REFLOW SOLDERING OF BGA COMPONENTS TO PCB BY HEATERS' OPERATION CONTROL

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The investigation deals with soldering of BGA (ball grid array) packaged components to PCB in a new kind of soldering equipment. Soldering equipment is based on low inert heaters for the middle IR spectral region. Due to low inertia of the heaters temperature changes in the soldering camera may be controlled precisely and the soldering cycle may be realized at the same place without conveyor belt. Experiments show that by proper operation control of this kind of soldering equipment uniform temperature distribution on the whole ball grid array may be achieved and desirable temperature profiles can be realized precisely.

Keywords: Infrared heating, infrared soldering, soldering equipment

1. INTRODUCTION

The high integration trend of functions introduced component packages such as BGAs, but the soldering of these components demands precise control of the parameters of the soldering regime. In the case of BGAs packages reflow soldering failures can occur easily [1] such as open joints, due to the warpage of the PCB and of the BGA package. At the same time these highly integrated circuits are relatively expensive and failures are absolutely non desirable.

For soldering of BGAs components convection type soldering ovens are recommended over the infrared type radiation ovens [2 - 6].

In this paper the results concerning the investigations on the possibility of application of new type of soldering equipment for soldering of BGAs packages are presented. Soldering equipment is based on low inert heaters [7 - 9] radiating in the middle IR spectral region. In soldering machine IR heating is supplemented with forced convection. By electronic control of the heaters' mode of operation fast changes in their surface temperature may be achieved. It 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 experiments [7] showed that by electronic control of the heaters' temperature soldering cycles for various PCBs can be realized precisely.

2. PROBLEM STATEMENT

Preheat Phase. <u>Temperature rise rate</u>: 1 - 4°C/s. If the temperature rise is too rapid in the preheat phase it may cause excessive slumping. <u>Time</u>: 60 – 120 seconds If the preheat is insufficient, rather large solder balls tend to be generated. <u>End Temperature</u>: 150 - 200°C. If the temperature is too low, non-melting tends to be caused in areas containing large heat capacity.

Heating/ Reflow Phase. The temperature rises above the liquidus temperature of 216 - 221°C. Avoid a sudden rise in temperature as the slump of the paste could become worse. Limit time above 220°C liquidus temperature: 20 - 40s. Peak reflow temperature: 230 - 250°C.

Cooling Phase. A controlled cooling avoids negative metallurgical effects (solder becomes more brittle) of the solder and possible mechanical tensions in the products. Temperature fall rate: max 3°C/s. Exceeding the maximum soldering temperature in the recommended soldering profile may permanently damage the module.

Additional demands from company, which ordered development of soldering process for some BGAs chips with different size in our soldering equipment, are (Fig. 1):

Solder paste - Lead free (Solder paste Sn/Ag/Cu). **Solder Reflow.** The following is the recommended solder reflow profile:

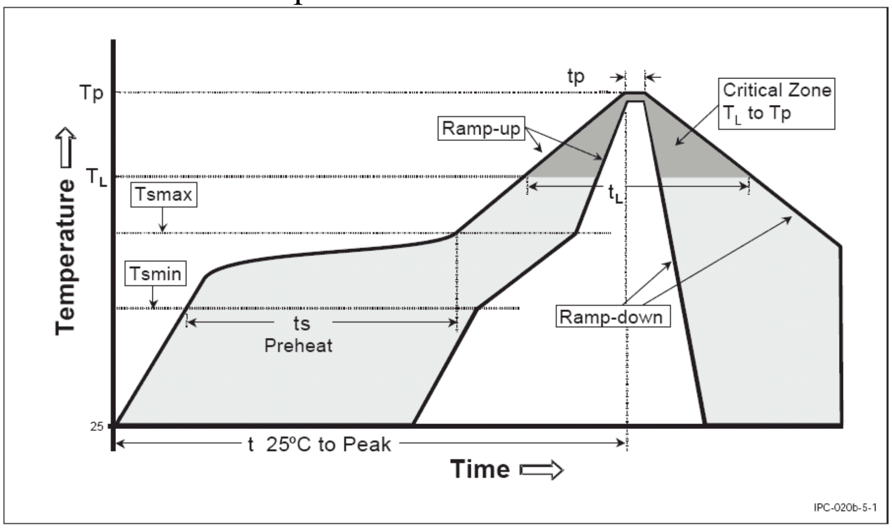

Fig. 1. Demands for soldering cycles parameters.

