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MODELING LOCAL INDUCTION HEATING OF SOLDER BALLS FOR FLIP-CHIP MOUNTING IN COMSOL MULTIPHYSICS

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Annotation: *For Flip-chip mounting, it is necessary to form contact bumps for 2.5D and 3D electronic modules. Exposure to the energy of high-frequency (HF) electromagnetic oscillations allows for high-performance non-contact heating in various processes for soldering electronic components. This paper presents studies of temperature fields during induction heating of solder balls with several types of copper concentrators made in the COMSOL MULTIPHYSICS software. The dependences of frequency of inductor on heating time and geometric shapes of copper concentrators on quality of the soldered sample were revealed.*

Key words: *Flip-Chip, 3D modules, COMSOL Multiphysics, induction heating, solder bumps.*

INTRODUCTION

Flip-Chip technology, also known as C4 (Controlled Collapse Chip Connection) is a method of interconnecting semiconductor devices such as integrated circuits and microelectromechanical systems (MEMS) [1].

Magnetic core induction systems have a wide range of applications. They can be used both for manual soldering of wires to the board, and for automated mounting of BGA components. Soldering such elements by traditional methods is carried out by heating the body itself and simultaneously heating the printed circuit board, which can adversely affect the performance of the microcircuit, cause warping of the printed circuit board and reduce the service life of the device. Induction soldering allows to heat only the solder balls of BGA components. This make the soldering process to be carried out without overheating the printed circuit board and the component case [2].

In science and technology, one constantly has to face the problem of physical systems that have a complex geometric configuration and an irregular physical structure. Computers make it possible to perform such modeling - using approximate numerical methods. The finite element method (FEM) is one of them, and in recent decades it has taken a leading position and has been widely used.

RESEARCH OF THERMAL FIELDS OF SOLDER BALLS

The simulation was carried out in the COMSOL Multiphysics package [3]. Solder balls with diameter of 0.76 mm were fixed on the contact copper pads of the board made of fiberglass FR4 with a thickness of 1.5 mm. The magnetic circuit is made of ferrite, inside which is placed a printed circuit board with solder balls and a concentrator applied to it. The simulation was carried out in the frequency range from 200 kHz to 900 kHz. The model of induction heating with an open magnetic circuit and a printed circuit board with solder balls on copper pads are shown in Figure 1. The geometric parameters of the components are given in Table 1.

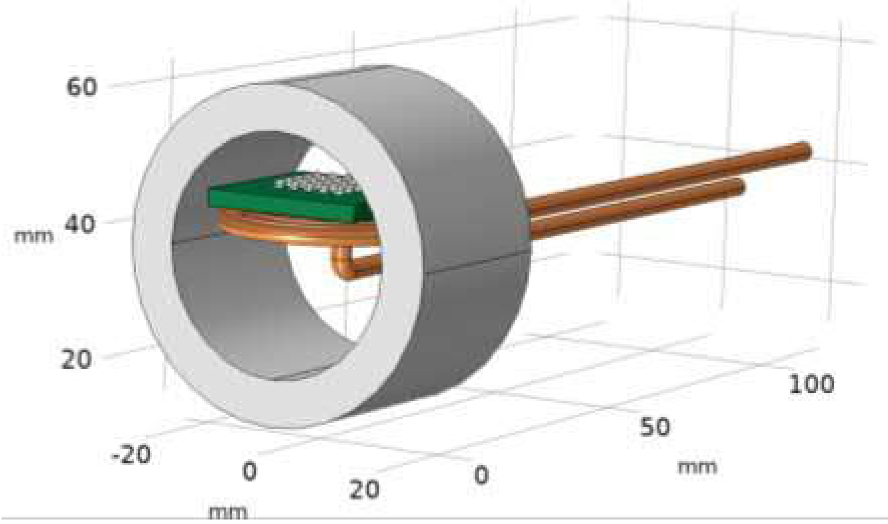


Figure 1 – Model of induction heating with a closed magnetic circuit and a printed circuit board with solder balls on copper contact pads

Table 1. – Geometric parameters of the components

The geometric dimensions of the board	25x25x2.54 mm
The geometric dimensions of concentrators	20x20x0.5 mm
Inductor tube diameter	3 mm
Solder ball size	0.760 mm
The geometric dimensions of contact pads	0.55 mm

Each component uses materials from the standard COMSOL Multiphysics material library. The materials used for the coil are copper, ferrite core – ferrite with magnetic permeability 2500, fiberglass FR – 4 for the printed circuit board, lead-free solder Sn–3.5Ag–0.5Cu with a diameter of 0.760 mm (Figure 2). The Induction Heating module includes Magnetic Fields and Heat Transfer in Solids, as well as the Electromagnetic Heating multiphysics module that connects them together.

