Металлофиз. новейшие технол. / Metallofiz. Noveishie Tekhnol.
2013, т. 35, № 12, сс. 1725–1731
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ФИЗИКА ПРОЧНОСТИ И ПЛАСТИЧНОСТИ

PACS numbers: 06.60.Vz, 62.20.fk, 81.20.Vj, 81.40.-z

Modern Technologies of Soldering, Providing Increased Strength and Ductility of Metal Joints

V. N. Shtennikov and B. T. Budai

First President of Russia B. N. Yeltsin Ural Federal University,
Mira Street, 19,
620002 Yekaterinburg, Russia

Sometimes, the operations of electronic devices have failures due to lack of strength and ductility of the metal solder joints. As known, a main condition for ensuring of the required strength and ductility of the metal compounds is the choice of optimal brazing temperature. As the result of theoretical and experimental studies, the dependences connecting the surface temperature of joint metals and alloys with the parameters of the wave, laser, convection soldering are obtained. The use of the mentioned relationships increases the efficiency of fabrication of strength and ductile solder joints.

При експлуатації електронних приладів іноді виникають відмови через недостатню міцність і пластичність паяних металевих з'єднань. Відомо, що основною умовою забезпечення необхідної міцности та пластичности металевих з'єднань є вибір оптимальної температури пайки. В результаті теоретичних і експериментальних досліджень одержано залежності, що зв'язують температуру поверхні металів і стопів, які з'єднуються, з параметрами хвильової, лазерної, конвекційної пайки. Застосування цих залежностей уможливило підвищити ефективність технології випуску міцних і пластичних з'єднань.

При эксплуатации электронных приборов иногда возникают отказы из-за недостаточной прочности и пластичности паяных металлических соединений. Известно, что основным условием обеспечения требуемой прочности и пластичности металлических соединений является выбор оптимальной температуры пайки. В результате теоретических и экспериментальных исследований получены зависимости, связывающие температуру поверхности соединяемых металлов и сплавов с параметрами волновой, лазерной, конвекционной пайки. Применение упомянутых зависимостей позволило повысить эффективность технологии выпуска прочных и пластичных паяных соединений.

Key words: metallic solder joints, temperature and time of soldering,

strength and ductility of solder joints.

(Received July 10, 2013)

1. INTRODUCTION

Experience in the production of electronic devices shows that their reliability is primarily determined by the quality of solder joints [1]. On the other hand, the characteristics of solder joints made, for example, using lead-tin eutectic, their strength and ductility, primarily depend on the brazing temperature [2, 3].

Thus, the solution of the problem to provide the required temperature of soldering is one of the key issues to improve the quality of solder joints and, therefore, of electronic devices. However, this problem was not enough discussed emphasis in the literature that determines its relevance.

2. THE METHODOLOGY OF THE RESEARCH AND RESULTS

The temperature was measured by a chromel–copel or copper–constantan thermocouple. In this case, the diameter of the thermocouple was much smaller than the diameter of the output electrode of component. To record the thermo-EMF, KSP-4 potentiometer with accuracy rating 0.25 was used. Temperature measuring accuracy was ±1°C. Soldering time was determined by an electronic stopwatch.

The quality of solder joints was evaluated: visually, using MBS-2 microscope, by the methods of the study of shapes and microsections of solder joints and their mechanical strength (testing of automation systems devices for the impact of blows).

2.1. Soldering by the Wave of Molten Solder

During wave soldering, the lower surface of the printed-circuit board (PCB), including the solder joints, is constantly washed by the molten solder. Therefore, soldering temperature is equal to the temperature of the molten solder. Soldering time depends on the speed of the board motion along the conveyor and the width of the wave. Thus, the basic parameters of soldering (temperature and time) are easily adjustable, ensuring consistent high quality of solder joints.

Figure 1 shows a multilayer printed-circuit board with the pads located on one level, soldered by the double wave of molten solder.