Profile Feature - Pb – Free Assembly; Average ramp – up rate (T_L to T_P) - 3^{o}C/s max; Preheat: - Temperature Min (Tsmin) – 150^{o}C; Temperature Max (Tsmax) – 200^{o}C; Time (min to max)(ts) – 60 ÷ 180 s; Tsmax to T_L: Ramp-up Rate – 3^{o}C/s max; Time maintained above: Temperature (T_L) – 217^{o}C; Time (t_L) – 60 ÷ 150 s; Peak Temperature(T_P): 245 +0/-5^{o}C; Time within 5^{o}C of actual Peak – 10 ÷ 30 s; Temperature (t_P) – Ramp-down Rate ÷ 6^{o}C/s max; Time 25^{o}C to Peak Temperature – 8 minutes max.

NOTE: All temperatures refer to topside of the package, measured on the package body surface.

NOTE: module can accept only one reflow process

3. EXPERIMENTAL

Experiments are carried out using soldering equipment, designed and produced in our laboratory [7 - 9]. Soldering camera is without conveyer (Fig. 2) - PCB doesn't move and the whole soldering cycle is realized at the same place and temperatures variations in different points of the PCB may be measured and controlled in situ during the soldering. It is due to application of low inert dark heaters for the middle

& far IR spectral regions, developed on our laboratory. They are made from thin metal sheets. Special coating upon the surface of the heaters ensures emissivity about 0.9. The heaters are warmed up directly by electric current and the heater's temperature can be increased with the rate more than 15°C/s at a proper current through the heater. 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.

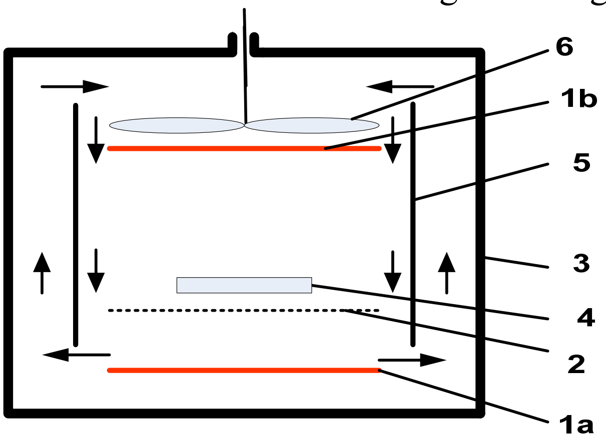

Fig. 2. Cross-section view of experimental soldering machine without conveyor: 1a and 1b – heaters; 2 – metal grid for PCBs mounting; 3 – heating chamber; 4 – PCB; 5 – reflecting screens; 6 – fan.

The dimensions of the metal grid (Fig. 2) are 300/350 mm. The maximal power of the heaters is about 9 KW. The velocity of the air, passing trough the heating camera may be controlled (from 0 to 5 m/s in the narrow part of the camera). The air flow passes trough the special metal grid over the upper heater 1b, which ensures turbulence of the flow and uniform temperature distribution on the whole area of the metal grid 2 (Fig. 2).