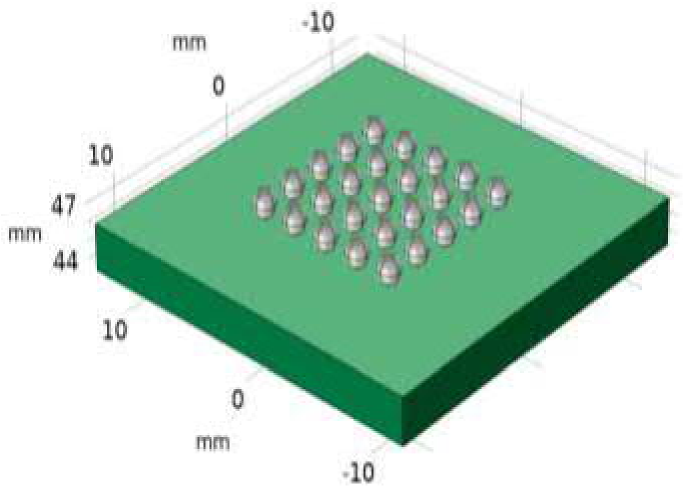
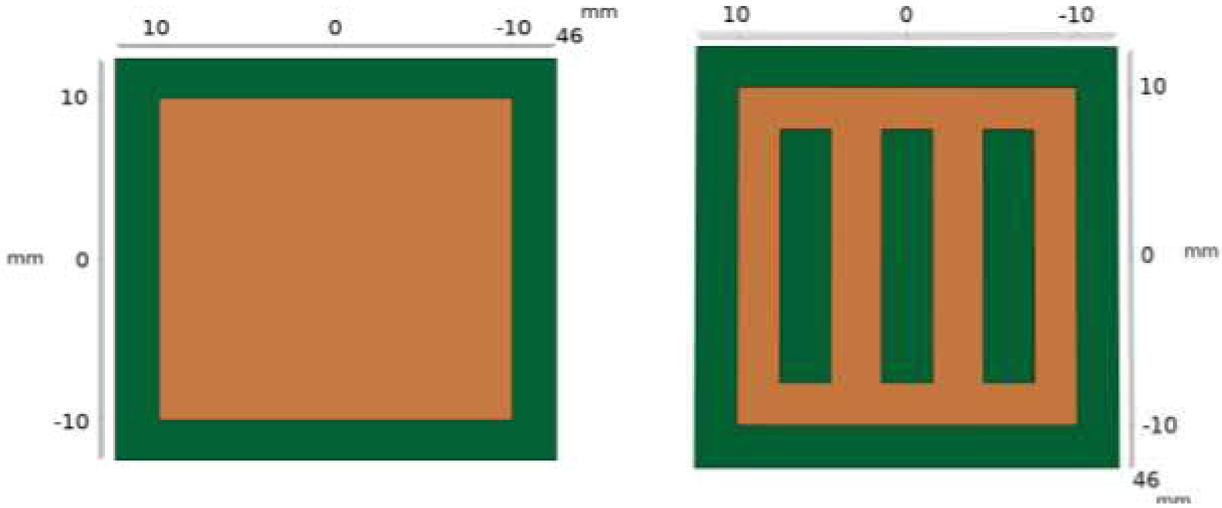


Figure 2 – PCB with an array of solder balls

To increase the heating efficiency, it is proposed to use concentrators of several patterns. As concentrator patterns, solid and in the form of strips of copper foil were chosen, forming a closed electrical circuit (Figure 3).



a *b*

Figure 3 – Solid copper concentrator (a) and with gaps (b)

Mesh setup, COMSOL Multiphysics allows you to perform both automatically and manually. In this task, the automatic mode is not suitable, since the mesh is not optimal due to the small size of the solder balls. Therefore, for solder balls, we use the Extra Fine mesh size, and for the remaining elements, a larger mesh size in order to optimize the model and thereby drastically reduce model calculation time.

As a result of the simulation, the thermal fields of the desired model were obtained (Figure 4). The power on the inductor at a frequency of 900 kHz was 29.97 W. The average temperature of the solder balls was 212°C, while the average temperature of the copper concentrator was 276°C.

