are insufficient to analyze the influence of external devices on chip temperature, and the influence of typical devices on chip temperature is rarely discussed. The established temperature curve is rarely described in three dimensional space and two dimensional profile near the chip [4-7].Voltage regulator is a kind of semiconductor device commonly used in the current circuit. It can flexibly adjust the voltage applied to the load through simple design. It is widely used in machinery, automobile, chemical industry and other industries . It is widely used in machinery, automobile, chemical industry and other industries. However, the voltage regulator will generate several watts of heat when working, and the maximum temperature can sometimes exceed 70 °C. Therefore, it is an important topic to study the relative position of the relevant heating elements and the chip with the voltage regulator as a typical device to explore whether its heat will lead to the reliability of the chip[8].

Based on this, this paper conducts a simulation study on the thermal state of the surface mounted silicon chip on the integrated circuit board near the voltage regulator, and explores the temperature rise characteristics of the chip under the joint action of the heat transfer of the voltage regulator and the self heating of its internal components. Firstly, the three-dimensional model of the specific integrated circuit structure is constructed to simulate the topology of the real surface mount silicon chip and its connector. Secondly, the influence of different heating power generated by the voltage regulator at a fixed position on the temperature distribution of the chip and the connector is analyzed. Finally, whether the chip will overheat due to the conducted heat during the operation of the voltage regulator is discussed.

2. Model and theoretical analysis

Integrated circuit is a kind of micro electronic device that uses a certain process to connect a certain number of transistors, resistors, capacitors and other elements to a semiconductor wafer. With the development of technology, people's demand is growing day by day, the integration degree of chip increases, power consumption decreases. However, the heat flux in the chip also increases rapidly, forming over hot spots or over hot areas in the IC. In most cases, the heat source is placed close to the heat-sensitive IC. Designers of printed circuit boards often need to consider the relative position of the thermal and thermal components so that the sensitive components do not overheat.

In this paper, through experimental simulation, the thermal condition of the surface mount silicon chip placed on the integrated circuit board near the voltage regulator is studied. The temperature rise of the chip is mainly affected by the heat from the voltage regulator and its internal heat [9].

The internal thermal resistance θ_{in} on the packaging surface of the heating chip is calculated by Equation (1):

$$\theta_{in} = \left(T_j - T_c\right)/P = L/(K \cdot S) \tag{1}$$

Where Tj stands for chip junction temperature *(℃)*, *Tc* stands for package shell surface temperature *(℃),P* stands for chip power consumption *(w),L* stands for path length of heat conduction direction*(m),K* stands for thermal conductivity *(w/m·K),* and *S* stands for transverse area perpendicular to heat flow *(m^2).*

The principle of heat flux measurement is to measure the temperature gradient ∇_T and the thermal conductivity coefficient *K* between two points and calculate the heat flux *Q* through Equation (2) :

$$\nabla \cdot (-k\nabla T) = Q \tag{2}$$

Where *K* is the thermal conductivity: ∇_T is the temperature difference between two points. "-" indicates that the direction of heat flow is opposite to the direction of the temperature gradient.

The heat dissipation from all air-exposed surfaces by forced heat convection, simulated using the heat transfer coefficient *h*, is calculated by Equation (3) as follows:

$$-n \cdot q = h(T_{inf} - T) \tag{3}$$

A voltage regulator is simulated by setting a fixed temperature on the surface. According to the following equation (4), the two-dimensional shell approximation is used to model the ground plane and the thin conductive layer of the connector inside the package:

$$\nabla_t \cdot (-d_s k \nabla_t T) = 0 \tag{4}$$

Here, *ds* is the layer thickness, and ∇_t denotes the Nabla operator projected to the plane direction. The model uses the heat transfer interface to describe the three-dimensional heat transfer and the two-dimensional shell heat transfer.

In addition, simulation software COMSOL Multiphysics AC/DC module includes steady state and dynamic electromagnetic field analysis in two-dimensional and three-dimensional space, as well as traditional passive and active components based on circuit simulation, MEMS module is used to simulate MEMS devices, microfluidic systems and MEMS in various physical phenomena. Its natural properties determine that its intrinsic nature is the coupling of multiple physical fields. The principle structure diagram is shown in Figure 1.