The operation of the heaters may be controlled by different manners [7] – for example, by measuring the temperature in a point on the PCB and the surface temperature of the heaters and control the operation of the heaters. During these experiments we established more suitable mode of control of heaters' operation – by control the mark-to-space ratio of the operation of the heaters. The temperature in one, properly determined point on the PCB is measured. When it reached a definite value, the desirable (previously programmed) mark-to-space ratio of the operation of the heaters is set. The power of the heaters may be expressed (1):

$$P_{HS} = \frac{U^2.k}{R_{oHS}\left[1+6{,}4.10^{-3}\left(t_{HS}-20\right)\right]}., \qquad (1)$$

where U is supply voltage, R_{oHS} is ohmic resistance of the heater at 20^oC, t_{HS} is the heaters temperature in ^oC, k is mark-to-space ratio of the operation of the heaters. Correlations between temperatures on PCB and t_{HS} is determined previously [8, 9]. Adjusting proper value of k from 0 to 1 it is possible to realize different temperature regimes. This approach ensures repeatability during soldering cycles and precise realization of desirable temperatures profiles.

In Fig. 3 is shown a cross – section view of BGA chip. Thermocouples are mounted in point 1 – in a solder joint between chip and PCB in the centre of BGA; point 2 – in a solder joint at the end of the chip; point 3 – on the surface of the chip. The temperature is measured by thermocouples type K and standard thermometers TM- 902.

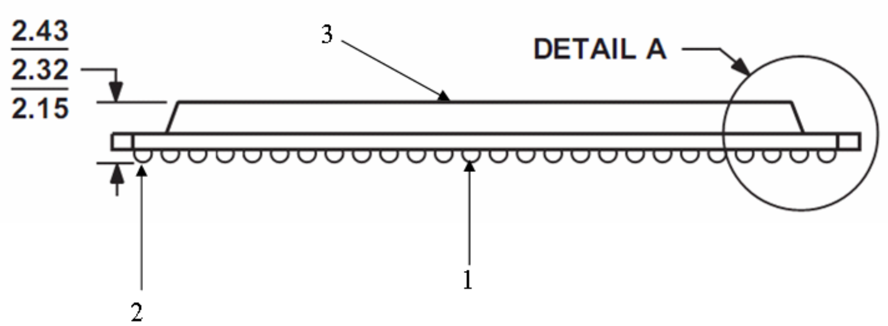

Fig. 3. Cross section of BGA chip; 1, 2 and 3 – places, where the thermocouples are mounted.

Experiments are carried out with the maximal size chips (35/35 mm), ordered by the company, because in this case maximal thermal differences between these points (Fig. 3) during soldering cycles can be expected.

4. EXPERIMENTAL

Soldering cycles at different modes of operation of the heating camera are realized. Modeling of the soldering in this type equipment (by COMSOL Multiphysics version 3.3) shows, that the influence of the hot air flow on the thermal processes is significant. To investigate this influence two series of experiments are made. Series A – with forced convection of the air in the heating camera (3 m/s air velocity in the narrow part of the camera, Fig. 2) and series B – without forced convection of the air.

