EQUIPMENT AND METHOD FOR LEAD FREE SOLDERING OF SMDS

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The investigation deals with new kind of infrared equipment for versatile utilizations in electronic industry. It is suitable for surface mounted devices (SMDs) soldering to printed circuit boards (PCBs) using conventional and lead free solder pastes, different kinds of annealing and others. By application of low inert radiation heaters for the middle IR region and microprocessor control of their operation, energy saving equipment is made. It allows realizing precise in situ control of the temperature on the PCB during the soldering processes; possibility of individual temperature profile for every printed board during the soldering process in dependence of its size, electronic components density and others. By electronic control of heating regimes the heaters' surface temperature may vary very quickly in a wide range from 430K to 1300K. This allows control of radiation spectra of energy emitted to PCB and electronic components according to their spectral characteristics and achievement of optimal heating regime for every PCB.

Keywords: Infrared heating, infrared soldering, soldering equipment

1. INTRODUCTION

From the standpoint of suppressing environmental pollution, it is known that the conventional solders containing lead for use in soldering machines must be replaced by lead-free solders. Some of electronic components have the endurable temperatures near the melting points of the lead-free solders. It is however difficult to realize uniform temperature field over the whole surface of the PCB so that the heating temperature should be held within the range of 230 to 240^{o}C. Such a difficulty has accompanied the problem that some of electronic parts may be thermally damaged. With the increasing versatility of electronic components to be mounted on PCB, it is desirable to heat circuit boards according to the optimal heating profile of each board. In accordance with spectral characteristics of PCB and electronic components on it an optimal configuration of heaters should be chosen. Main problems concerning soldering techniques, in which the spectral characteristics of the IR radiation during soldering processes are chosen depending on the spectral properties of the heating objects, are discussed in [1 - 9].

In this report the investigations on equipment for soldering processes with low inert heaters radiating in the middle IR region and method of control of their spectral characteristics are presented.

2. PROBLEM STATEMENT

Typical process of soldering of SMDs to PCBs includes the following main steps [6 - 8]: rising of PCB temperature with definite rate; keeping of the temperature about 160^{o}C during 60 – 90 s (necessary for chemical activation of the soldering paste); temperature rising up to the soldering temperature; keeping 5 – 10 s at this temperature – reflow process; cooling the PCB with definite rate. Main zones in the typical time – temperature dependence for the PCB are shown in Fig. 1. The temperatures may vary in dependence on the solder pastes types and the producer prescriptions. In every case it is desirable the temperature profile to be realized with precision better than 3 – 4^{o}C. It is a difficult technical problem because its solving depends on PCB's size and weight, electronic components density et al.

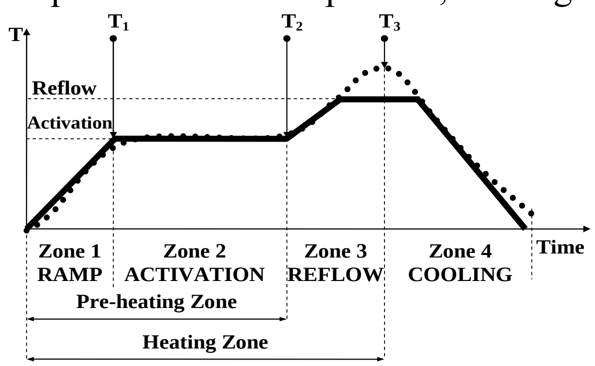


Fig. 1. Typical time – temperature dependence for PCB [6]: solid line – ideal reflow profile; dotted line – typical reflow profile.

Application of low inert IR heaters (Fig. 4 and Fig. 5) in equipment for IR soldering of SMDs to PCBs allows solution of the main problems in soldering techniques. The heaters 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^{o}C/s. Radiation power density emitted from the heaters is uniform upon the whole processing area. In combination with hot air flow the heaters ensure minimal temperature differences on PCB's surface. The hot air (or inert gas) circulating in the heating camera passes through the heaters and is warmed up. In this way additional gas heating is not necessary. The temperature of the circulating gas in the heating camera may also be controlled precisely with high velocity [10].

