THERMAL PROCESSES MODELING DURING SOLDERING OF BGA COMPONENTS TO PCB

Angel Valentinov Valchev, Petko Hristov Mashkov, Tamara Grigorievna Pencheva, Berkant Sejdaly Gyoch

Physics Department, University of Rousse, 7017 8 Studentska str., Bulgaria, phone: +359 82 888 218

tgp@ru.acad.bg; avalchev@ru.acad.bg; pmashkov@ru.acad.bg

The investigation deals with modeling of soldering processes in new equipment for surface mounting technologies (SMT) with new type of low inert heaters for the middle infrared spectral region. The results obtained may be used for optimization of soldering equipment control during soldering processes. It is very important, especially for high integration packages, such as BGAs. The main parameters of heat transfer processes are analyzed. The heat transfer modeling method for the soldering processes of BGAs to printed circuit boards using low inert infrared heaters is presented. It is realized with Comsol Multiphysics 3.3. Influence of main parameters of heaters' operation and hot gas circulation on temperature distribution in the camera for the whole BGA is investigated.

Keywords: Modeling of soldering processes, BGA's soldering

1. INTRODUCTION

Nowadays in electronic industry enhancement of electronic elements' density upon Printed Circuit Board (PCB), utilization of PCB with large area and implementation of lead free solder pastes introduces new demands to soldering equipment [1 - 5]. High integration component packages such as Ball Grid Array (BGA) demand precise control of the parameters of the soldering regime. At the same time these highly integrated circuits are relatively expensive and failures are absolutely undesirable. Up to this investigation it was considered that For soldering of BGA components conventional convection type soldering ovens are preferred to the clear infrared (IR) type radiation ovens because of possibility to control precisely temperature regimes during soldering process. It is considered that infrared ovens are unsuitable for these types of high integrated chips [3].

The results of experimental investigations of applicability of new kind soldering equipment for soldering of Surface-Mounted Devices (SMDs) to PCB using IR radiation are presented in [5]. The equipment is based on low inert infrared heaters for the middle infrared spectral region. Infrared heating in the heating camera is combined with forced air convection [2, 3 and 5]. Due to the low inertia of the heaters desirable soldering cycles may be realized precisely. By electronic control of the operation of the heaters fast changes in their surface temperature may be achieved. The whole soldering cycle may be realized at the same place – without conveyor. The equipment allows in situ control of the spectral characteristics of radiation emitted by the heaters and the part of energy transported by the hot gas circulating in the heating camera. Previous investigations [5] show that this type of equipment is very suitable for realization of individual temperature cycles for every PCB in dependence of its size, electronic component's density and others.

In this paper the main results of thermal processes modeling for new type IR soldering equipment for large area BGA package integrated circuits according to firm's demands are presented. To estimate influence of different parameters of soldering camera operation modeling of thermal processes in dependence of heater's operation mode, air flow velocity, etc. during soldering is performed. The modeling of soldering process is realized using the program product COMSOL Multiphysics version 3.3. The best estimated camera's operation parameters are chosen in accordance with [3, 5, 9, 10].

2. DESCRIPTION OF THE OBJECT FOR MODELLING

Previous investigations [10], connected with thermal process modeling during soldering of SMD to PCB show that best results may be achieved when heater's surface temperature and air temperature variations are used as inlet parameters. The soldering processes are realized by control of operation of the heaters in dependence of temperature in one point on the PCB (in a solder joint).

In Figure 1 a typical soldering cycle for BGAs chips is shown [3, 9]. Experiments are carried out using soldering equipment, designed and produced in our laboratory [5]. Soldering camera is without conveyer (Figure 2) - PCB doesn't move and the whole soldering cycle is realized at the same place. Temperature variations in different points of the PCB may be measured and controlled in situ during the soldering.