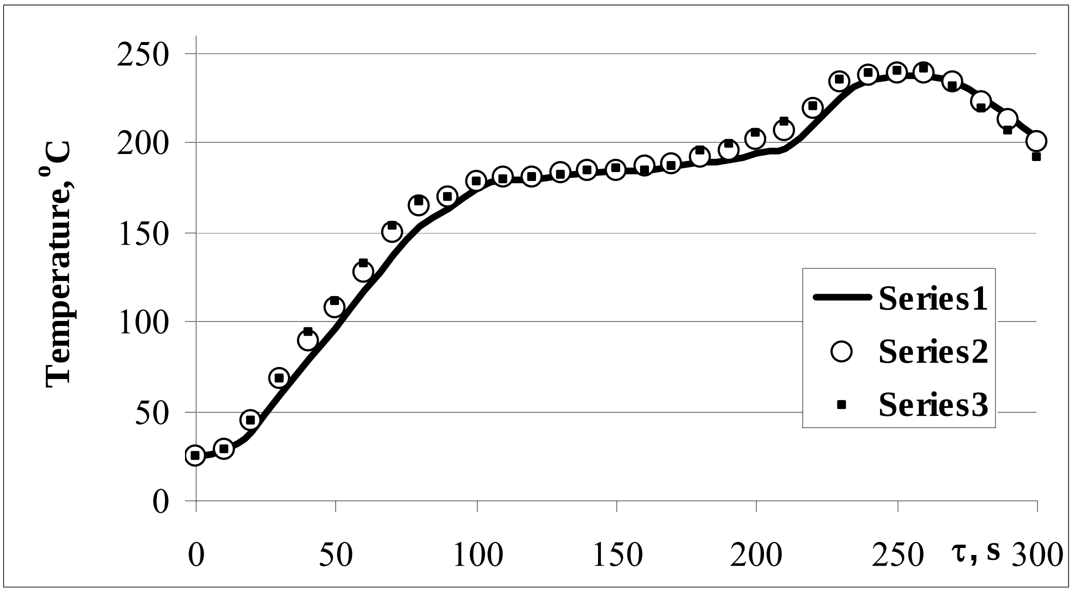

Fig. 4. **Regime A (**with forced air convection**).** Temperature – time dependence during soldering cycle; series 1 –at the centre of the chip (see Fig. 3); series 2 - at the end of the chip; series 3 – on the surface of the chip.

In Fig. 4 and 5 results of temperatures changes in points 1, 2 and 3 (Fig. 3) during soldering cycles at regimes A and B are shown.

As it can be seen from the figures, necessary temperature cycles for soldering of these BGA chips, recommended from the company (see Fig. 1), can be realized successfully in this type soldering equipment. Comparison between results, obtained at different modes of operation of the heating camera, shows that forced convection of the gas in the camera is absolutely necessary.

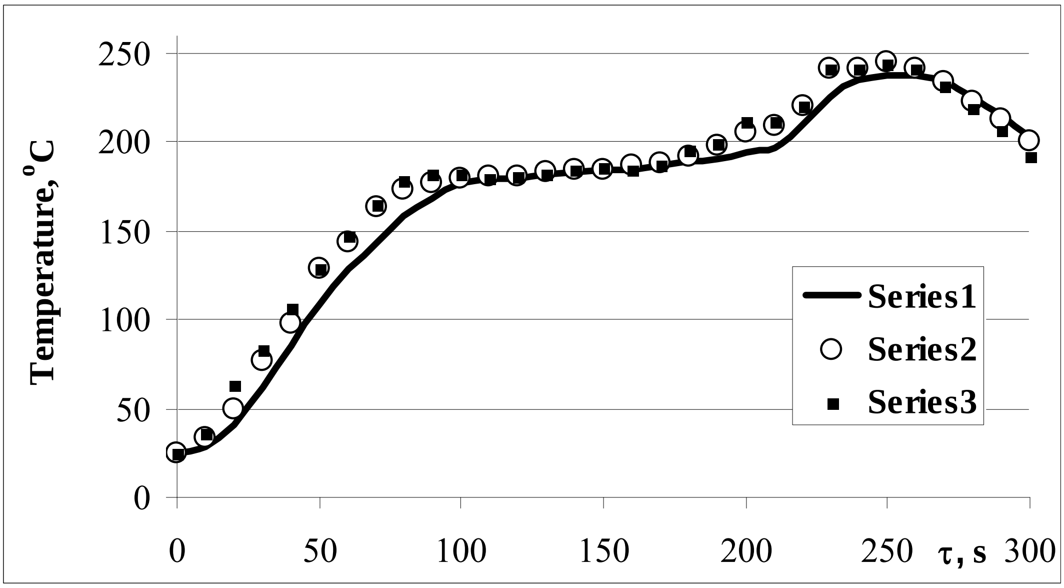

Fig. 5. **Regime B (**without forced air convection**).** Temperature – time dependence during soldering cycle; series 1 –at the centre of the chip (see Fig. 3); series 2 - at the end of the chip; series 3 – on the surface of the chip.

