SOLDERING CONNECTIONS FORMATION AT INFLUENCE OF ENERGY OF ELECTROMAGNETIC FIELDS IN WIDE FREQUENCY BAND

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Abstract:

In result of investigations of frequency bands of electromagnetic fields energy influence on soldering processes of electronic modules defined conditions of reliable soldering connections formation with low transitive electric resistance and high mechanical durability. Low frequency vibrations at soldering allow receiving a low heat-transfer resistance between chip and package. Activation US vibrations allow to realize flux-free soldering difficult solderable metals. Modeling and investigation of electromagnetic heating in soldering processes has allowed optimizing heating speed in local zones of formation of soldering connections.

Key words: Soldering, Connections, Electromagnetic Fields, Electronic modules.

1. Introduction

In modern 3D electronic micromodules with surface mount technology (SMT) it is necessary to provide high density of contact connections, which should have the minimum transitive electric resistance (to 2,0 mOm), high mechanical durability, stability of electric and mechanical parameters at various climatic influences, high reliability and durability in the set conditions of operation, and also ease and reliability of quality assurance [1].

Electric and mechanical properties of soldering connections in many respects depend on character of the physical and chemical processes proceeding at their formation. Kinetic processes of wetting, diffusion, absorption of energy, physical and chemical interaction of components of a melt and materials it is intensified at influence of electromagnetic energy in a range from units of Hz to MHz [2].

It allows to accelerate removal oxide films, wetting and diffusion, to increase thermal energy as a result of absorption, to accelerate mobility of charge carriers in melts and the directed diffusion of is reactionary-active components. Low-frequency (LF) of vibration supersedes oxide films from a soldering zone, providing uniformity of soldering connection. Ultrasonic (US) vibrations in a range 20–66 kHz destroy oxide films and accelerate wetting and diffusion processes at soldering [2].

High frequency (HF) electromagnetic heating allows achieving high heating speed, activating solder and improving wetting solderable surfaces [3]. A number of advantages has infrared (IR) heating for mounting and de-mounting surface mount devices (SMD), however effective realization of process depends on geometry of radiation reflector and parameters IR source [4].

Transition on Pb-free technology of the soldering puts the key requirement to soldering equipment stability of a temperature profile of process. As the soldering temperature has raised on 40 degrees and is close to maximum permissible temperature for SMDs decrease in accuracy of a profile of heating increases risk of thermal damage of components [5]. Maintenance of high quality of soldering connections in the conditions of the automated manufacture is impossible without the authentic mathematical models describing soldering processes at electromagnetic fields energy influence of a wide frequency range.

2. Modeling of soldering connection formation processes

Soldering chips in the package by fusible solders it is necessary to provide an exact arrangement of chips on substrate, strong mechanical connection, reliable electric contact and a good heat-conducting path. Latent defects (emptiness, micro cracks) create a zone with is abnormal high thermal resistance that reduces reliability of chips at operation in the conditions of thermocyclic influences.

Replacement of oxide films on solderable surfaces and solder the chip mechanically moved concerning a substrate by means of LF vibrations. For formation of soldering connection of the chip with the package (Fig 1) it is necessary, that work of forces of vibration considerably surpassed work of forces cohesion a melt:

$$W_w \geq (5-10)W_c = ISt \geq (5-10) \times 2\sigma S \,. \qquad (1)$$

Where: I is intensity LF vibrations, S is chip area, t is time, σ is surface tension of solder.

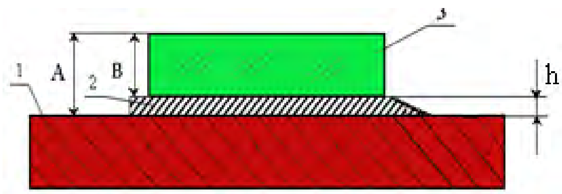

Fig. 1. Chip mounting scheme: 1 – package, 2 – solder, 3 –chip.

At soldering temperature 300–350°C, and amplitudes of LF vibrations 75–150 microns promotes effective removal of oxides from a zone of mounting, achieve optimal thickness of solder h within 25–50 μm [6], thus emptiness and sites which are not containing solder under a crystal are excluded, as allows to receive a demanded level of heat-transfer resistance.

The action of the US field energy on the melt increases the diffusion coefficient and activates the nucleation process [7]

$$D' = D_0 e^{-\frac{E-\Delta E}{RT}} \qquad (2)$$

Where D_0 is pre exponential factor, E is energy of the diffusion activation, ΔE is change in the energy of the diffusion activation in the US field, and R is gas constant.

In the US field, the force F acts on the diffusing particles, and, under its action, the substance particles move with the average velocity:

$$U = \upsilon F \qquad (3)$$

Where υ is the particle mobility.

