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Numerical Simulation of Tantalum Capacitor Reflow Soldering in Temperature Field

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Abstract. This article aims to simulate and design the thermal stress during the welding process of tantalum capacitors, which is prone to failure. In this paper, the subsection function is defined, the boundary conditions of thermal stress are set, and the mesh is divided through the temperature diagram of high temperature reflow welding process; Analyze the temperature changes in the welding machine based on time changes, and conduct simulation analysis of thermal stress and cross-sectional analysis of thermal stress. Through simulation results, improve the design structure to minimize the impact of welding process on capacitor failure.

Keywords: Thermal Stress; Border Conditions; Simulation Analysis; Tantalum Capacitance.

1. Introduction

Tantalum capacitor is a kind of capacitor with small size but large capacity, so it has been widely used in different fields such as military, aerospace, film and television since it was successfully researched by Bell Labs in 1956.Tantalum capacitors can withstand high temperature during reflow soldering, achieve high accuracy, and will not rapidly increase or decrease capacity due to some extreme environmental changes, and have good "self-healing" characteristics, which meet the requirements of some high or low temperature operating conditions.

Reflow soldering technology in the field of electronics manufacturing has been very familiar, in the use of some components within the computer are soldered to the circuit board through the reflow process, its development has shown a rapid upward trend. In the process of welding, the thermal stress of tantalum capacitors is a process that involves heat transfer, physics, mechanics and other aspects, including the stress of the welding process, etc. The thermal stress of welding will affect some of our manufacturing processes and the use of performance in the welding process, etc.

Through simulation analysis of the thermal stress of tantalum capacitor in the welding process, the temperature and stress distribution of tantalum capacitor in the three-dimensional state can be visually observed, that is, how the stress will change when the temperature changes. Optimisation of model shape etc. for different stress conditions.

2. Temperature Thermal Stress

Heat conduction, heat convection and heat radiation are the three common ways of transferring heat.These three heat transfer modes are very common in the process of material processing. When the temperature of the object changes in a certain environment, the object has internal and external stress constraints due to the different internal and external environment, so that it can not freely grow and shrink with the temperature change and the stress is called thermal stress[4].

When solving for temperature stresses, the temperature field is first determined, which in turn determines the displacement, strain and stress fields.The temperature field is a general term for the distribution of temperature at various points in an object at various times. The mathematical expression for the temperature field in a thermally conductive object is based on the conservation of energy and Fourier's law[5]:

$$\frac{\partial(\rho c t)}{\partial \Gamma} = \frac{\partial}{\partial_x}(\lambda_x \frac{\partial_t}{\partial_x}) + \frac{\partial}{\partial_y}(\lambda_y \frac{\partial_t}{\partial_y}) + \frac{\partial}{\partial_z}(\lambda_z \frac{\partial_t}{\partial_z}) + Q$$

In the formula, the first term refers to the heat required by the object to warm up; the second, third and fourth terms refer to the heat flowing into the object in x, y and z directions; and the last term refers to the heat generated by the heat source inside the object, the equation applies not only to heat transfer from solids but also to heat transfer from fluids, ρ is the material density; c is the specific heat capacity of the material; λ_x, λ_y, λ_z is the thermal conductivity of the material along the x, y and z directions; Q is the density of the heat source inside the material. The equation shows the principle that the temperature of an object changes continuously with time and space, and that the heat of an object's temperature increase is equal to the sum of the heat present in the object heated by the outside world and the heat generated by the object itself[5].

Usually, the temperature stress is solved by the heat transfer equation and boundary conditions to find the temperature distribution; then the thermoelasticity equation is used to solve for the displacement and stress [5].

3. The Simulation Model of Temperature Thermal Stress

3.1. The Construction of Tantalum Capacitor

The geometrical model of a tantalum capacitor is a combination of several different materials. Tantalum is a relatively rare metal and its oxide is produced on the surface of the metal. Tantalum capacitors use tantalum metal as a medium and do not need to be fired with aluminum-coated capacitor paper like ordinary electrolytic capacitors. Materials from the inside out: tantalum, tantalum pentoxide, manganese dioxide, graphite and silver paste, protective film. The negative side of the pin is led from the silver paste and the positive tantalum wire is soldered to the positive pin frame. The actual simulation process is simplified by modelling, in which the internal tantalum block (tantalum core) is seen as a part, the manganese dioxide layer, the graphite layer, the silver pastes layer and the bonding silver paste (graphite silver paste after the tantalum core) are seen as one kind of simulation, the PTFE sheet can be disregarded first, and the other structures are carried out according to the actual.