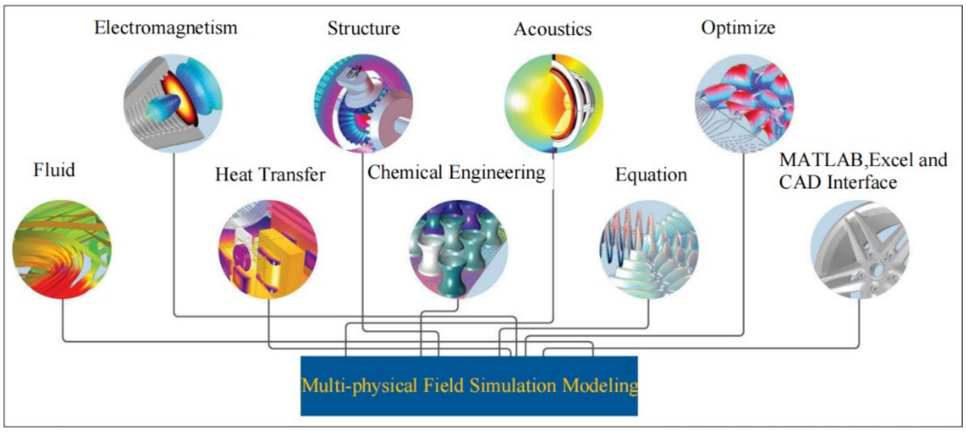


Figure 1: Multi-physics field simulation model

3. Simulation model analysis

3.1 The model definition

This simulation uses Comsol software, and its heat transfer module is used to simulate the heat distribution. The circuit board primitive of 20*10*1mm is intercepted as the model of the overall research. The 16-pin chip is located in its central position, the size is half of the circuit board primitive, and the height is 0.2mm. The connector between the chip pin and the circuit board is built by using simple operations such as translation, stretching and mirroring. For the convenience of research and concise observation, the floor and the temperature generated by the voltage regulator are represented by a surface respectively. After the completion of the model construction, each part of the material is set separately, in which the main body of the chip is made of silicon, the pin part is filled with aluminum, and the chip package is set with the properties of plastic. Part of the circuit board software is filled with inherent material FR4, and the outer boundary is covered with copper. Under this setting, each part of the material of the integrated circuit is truly simulated, which makes the change of reaction temperature conduction more real and objective.

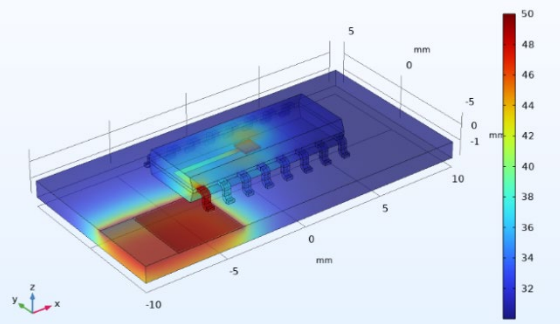
In the heat setting part, the ambient temperature is set at 30 ℃ and the voltage regulator temperature is 50 ℃. Because the size of the chip is very small, the connectors between the chip and the grounding pins are connected to the floor and the voltage regulator can be regarded as "thin layer". Setting the property to thermal thin approximation can well simulate the heat transfer. Finally, the temperature plane of the voltage regulator is defined as the solid heat transfer surface, and the temperature distribution under different conditions can be obtained by changing its heating power.

In order to make the temperature distribution more detailed and the distribution map more intuitive, we finally use grid operation before the model calculation. The free tetrahedral network is used to set the boundary of the model, in which the connecting floor and the voltage regulator plane are ultra-refined, and the rest are refined. The resulting grid contains about 30000 elements, and the temperature distribution map is natural.

3.2 Discussion and analysis of simulation results

During the simulation, the heating power of the voltage regulator is changed many times, and the temperature characteristics from 2e6w/m^3 to 2e9w/m^3 are studied at intervals of ten times. The temperature distribution of the model as a whole, the chip surface, the circuit board and connector and the chip package shell are plotted respectively, as shown in figure 2. From the distribution point of view, due to the use of gridding operation, the temperature of the whole model is clear and intuitive, and the color transition is smooth. There are two temperature hot zones in the whole model, which are the chip region and the temperature surface position of the voltage regulator, which is in line with the research expectation.