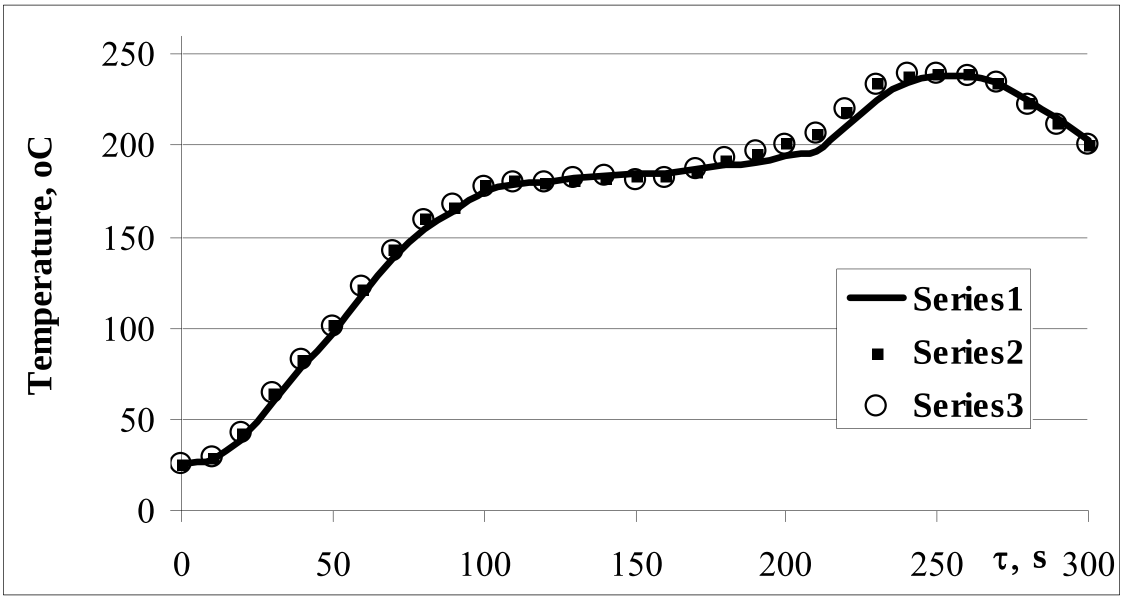

Fig. 6. **Regime C (**with forced air convection and screen over the PCB**).** Temperature – time dependence during soldering cycle; series 1 –at the centre of the chip (see Fig. 3); series 2 – at the end of the chip; series 3 – on the surface of the chip.

When infrared heating is combined with forced convection temperature differences between points 1, 2 and 3 don't exceed 6 – 7 degrees during preheating and at the beginning of the reflow process. If the heating is realized only by IR radiation, temperature differences between surface temperature and the temperature at the centre of the chip exceed 15 degrees, which is inadmissible.

As a development of the technological process, a modification of the heating camera is made. Aluminum screen (200/200mm) between upper heater 1b (Fig. 2) and the PCB is placed. The PCB is in the shadow of the screen from the radiation of the upper heater 1b. In the same time the bottom side of the PCB is irradiated and uniformly heated from the lower heater 1a (Fig. 2). The results of time – temperature dependences (Regime C) for points 1, 2 and 3 (Fig. 3) during soldering are shown in Fig. 6.

As it can be seen from Fig. 6, obtained results are the best in comparison to those at other operating regimes of the heating camera. Differences between temperatures at the center, at the end and at the surface of the BGA chip don't exceed 3 – 4 degrees during the whole soldering cycle. Parameters of the soldering cycles (temperatures, preheating time, ramp- up and ramp – down rate, etc.) may be chosen and controlled precisely by adjusting mark-to-space ratio of the operation of the heaters.

5. Conclusions

Investigations for applicability of new type soldering equipment, based on low inert dark IR heaters for reflow soldering of BGA components are made. Experiments showed that this kind of equipment is proper for realization of BGAs soldering when IR heating is supplemented with forced convection in the heating camera. Best results are obtained when aluminum screen is placed over the surface of the chips and the bottom side of the PCB is heated from IR radiation. Soldering cycles are realized by control of the mark-to-space ratio of the operation of the heaters.

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6. References

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