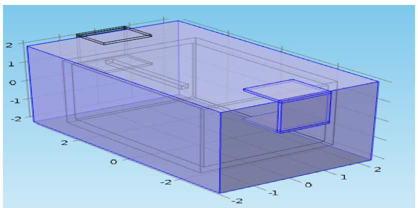

Figure 1. The structure of tantalum flakes in COMSOL

3.2. Thermal Stress Boundary Condition Setting

Reflow soldering machine with eight temperature zones with boundary conditions: 8 temperature zones: 120, 140, 165, 170, 183, 260, 30, 30. The reflow speed is 55 cm/min and the total reflow time is approximately 8 min.

The first stage is the process of raising the temperature from room temperature. During this temperature rise, the solvent in the solder paste evaporates. If the temperature slope is too high, the temperature rises too quickly; as the solvent evaporates too quickly from the paste, it causes a "mini explosion" in the paste and produces beads. In this area, we recommend a temperature rise rate of between 1°C/S and 3°C/S. Too high a temperature tilt rate can also lead to the bursting of some components.

Define the segmentation function:

Table 1. Define the segmentation function

Start	End	Functions
0	1.5	60*t+30
1.5	3	30*t+75
3	4.5	12*t+129
4.5	6	148*t*t+1554*t-3813
6	8	76.5*t+642

The thermal stress boundary conditions are set as follows:

(1) Heat transfer from solids

initial value - the ambient temperature;

temperature - set temperature T0 as a segmentation function p(t), the boundary is the lead frame and moulded cake material;

heat flux - set convective heat flux, heat transfer coefficient h = 400, the boundary is the lead frame;

heat flux - set convective heat flux with a heat transfer coefficient h = 0.2, the boundary is the moulded cake material;

thermal contact - set contact pressure to 0 [kPa], the boundary is all boundaries.

(2) Solid Dynamics

Fixed constraint - sets the leadframe domain and the tantalum filament domain;

Free - sets all boundaries other than leadframe and tantalum wire;

Specified displacement - sets all boundaries, specifying the standard representation of the displacement selection, with all reference points being 0.

3.3. Grid Divisions

A conventional grid was chosen and the grid is shown in Figure 2.

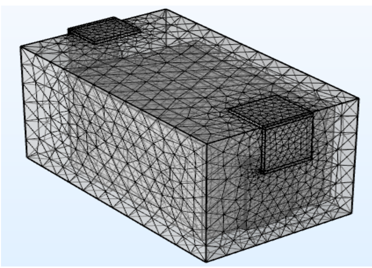

Figure 2. Grid divisions

4. Thermal Stress Simulation Analysis

4.1. Thermal Stress Analysis

(1) The time is 0min, the temperature is close to the ambient temperature at the beginning, and the temperature is highest at the place where the boundary condition is added, the temperature on the tantalum capacitor is not big at this time. The stresses are shown in Figure 3-6.

(2) The boundary conditions are as above. When the time is 1min, the temperature of the whole is increasing, up to 89.5 degrees Celsius, influenced by the material and its thermal conductivity, the temperature is lower in some places, the lowest temperature is 20 degrees Celsius, the temperature

distribution is more uniform, the highest temperature is in the place where the temperature boundary condition is added, the local temperature is lower with other boundary places where the temperature is not added, the highest temperature is in the outer moulded cake material and lead frame, the temperature of graphite silver paste layer is slightly lower.

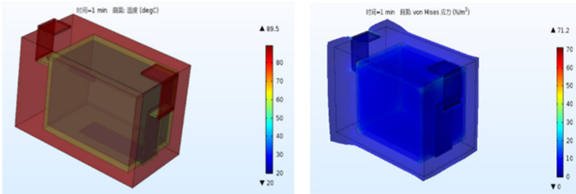

Figure 3. Time = 1min Temperature and stress distribution diagram

At time = 1 min, the stresses change accordingly as the temperature rises, with the greatest stresses occurring in the area where the leadframe is in contact with the tantalum wire, and the other where the leadframe is in contact with the moulded cake material and its surroundings are also affected. As well as the edges of the graphite silver paste layer are also stressed more. This is due to the fact that both the moulded pastry layer and the graphite silver paste layer have right angles to the edges, and that the contact between the leadframe and the tantalum wire is the more vulnerable area inside it, as well as the right angle of the tantalum capacitor shape, which tends to lead to stress concentration and thus the greatest thermal stress and therefore the greatest deformation. Therefore, model shape optimisation is considered.

(1) Boundary conditions as above. At a time of 5.3min, the maximum temperature of 265 degrees Celsius is reached at this point, and the lowest temperature of 20 degrees Celsius exists, influenced by the thermal conductivity of the material and the location of the distribution, with a relatively uniform temperature distribution, same as before, the highest temperature is in the place where the temperature boundary condition is added, with the moulded cake material and the lead frame and the graphite silver paste layer at a higher temperature, and the tantalum core and tantalum wire at a lower temperature within the tantalum capacitor.