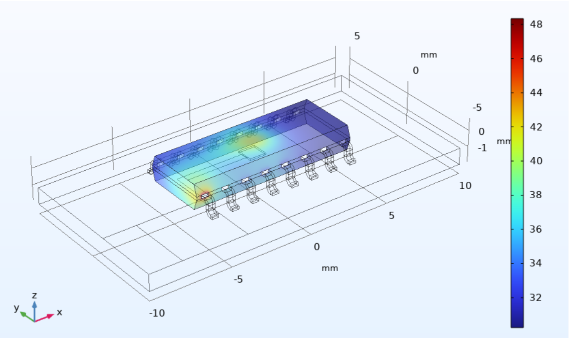
The heat conduction effect of the connector is obvious, and the temperature varies greatly with the position, which accords with the characteristics of thermal thinness approximation, which shows that the simulation can well reflect the thermal effect of the integrated circuit.



(heating power is2e8w/m3 , The unit of variable in the figure is ℃)

Figure 2: Overall temperature distribution of the model

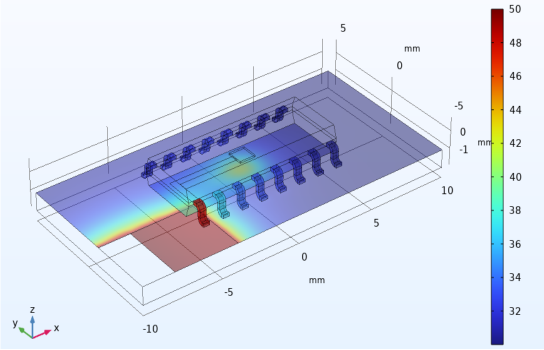
In order to better study the temperature status of each device in the circuit, we study different parts separately in order to avoid the thermal color interference of other devices. Taking the heating power at 2e8 w/m^3 as an example, the highest temperature of the chip shell appears at the contact point between the connector closest to the voltage regulator and the chip shell, which is about 46℃, as shown in figure 3. The temperature of other relatively distant positions decreases obviously, and the temperature is all above and below 35℃, indicating that the heating of the voltage regulator and the chip has a significant effect on the shell, but the influence distance is short, and it will attenuate quickly in a very short distance.



(The heating power is 2e8w/m3, The unit of variable in the figure is ℃)

Figure 3: Chip shell temperature distribution

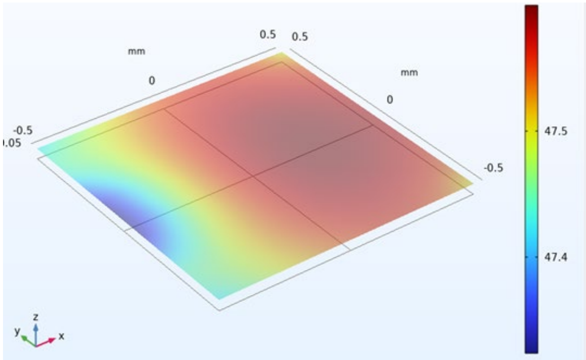
In the study of circuit boards and connectors, when the heating power is 2e8 w/m^3, most areas of the circuit board keep a low temperature, about 35°C or so, which is approximately consistent with the temperature of the chip shell. One of the higher temperature areas appears around the temperature plane of the voltage regulator, which attenuates rapidly around its temperature plane, and the other is on the circuit board at the chip, as shown in figure 4, in line with the research expectations. The connector closest to the voltage regulator plane has a higher temperature, and the temperature rises to about 50°C, which is related to its good heat conduction characteristics.



(The heating power is 2e8w/m3, The unit of variable in the figure is ℃)

Figure 4: Circuit board and connector temperature distribution

In order to better reflect the temperature characteristics of the chip, we separately cut the lower surface of the chip for observation, as shown in figure 5, In the current case, the maximum temperature of the chip is about 47.7°C and the temperature difference of the whole chip is very small, less than 0.5 °C. It shows that the model reflects the temperature of the chip in general working state. According to the general law, the chip can work stably under the condition of normal life.