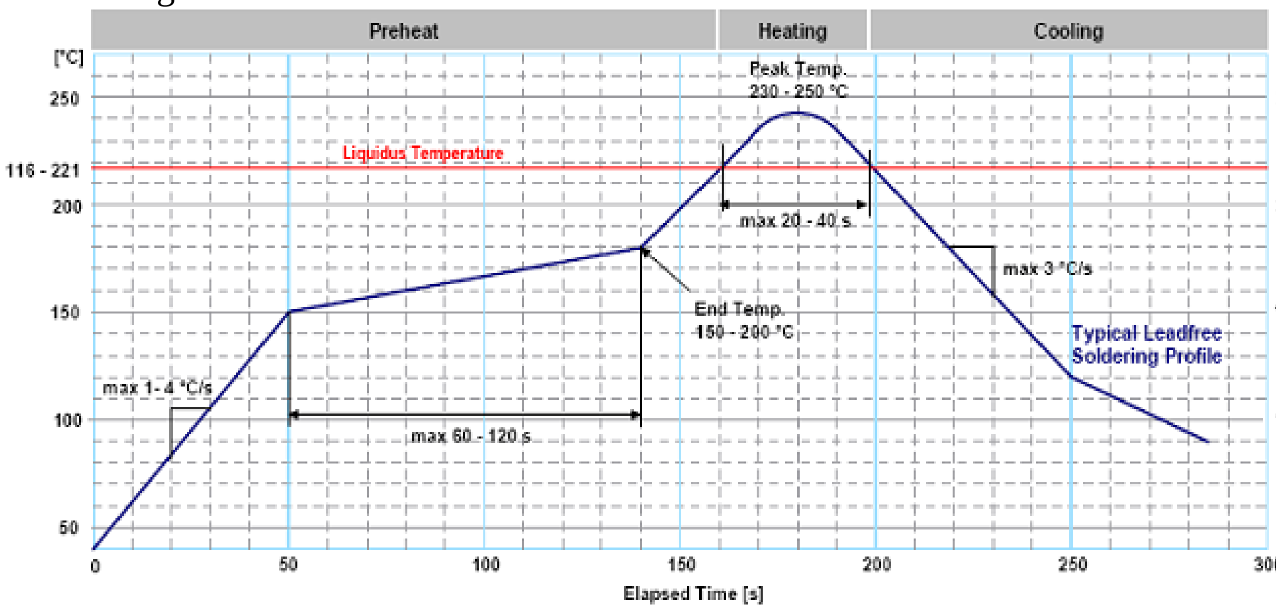

Figure 1: Typical soldering cycle for BGA chip (lead free soldering).

The heaters are made from thin metal sheets. Special coating upon the surface of the heaters ensures emissivity about 0.9. They are warmed up directly by electric current and their temperature can be increased with the rate more than 15^{o}C/s. Radiation power density emitted from these heaters is uniform upon the whole processing area. In combination with hot air flow these heaters ensure minimal temperature differences on PCB's surface. The hot air (or inert gas) circulating in the heat camera passes through the heaters and is warmed up. In this way there is no need of additional gas heating.

Temperature-time dependencies during typical soldering cycle (see Figure 1), realized in upper described equipment is shown in Figure 3. Temperature variations during soldering cycle for heaters' surface temperature and air temperature are used for modeling thermal processes on surface and solder joints of the BGA chip. Experiments are carried out with the chips with size (35/35 mm), because in this case maximal thermal differences between these points (Points 1, 2, 3 - Figures 4, 5) during soldering cycles can be expected.

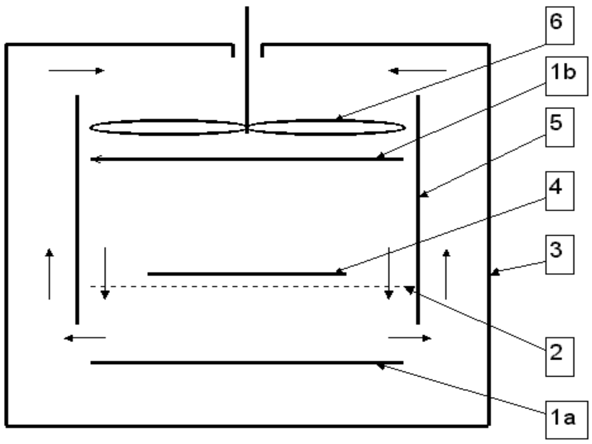

Figure 2. Cross-section view of an experimental soldering machine: 1a and 1b – heaters; 2 – grid, 3 – heating chamber; 4 – PCB; 5 – reflecting screens; 6 – fan.