3. RESULTS

Two types of soldering machines are designed in our laboratory. The schemes of the experimental soldering machines with and without conveyor are shown in Fig. 2 and Fig. 3. Due to low inertia of the heaters they are suitable for realization of the whole temperature profile desirable for soldering processes in one chamber without conveyor. The choice of the soldering machine type depends on desirable productivity. This type of cameras can be ready for realization of desirable temperature profile for a few seconds after switching on. In both cases they may be turned off when they are out of use. It permits to save energy in comparison with conventional soldering machines. Due to their flexibility it is possible to realize different temperature profiles with very short time intervals between them.

Two methods for control of spectral characteristics of IR radiation emitted from the heaters during soldering processes are proposed. The first one concludes production of heaters with different width of the heater's belts, Fig. 4. In produced heaters the width of every third belt is reduced to 3 mm or 2.5 mm. As a result the spectral characteristics of the IR radiation in the heating camera are changed: emitted spectrum becomes wider with respect to spectrum of the heater with equal belts' width.

In the second method new design of the low inert IR heaters is proposed, Fig. 5.

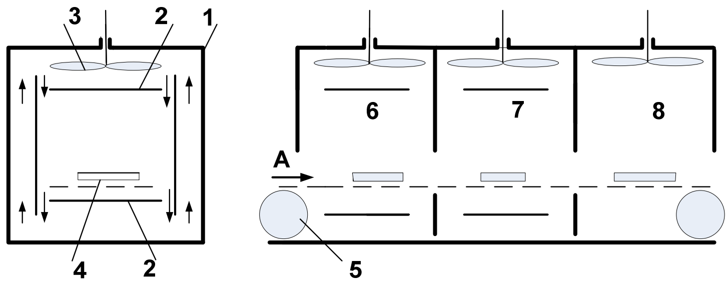


Fig. 2. Cross-section views of experimental soldering machine with conveyor: 1 - heating chamber; 2 – heaters; 3 – fan; 4 – PCB; 5 –conveyor; 6 – preheating part of the camera; 7 – main heating zone; 8 – cooling zone. A – direction of conveyor motion.

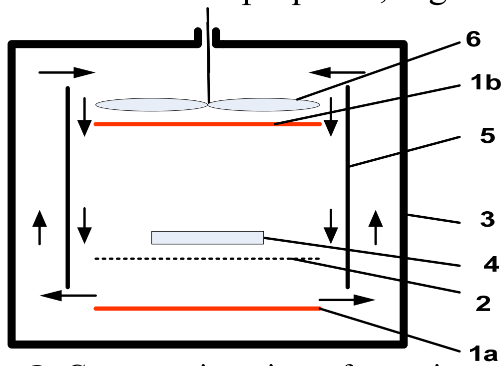
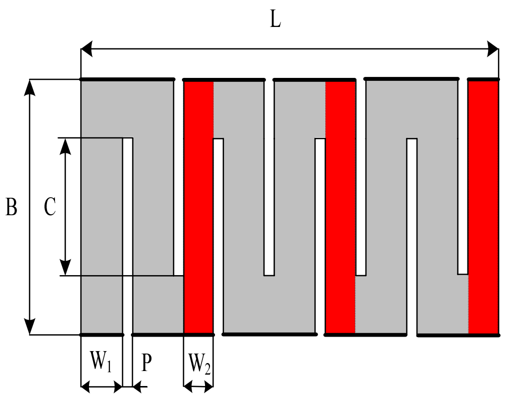


Fig. 3. Cross-section view of experimental soldering machine without conveyor: 1a and 1b – heaters; 2 – metal grid for PCBs mounting; 3 – heating chamber; 4 – PCB; 5 – reflecting screens; 6 – fan.

In the same heating camera [11] the heaters are divided into two sections. The temperature of each heater's section is measured (by thermocouples) and controlled separately. Spectral characteristics of emitted radiation from both sections are different because of different surface temperatures. The resulting spectrum of the radiation in camera becomes wider. Through the choice of the areas of the heaters' sections and its surface temperatures it is possible to realize quite different spectral distributions of the radiation in the camera depending on the properties of heated objects.