The joints made without abutting of output electrodes to the pads located on different levels of PCB soldered by the wave, laser or convection soldering have a characteristic shape: if the gap between the

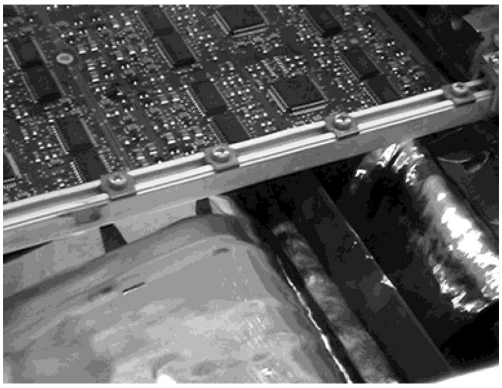

Fig. 1. Soldering of the printed-circuit board with contact pads located on one level by the double wave of molten solder.

output electrode of the component and the contact pad is more than 0.2 mm, the solder connection is not formed and the whole solder remains on the output electrode [4].

Our experimental studies have shown that for the molten solder wave soldering, unlike the manual soldering using soldering tools, the following shapes of solder joints and the types of defects are typical: filled shape of the solder joint with dimensions larger than the contact pad, through-shell, dry joint, cavities and pores, solder bridges between adjacent pads.

2.2. Laser Soldering

The results of research on laser brazing showed the possibility of its application for assembling of electron devices if the PCB contact pads are located on the one level. This method allows producing the solder joints in electronic devices with high-density of assembling and fine pitch of output electrodes without formation of jumpers and solder balls. During soldering, PCBs and packages of components do not practically heat up, which allows one to mount chips that are sensitive to heat. As established, the packages of chips are not subjected to direct laser exposure, so they are heated during soldering of output electrodes to temperature not higher than 113°C. Strength of solder joints of boards produced by laser soldering automatic machine coated with hot POS61 is 11 Newtons per output for joints with solder excess and 6.60 Newtons per output for joints of skeletal shape. The average value of the mechanical peel strength was 8.80 Newtons per output electrode for single contact pads. The rupture of solder joints propagates along the output electrode–solder interface.

Knowing the power of radiation and the absorption coefficient of the

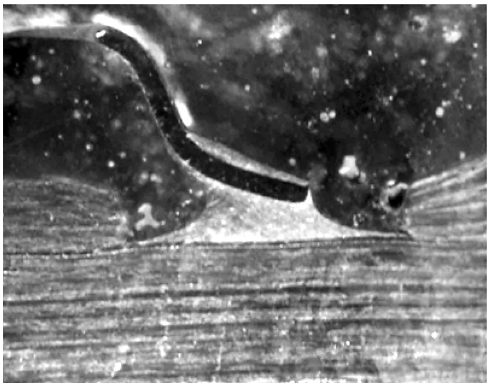

Fig. 2. Microsection of joint made by laser, infrared or convection soldering on the contact pads located at different levels.

surface, one can determine the intensity of the heat flux of radiation and solve the problem for heating a semi-closed plate, on the surface of which heat flux is specified [5].

If the intensity of the heat flux at the surface of semi-closed body is proportional to $\tau^{-1/2}$, the temperature gradient can be calculated as in the case of contact soldering according to equation [5]:

$$t_{n(x,\tau)} = t_{n(x=0)}\left[1 - \Phi\left(\frac{x}{2\sqrt{a\tau_n}}\right)\right], \tag{1}$$

where $t_{n(x,\tau)}$ is soldering temperature, τ_n is the soldering time, $a = \lambda/(\rho \cdot c)$ is thermal conductivity, λ is the heat conductivity factor, ρ is density, c is specific heat, $\Phi(u) = 2\pi^{-1/2}\int_0^u e^{-\xi^2} d\xi$ is the probability integral.

To avoid overheating of heat sensitive components, the temperature of heating surface should not exceed 265°C and at a maximum distance—at least 230°C to ensure good quality of solder joints. Taking into account the temperature measurement accuracy of soldering tool (before soldering) and of soldering temperature, the permissible range of the soldering temperature will not exceed 10°C. In accordance with these restrictions, the maximum permissible value of the relative change in temperature with depth of solder joint will be $10/265 = 0.037$.

This condition imposes restriction on the time τ_n allowed for soldering of the solder joint with a given thickness x. For example, in the case of soldering of the copper output electrode of the component and solder plated hole in circuit board with a thickness of 1.5 mm, minimum soldering time is of about 1.4 sec. In the case of soldering of the Kovar planar output electrode of chip with a thickness of 0.2 mm and PCB contact pad, the thermal diffusivity of Kovar is approximately 10 times less than that of copper (depth of the solder joint coincides with the thickness of the output electrode); the minimum soldering time is of about 0.4 sec. [6].

2.3. Convection Soldering

It is determined that the use of printed circuit boards with contact pads in one level convection heating is the most promising method, which provides a significantly smaller temperature variation over the surface of the printed circuit board than the infrared soldering.