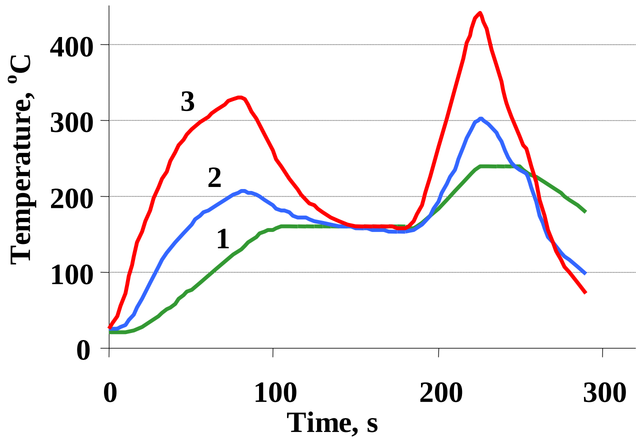

Figure 3. Temperature-time dependencies during soldering processes: 1 – of the solder joint on PCB; 2 – of circulating gas; 3 – on the heater's surface (maximal temperature of the solder joint is about 240°C).

3. Modelling Approach

For realization of the thermal processes modeling during soldering of BGA components to PCB the main equations, material properties and boundary conditions are specified.

The convective heat transfer modeling is carried out by combining the general dependences for heat transfer and fluid-flow field. The model is based on work published by A. Ortega [6]. The model of the heat transfer for a circuit-board assembly is realized using Comsol Multiphysics version 3.3 through modules: General Heat Transfer and Non-Isothermal Flow. Therefore the model is performed using the both modes at the same time and there are two cases for specifying subdomain settings and boundary conditions.

The **Non-Isothermal Flow** case is performed using the Navier-Stokes equations. In this case modeling includes the air velocity $\boldsymbol{u}$, and air pressure $\boldsymbol{p}$ as [6]:

$$\rho u \nabla u = \nabla \left[-pI + \eta(\nabla u + (\nabla u)^T) - (\frac{2\eta}{3} - \kappa)(\nabla u) I \right] + (\rho - \rho_0) g; \quad \nabla(\rho u) = 0. \qquad (1)$$

Due to heating of the air, there is a difference between the local air density $\boldsymbol{\rho}$, and inlet air density $\boldsymbol{\rho_0}$. The air viscosity $\boldsymbol{\eta}$, is also temperature dependent parameter, $\boldsymbol{\kappa}$ is the dilatational viscosity . In our case it is set to zero. The air flow setting up is made by defining the convective flux direction and velocity.

The **General Heat Transfer** case is described by equation related to general energy balance [6]:

$$\nabla(-k\nabla T) = Q - \rho C_p u \nabla T \text{,} \tag{2}$$

where $\boldsymbol{k}$ is thermal conductivity; $\boldsymbol{C_P}$ is the specific heat capacity; and $\boldsymbol{Q}$ is the heating power per unit volume, T?.