W_1 = 4 mm, W_2 = 3 mm

Fig. 4. Flat low inert IR heater element, type I: *B* – element's width; *L* – element's length; c and *W* – the length and the width of the belts correspondingly; *P* - the distance between the heater's belts.

The spectral distribution of energy emitted from the heater may be calculated using the Plank's law:

$$E(\lambda, T) = \frac{C_1}{\lambda^5} \frac{1}{e^{\frac{c_2}{\lambda T}} - 1}. \quad (1)$$

The whole temperature cycle is divided into the intervals of 10 seconds. In every interval it may be accepted that the temperature changes linearly: $T = T_i + a_i \tau_i$, here $a_i = (T_{i+1} - T_i)/\Delta\tau_i$, Fig. 8a. Emitted energy spectral distribution for each time interval can be calculated:

$$E_i(\lambda) = \varepsilon.S \int_{\tau_i}^{\tau_{i+1}} \frac{C_1}{\lambda^5} \frac{1}{e^{\frac{c_2}{\lambda(T_i + a_i.\tau)}} - 1} d\tau, \quad (2)$$

where $E_i(\lambda)$ is the spectral energy distribution in i-th interval; τ_i and τ_{i+1} are the beginning and the end of time interval; ε is heater's surface emissivity; S is heater's surface. Spectral distribution of IR radiation during soldering process $E_\Sigma(\lambda)$ can be calculated by summing results of equation (2):

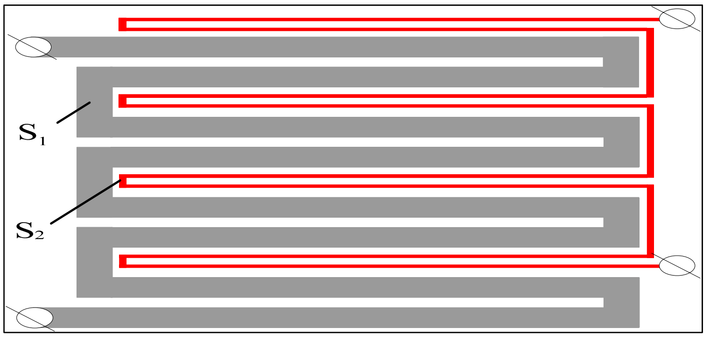


Fig. 5. Flat low inert IR heater element, type II: S_1 – surface of the first section, S_2 – surface of the second section of the heater.

$$E_\Sigma(\lambda) = \Sigma_i E_i(\lambda). \qquad (3)$$

Possibility of emitted spectra distribution control is demonstrated in Fig. 6. By application of electronic control of the heaters’ operation it is possible to control effectively spectral characteristics of the radiation in the camera during soldering processes in the spectral region between 3 and 8 μm.

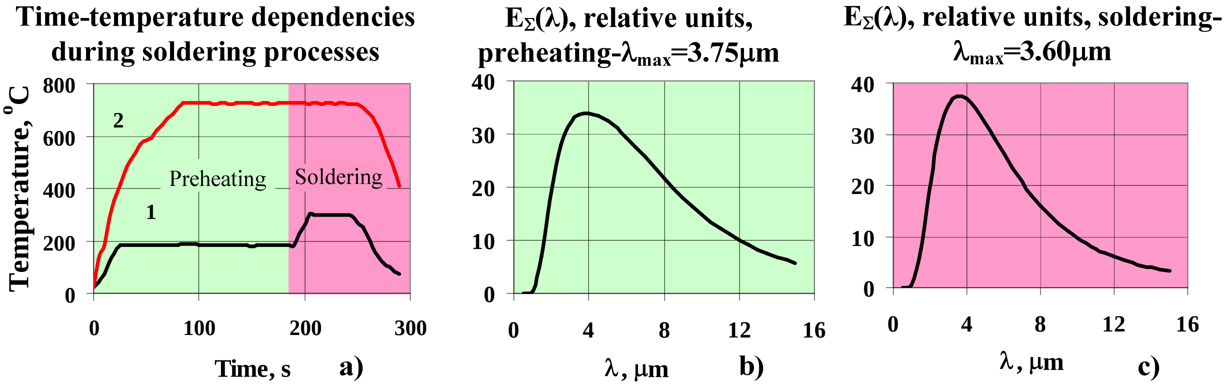


Fig. 6. Time-temperature dependencies (Fig. 6a) and spectral distribution of energy (Fig. 6b, 6c) for heater from Fig. 5: a) 1 – first section of the heater; 2 – second section of the heater.