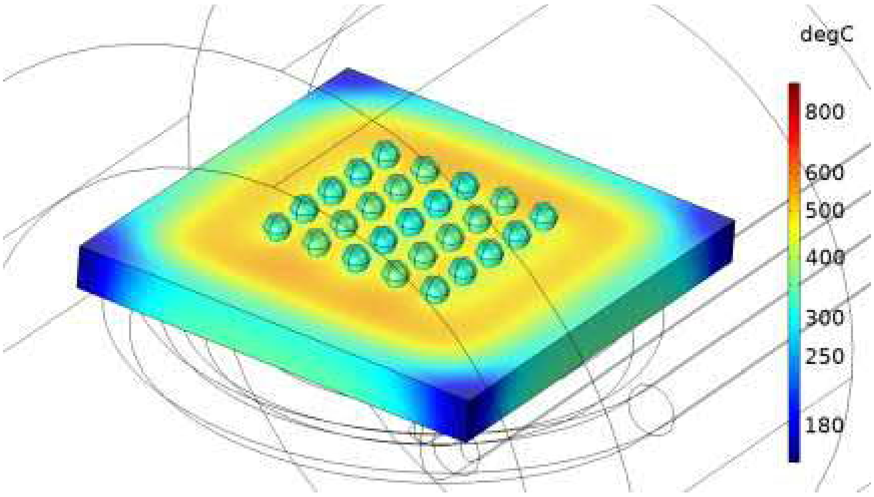


Figure 4 – Temperature fields of printed circuit board with solder balls

The temperature fields of the printed circuit board with solder balls are shown in Figure 5

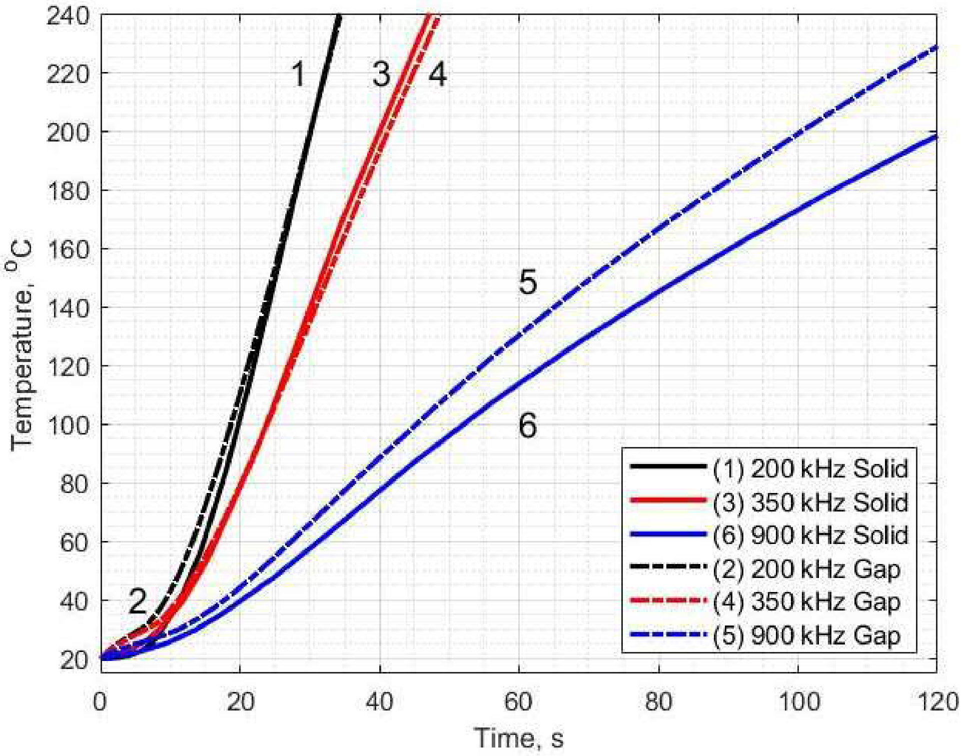


Figure 5 –Temperature fields of printed circuit board with solder balls

As can be seen from the graphs, the influence of geometry of concentrator on heating of solder balls occurs only at frequencies above 400 kHz. At low frequencies, the heating is too high over 300°C, which can lead to burning of printed circuit board. The calculation of the penetration depth was carried out according to formula 1. The calculation data are presented in Table 2.

$$\delta = \sqrt{\frac{\rho}{\mu \cdot f}}, \qquad (1)$$

where ρ – resistivity; μ–relative magnetic permeability; *f* – frequency.

Table 2 – Depth of penetration at different frequencies

Frequency, kHz	Penetration depth, mm
200	$7.54 \cdot 10^{-4}$
350	$5.7 \cdot 10^{-4}$
900	$3.55 \cdot 10^{-4}$

With increase in frequency from 200 to 900 kHz, the penetration depth decreases from $7.54 \cdot 10^{-4}$ to $3.55 \cdot 10^{-4}$ mm, which ensures the reproducibility of height of the solder balls but at the same time increases heating time by reducing heating rate of the eddy current concentrator.

Conclusion

As a result of the simulation, the parameters of induction heating were obtained and optimized in the COMSOL Multiphysics software package. The use of copper hubs and a ferrite core increased the heating efficiency. In this case, the geometric shape of the concentrator affects the heating of the solder balls only at frequencies above 400 kHz. At the same time, at frequencies below 200 kHz, copper plastic heats up to too high temperatures (more than 300 °C), which can lead to burning of the printed circuit board. The heating power about 30 W proves more effectiveness of induction systems.

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