The material properties are determined and shown in Table 1:

Table 1: Material properties

Material property	Heating Steel	PCB [7]
Density $\boldsymbol{\rho}$ (kg/m^3)	7850	1900
Thermal conductivity $\boldsymbol{k}$ (W/mK)	44.5	0.3
Heat capacity $\boldsymbol{C_P}$(J/kgK)	475	1369

The air parameters in use are temperature dependent [8]:

$$\rho = \frac{(p_0 M_W)}{(RT)} \text{,} \tag{3}$$

where p_0=101.3kPa, M_W=0.0288 (kg/mol) is molecular mass, R = 8.314 (J/molK) is gas constant, Cp=1100 (J/kgK) is heat capacity[8]:

$$\log k = (-3.723 + 0.865\log(T)) \text{,} \tag{4}$$

$$\eta = 6.0\times10^{-6} + 4.0\times10^{-8}T \text{.} \tag{5}$$

The direction of the air flow is normal to BGA chip surface. In the case of natural convection the air flow velocity is zero. In the case of forced convection the air flow velocity may be expressed [8]:

$$u_y = s(1-s)4u_{\max} \text{ ,} \tag{6}$$

where $\boldsymbol{s}$ represents the normalized inlet flow width; this parameter in Comsol Multiphysics varies between 0 and 1 along each boundary segment. Initial temperature at inlet boundary is 300 K (room temperature). For the case of forced convection $u_y \neq 0$.

4. MODELING RESULTS

As it is known [2, 3, 5] convection types ovens are recommended for reflow soldering of high integrated circuits such as BGAs. To estimate the influence of forced air flow in this new soldering equipment thermal processes for two modes of operation of the heating camera are modeled.

- First mode of operation – without forced air convection. Heating is realized only by infrared radiation from heaters.
- Second mode of operation – with forced air convection in the heating camera. Air flow passes through the heaters and there is no need of additional gas heating.

First mode operation modeling results connected with time-temperature dependences in a few points of the chip during soldering cycle are shown in Figure 4.

As it can be seen from the Figures 4-7 when the heating process is performed by infrared radiation only and it is not supplemented with forced air convection, differences between temperatures on the surface in the center and at the end of the chip are too big (up to 30 degrees).

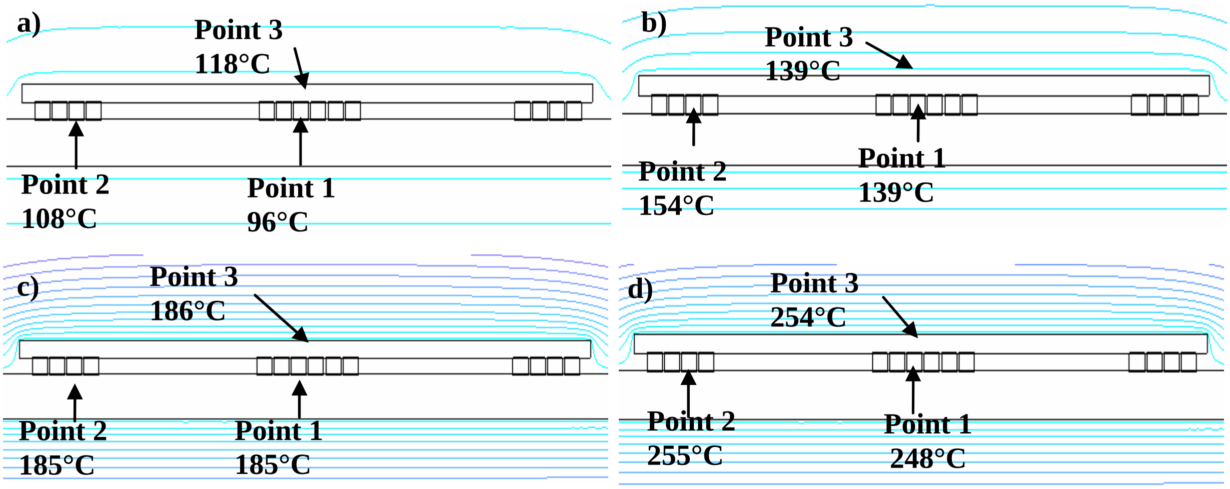

Figure 4. First mode of operation of the soldering camera – without forced air convection: temperature distribution at: **a)** 40 seconds; 60 seconds, **b);** 150 seconds, **c);** 250 seconds, **d)**, from the beginning of the soldering cycle. Where: 1- temperature on the surface of the chip, 2 – temperature in a solder joint in the center of the chip; 3 – temperature in a solder joint at the end of the chip.