This spectral region is important due to specificity of spectral characteristics of most of materials used in electronic technologies [1 - 9].

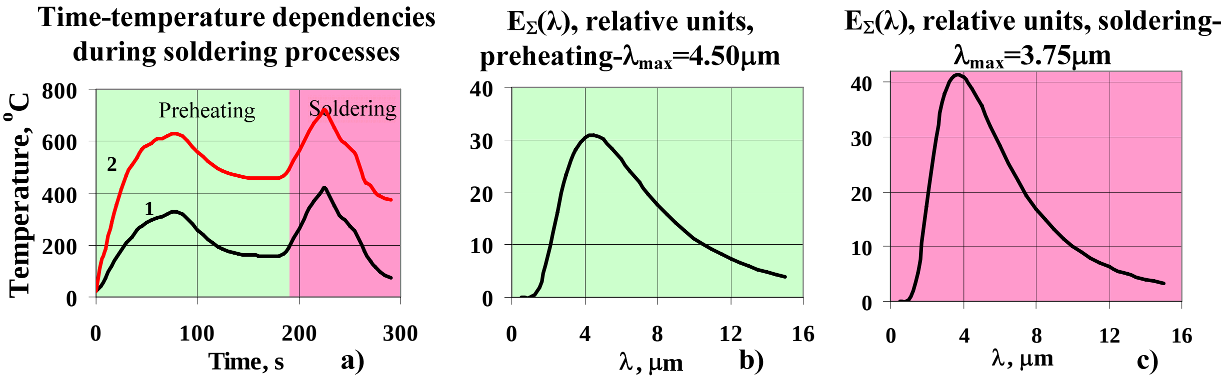


Fig. 7. Time-temperature dependencies (Fig. 7a) and spectral distribution of energy (Fig. 7b, 7c) for heater from Fig. 4: a) 1 – 4 mm belt’s width; 2 – 2.5 mm belt’s width.

The experimental time-temperature dependencies during soldering processes and corresponding spectral distribution of energy emitted from the heaters for preheating and reflow processes for the heaters shown in Fig. 4 are presented in Fig. 7. Spectral distribution of energy emitted from the heaters for preheating and reflow processes are shown in Fig. 7 for the heaters with different belt’s width and in Fig. 8 for the heaters with equal belt’s width. As it can be seen maxima in the spectral distributions are moved to the shorter wavelengths. It is reasonable because one part of the heaters’ area is heated up to the significantly higher temperature, see Fig. 7, curve 2. As a result of experimental investigations and calculations it may be concluded that for this types of heater design the spectral energy distribution is moved to the short-wavelengths. Maximal operating temperatures which may be reached at described methods of control of radiation spectral characteristics are below 1300 K. Theoretical and experimental research show that the reliability of the heaters at these conditions of operation are good enough (longevity more than 9000 hours).