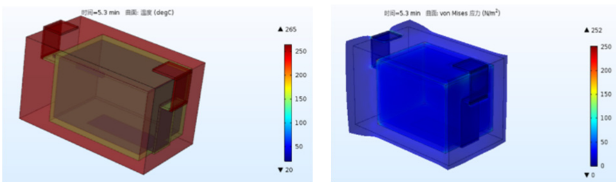

Figure 4. Time = 5.3min Temperature and stress distribution diagram

When the time is 5.3 min, the temperature reaches its maximum corresponding to the stress-strain is also the maximum, reaching the welding temperature, subjected to high temperature, the moulded cake of the model is obviously deformed at this time, the moulded cake is the most prone to cracking at this time, is also the most prone to failure.

(2) The boundary conditions are the same as above. When the time is 8min, the welding is completed and the temperature decreases, the highest temperature is 38.3 degree Celsius and the lowest is 20 degree Celsius, the temperature of the whole tantalum capacitor is basically the same, but due to the influence of the material properties, there are local places where the temperature is significantly higher than other places, the distribution is more uniform.

When the time is 8min, the temperature decreases again with the change of time, and the force also decreases, but the place of stress is basically unchanged, and the maximum stress is still concentrated in the place where the lead frame is in contact with the moulded cake material and the place around the moulded cake material, as well as the right angle position of the graphite silver paste layer edge, and the stress influence is less at this time.

4.2. Thermal Stress Cross Section Analysis

When the time t=5.3min, the temperature reaches the maximum, reaching the welding temperature, by the high temperature, the molded cake of the model is obviously deformed at this time, when the molded cake is the most prone to cracking, but also the most prone to failure. So we analyze the stress distribution of the cross section when the time t=5.3min, the stress distribution is shown in the figure.

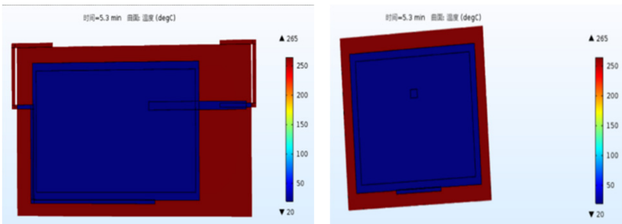

Figure 5. Cross-sectional temperature distribution diagram

From the figure, it can be seen that the temperature distribution is uniform at this time, the lower end of the lead frame is in the inner layer of the tantalum capacitor, so it is subjected to a slightly lower temperature than the upper end and other surrounding parts, and the temperature of each layer is clearly visible from the two cross sections, the highest temperature is on the lead frame and molded cake material with added temperature conditions, but the temperature of each place is different because of the different material properties.

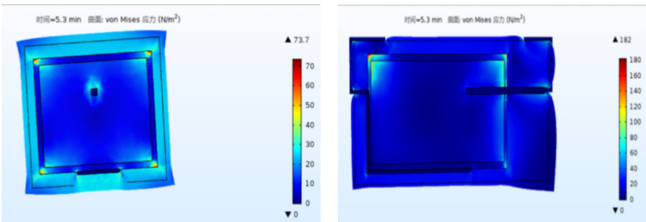

Figure 6. Cross-sectional stress distribution diagram

From the first cross-section, the model's molded cake layer is clearly deformed, although it is not the most stressed, but the influence of temperature and material properties makes it the most deformed. There is a high stress in and around the part of the leadframe in contact with the tantalum wire, as well as a high stress around the contact between the leadframe and the molded cake material, and a high concentration of stress at the edges of the graphite silver paste layer and the tantalum core.From the second cross section, the outermost layer has the largest deformation, which is the molded cake material layer, and the largest stress at the right angle, which is caused by the stress concentration at the right angle, and the second largest around the right angle, which is also caused by the stress concentration at the right angle. The simulation results of the above two figures show that the deformation of the molded cake layer is serious, which is the most prone to deformation and rupture failure, so the tantalum capacitor model is considered to be optimized.

5. Conclusion

At the maximum temperature, the model deforms, with different degrees of deformation at each location. Due to the influence of temperature gradient change, temperature stress is generated, and the stress is higher at the contact between the tantalum wire and lead frame, the outer molded cake is deformed, the deformation is the highest at the contact between the lead frame and the molded cakes, and the stress is also higher due to the highest temperature of the lead frame and the outer layer of the molded cakes, and the stress in the right angle of the graphite silver paste layer and the edge of the tantalum core is also higher due to the stress concentration. Due to the different materials of lead frame and molded cake material, they are more affected by temperature stresses because the temperature gradient of both changes more in the subsequent temperature change.

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