Temperatures become almost equal at the end of the preheating, but during reflow process temperature differences increase again, Figure 4d. These big temperatures' gradients may cause thermal deformations and warp of the chip and PCB [3, 5] which causes failure of the solder joints. As it was mentioned above this is inadmissible.

Modeling results for second mode of operation of the heating camera (with forced air convection) are presented in Figure5.

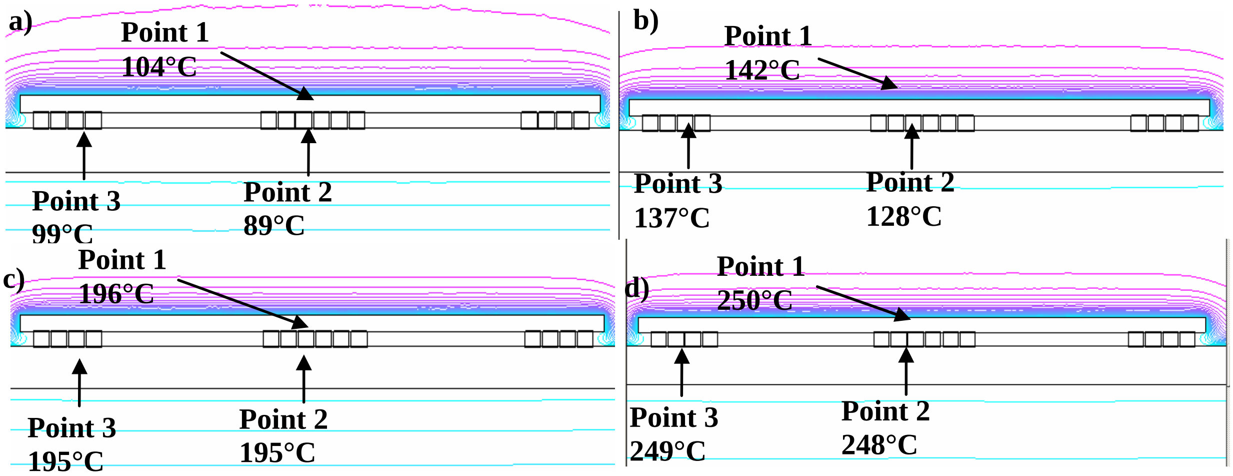

Figure 5. Second mode of operation of the soldering camera – without forced air convection: temperature distribution at: 40 seconds, **a)**; 60 seconds, **b);** 150 seconds, **c)**; 250 seconds, **d)**, from the beginning of the soldering cycle. Where: 1- temperature on the surface of the chip, 2 – temperature in a solder joint in the center of the chip; 3 – temperature in a solder joint at the end of the chip.

The best results are estimated at air flow velocity of 2 m/s for camera's narrow areas. In the case of forced convection the measured temperature differences between Point 1, Point 2 and Point 3 decreases vastly. As it could be seen it is between 1 and 2 degrees at Figures 5c, d.

It means that the second mode of soldering is safer and with higher quality than the first mode. Therefore the case of forced convection is more suitable than the case without air flow as concerns to the soldering of BGA components to PCB.

5. CONCLUSIONS

Thermal processes modeling during soldering of BGA components to PCB with the program product Comsol Multiphysics version 3.3 is suitable to determine the temperature in IR camera at any point. It is good advantage because the BGA joint temperature measurement at center of the chip is not easy task. The best results are estimated for the air velocities of large camera area 0.2 m/s and for the narrow camera area 2 m/s. There is slight estimated temperature difference between PCB and BGA chip. It could be considered that the estimated model results are in conformity with measured experimental results. Therefore it may be summarized that the method of using of IR cameras ensures safe and high quality soldering of BGA components to PCB.

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