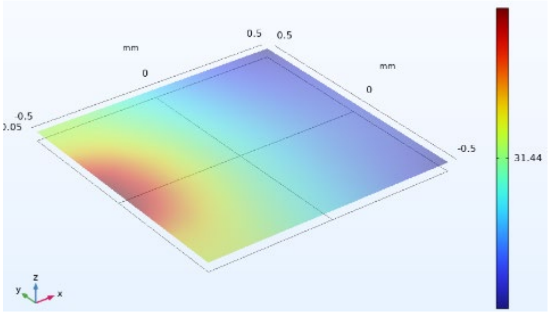


(The heating power is 2e8w/m3, The unit of variable in the figure is ℃)

Figure 5: Temperature distribution on the lower surface of the chip

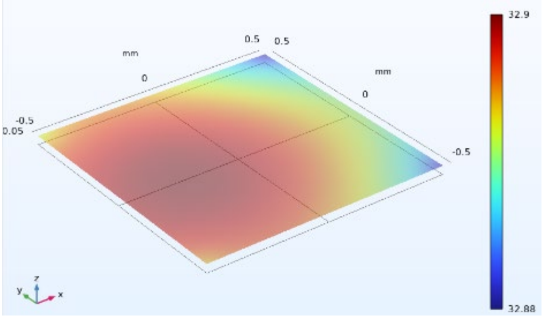
In order to explore the influence of the heating power of the voltage regulator on the chip and other devices, we have studied the temperature of each device under different power. The following is an example of the temperature of the lower surface of the chip. When the heating power increases from 2e6w/m^3 (as shown in figure. 6) to 2e7w/m^3 (as shown in figure. 7), although the power changes ten times, the temperature of the chip only changes slightly, and the temperature only changes by about 1℃, indicating that the heating power of the voltage regulator has little influence on the chip temperature at this time, and the chip can operate normally and continuously at a low temperature.

When the heating power of the voltage regulator reaches 2e8 w/m^3, as shown in Fig. 8, the chip temperature changes greatly. As shown above, the maximum temperature is above 47 ℃. Generally, if the chip temperature is higher than 50 ℃, its working life will be affected. At this time, it is close to the edge of normal operation. When the power of the voltage regulator is increased to 2e9 w/m^3, the theoretical chip temperature will be close to 200 ℃, and the chip will be burnt and unable to work. It can be seen that the temperature of the device increases exponentially with the increase of power by ten times.



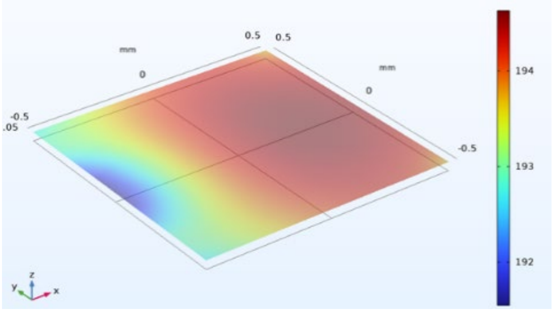
(The heating power is 2e6w/m3, The unit of variable in the figure is ℃)

Figure 6: Temperature distribution on the lower surface of the chip.



(The heating power is 2e7w/m3, The unit of variable in the figure is ℃)

Figure 7: Temperature distribution on the lower surface of the chip.



(The heating power is 2e9w/m3, The unit of variable in the figure is ℃)

Figure 8: Temperature distribution on the lower surface of the chip.

4. Conclusion

In this paper, the thermal state of the surface mounted silicon chip close to the voltage regulator on the integrated circuit board is simulated, and the temperature rise characteristics of the chip under the joint action of the heat transfer of the voltage regulator and the heating of its internal components are explored. The following conclusions are drawn:

(1) In the simulation case, when the voltage regulator power is *2e9* w/m^3, the IC heating is the most serious, at this time all parts of the device has exceeded 120 ℃, out of the normal working range, at this time will burn out, can not work normally. When its power is less than or equal to 2e8 w/m^3, the temperature of the chip is less than 50℃, and it can work continuously for a long time without affecting its life.

(2) The connector closest to the voltage regulator and connected to the chip package shell is the part with the most serious heat. When the voltage regulator power is 2e8w/m^3, the temperature is about 50℃, and the temperature of other devices is lower than this temperature, then the limit power of safe and stable operation of all parts of devices is about 2e8 w/m^3 without affecting their service life.

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