Within the assumption of a constant heat-transfer coefficient between the surface of the printing unit and the air, at the inhomogeneity of the temperature field in the bulk of printing unit much smaller than its mean excess temperature, the following formula for heating temperature of the printed unit was obtained:

$$t_h = t_{\max}(1 - e^{-\tau/\tau_0^h}). \quad (2)$$

Solving a similar problem for the cooling mode, one can obtain the corresponding relationship for the temperature of the cooling printed unit:

$$t_c = t_{\max} e^{-\tau/\tau_0^c}. \quad (3)$$

In Equations (2), (3), quantity $t_{\max}$ is maximum heating temperature of the printed unit, τ_0^c and τ_0^h are constant cooling and heating times of printed unit, respectively:

$$\tau_0^c \cong \tau_0^h = \frac{C_n}{\alpha S_n}, \quad (4)$$

where S_n is the surface area of the printed unit, C_n is heat capacity of the printed unit, α is heat-transfer coefficient.

These relations allow us to estimate reasonably correctly the average temperature of the printed unit depending on coolant temperature (air or nitrogen), the surface area of the printed unit, its heat capacity, and heat-transfer coefficient [7].

In general, the time constants (4) of the heating and cooling of the printed unit may differ due to different rates of blowing and composition of heat-transfer medium.

From equations (4), the conclusion is made that a constants of temperature changes in the printed unit at convection heating and cooling are proportional to their specific heat, and are inversely proportional to heat-transfer coefficient and their surface area. In particular, the solder joints, which are in different conditions of blowing by heat-transfer medium, are heated with different rates. For this reason, the lower surface of BGA components, where the ball output electrodes are located, is heated slower than the side surface of components with planar output electrodes.

Holding at a temperature below the melting temperature of solder, before finishing heating of the printed unit up to the soldering temperature by changing of the temperature of the heat-transfer medium and its speed, makes it possible to heat the electronic components more evenly, regardless of their relative surface area and specific heat.

On the other hand, the components on the circuit board in the identical housings eliminates mentioned holding without reducing of soldering quality, which is confirmed by our experimental data when implementing technologies of convection soldering of printed circuit boards with chips having a lead pitch of 0.5 mm.

The quality of solder joints on the tested circuit boards meets the requirements of the IPC-A-610D international standard 'Acceptability of Electronic Assemblies'. Metallographic analysis showed no internal voids and pores.

Solder joints have a concave fillet, indicating good wetting of both the material of output electrodes and the contact pads. All joints have a shiny surface and no shrinkage cavities and pores on the surface. Modes of surface mounting of chips with the lead pitch of 0.5 mm are introduced in the batch production of printed circuit boards and are recommended for use in the manufacture of electronic devices for different purposes on the basis of the surface mounting.

3. CONCLUSIONS

1. The possibility of compliance with required soldering temperature regimes, and thus the strength and ductility of solder joints for solder wave soldering, laser soldering, and convection soldering is estimated.
2. It is determined that convection and wave soldering provide reasonably precise optimum temperature of soldering, smaller temperature difference in the depth of solder joints compared with manual contact or laser soldering.
3. It is determined that heating of the solder joints and temperature drop by their depth during laser soldering may be estimated by the heat conduction equations for a half-closed plate with a predetermined heat flux at the surface. Warming up of the printed unit and, therefore, the solder joint at convection soldering can be described by equations of the regular mode.
4. As shown, the time constants of heating and cooling of the printed

unit are proportional to the heat capacity and inversely proportional to the surface area of the printed unit and its heat-transfer coefficient, which, in turn, depends on the speed of heat-transfer medium and its composition.

5. High quality solder joints made by traditional and unique technologies using wave or convection soldering is confirmed by complex testing of automation systems for resistance to the influence of mechanical effects and alternating thermal loads, checking the mechanical strength of several hundreds of solder joints, visual inspection of the tens of thousands of solder joints, study of microsections of solder joints and shapes of solder joints, study of the external view of the broken solder joints.

6. Convection and wave soldering provide higher quality of solder joints compared with manual or laser soldering. Furthermore, the cost of wave and convection soldering is lower than that of manual or laser soldering. It is reasonable to use the convection and wave soldering.

The results are introduced into batch production of devices for different purposes and have shown high efficiency of production of strength and ductile metal joints.

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