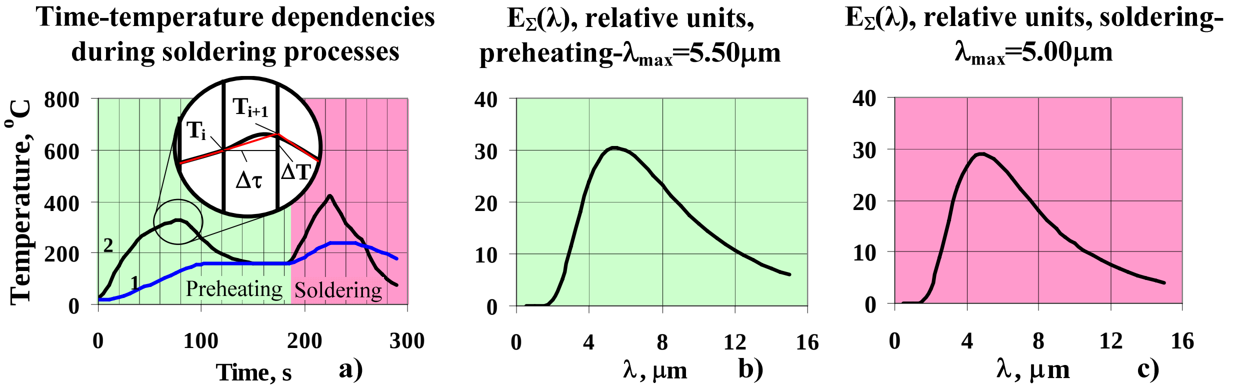


Fig. 8. Time-temperature dependencies (Fig. 8a) and spectral distribution of energy (Fig. 8b, 8c) for heater from Fig. 4 with equal belt's width: a) 1 – temperature on the solder joint; 2 - temperature on the surface of the heater.

In Fig. 9 results of the investigation on possibility of realization of different kinds of temperature regimes during soldering processes for surface mounted devices to PCB is demonstrated. Experiments are carried out using heating camera without conveyor. The chosen temperature regimes are close to ones necessary for lead free solder pastes [6, 7]. The realized temperature regimes for soldering processes are recommended by producers of lead-free solders [6, 7]. In Fig. 9 the temperature variations on different kinds of electronic components packages with respect to temperature regime upon the solder joint are shown. The hot end of the thermocouples is mounted on: solder joint on the PCB; on the bottom side of a capacitor; on the bottom side of electronic chips with quad flat packages (QFP), small outline packages (SOP) with different dimensions etc.

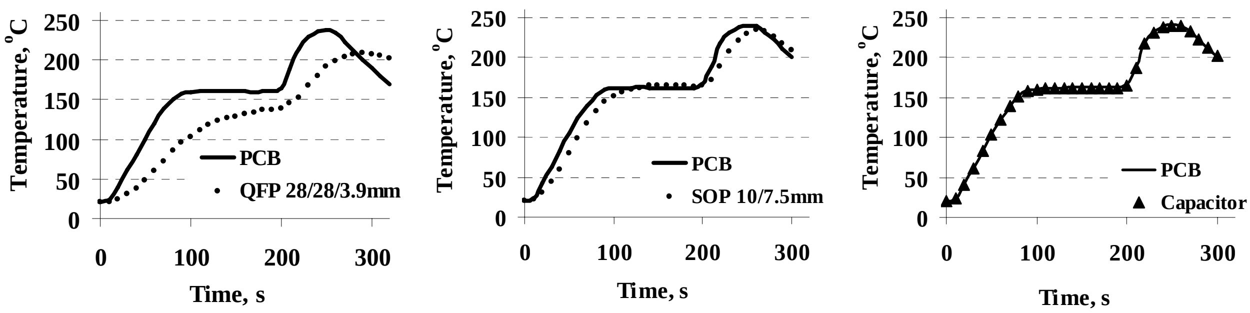


Fig. 9. Time-temperature dependencies during soldering processes: of the solder joint on PCB (solid line); of the chip (dotted line).

From the Fig. 9 it can be seen that the temperature of all electronic components used in our experiments stays under 240°C at the temperature of the solder joint about

240°C. For presented soldering equipment temperature profiles shown before may be realized with very good reproducibility for different size of PCB and different electronic components density. This ensures avoiding of temperature regimes dangerous for the electronic components in case of utilization of lead free solders.

4. CONCLUSIONS

The investigation of new kind of infrared equipment for electronic industry with low inert heaters (designed and produced in our laboratory) shows a lot of advantages and gives possibility to realize:

- versatile constructions, proper for all kinds of solder pastes;
- precise control (in situ) of the temperature on PCB during the soldering processes;
- possibility of realization of individual temperature profile for every PCB during soldering process in dependence of its size, electronic components density et al.;
- possibility of radiation spectral characteristics control;
- uniform temperature field on large area PCB;
- small dimensions heating cameras (suitable for large area PCB) without conveyor where the desirable temperature profiles may be realized by electronic control of the heaters' operation;
- energy saving: there's no need soldering machine to be switched on continuously, because the desirable temperatures can be reached for a few seconds.

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