At the activation in the US field, a flux of particles, which move under the action of the force of US vibrations F is added to the diffusion flux; then, the entire flux amounts to

$$J = -D' \frac{\partial C}{\partial x} + UC_1 \cos\beta \qquad (4)$$

Where C_1 is the concentration of mobile particles, and β is the angle between the vector of the force of the US field and the diffusion flux vector.

Effective HF heating power is generally equal:

$$P = \frac{U^2 \cos\varphi \cdot \eta}{R_h} \qquad (5)$$

Where: U is effective voltage on inductor, $cos\varphi$ is power factor, η is heating efficiency, R_h is electric resistance in heating zone.

Electric resistance to HF currents can be defined from the assumption, that the width of a heating zone at small gap sizes h is equal to a projection of inductor diameter (Fig 2):

$$R_h = \frac{2\pi L_h \sqrt{\rho \cdot \mu \cdot f}}{h}, \qquad (6)$$

Where: L_h is length heating zone, ρ is specific electric resistance, μ is magnetic penetrate, f is frequency.
In other equal conditions magnetic materials require smaller specific power at HF heating. Heating power is nonlinear decrease with HF frequency in consequence of superficial effect.

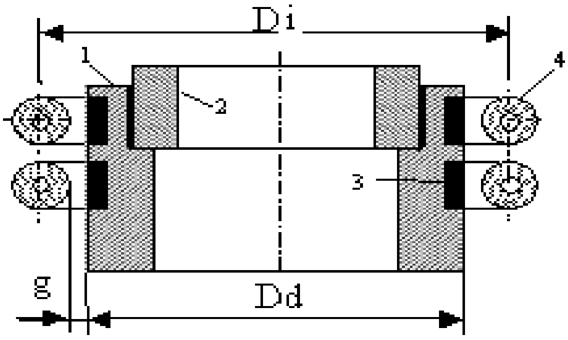

Fig. 2. Scheme induction heating: 1and 2 – solderable details, 3 – heating zone, 4 –inductor.

IR radiate providing a high rate of the local contactless heating and effective control the temperature profile is the most promising for modern soldering technologies. Within the entire IR spectrum with its wavelength range of 0,72–1000 µm, a small part of this range is used only for soldering, i.e., near- (0.72–1.5 µm), middle-(1.5–5.6 µm), and far-(5.6–10.0) IR radiation. The temperature of the heating body depends on the radiation wavelength, its emissivity factor or reflectivity, duration of irradiation and the body's mass. The effective power of IR heating is as follows [4]:

$$P = k\varepsilon S\Delta T \qquad (7)$$

Where k is the Stephan-Boltzmann constant, ε is the emissivity of the body, S is the body surface, and ΔT is the temperature variation. The shorter the radiation wavelength is, the deeper it penetrates the body; therefore, near-IR radiation possesses deeper penetration ability than compared with middle- and far-range radiation.

3. Experimental results and discussion

At amplitude of LF of vibrations less than 250 µm quality of soldering connection between chip and substrate worsens because of formations of the local sites not moistened with solder in the central part of a chip and components to 25–30 % of the area of active transistor structure. Formed to heterogeneity promote development of thermal instability of contact connection, distortion of thermal front and, at the expense of it to chip overheat.
Soldering chips with amplitude of LF vibrations 350-500 µm are formed faultless soldering connection at an optimum thickness of solder within 30-35 microns (Fig 3). It allows to receive reliable powerful transistor structures for power supplies [8].

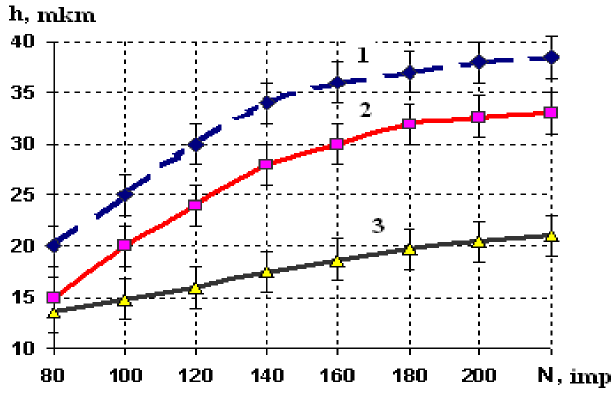

Fig. 3. Thickness of solder vs. solder dose (Nimp) and amplitude vibration: 1 - 250 µm, 2 - 500 µm, 3 - 750 µm.

Influence US activation on process of diffusion of solder system Sn-Zn in aluminum alloy Al-Mg was modeled under following boundary conditions: the area of contact 10 - 50 mm2, amplitude of fluctuations 10–20 µm, time of diffusion 5–15 with, US frequency 22 kHz. Results have shown that US activation increases concentration Al on boundary depth on the average by 15-20 % (Fig 4).

With increase of US frequency is observed a concentration gain as the quantity of the energy absorbed by a material of the processed detail thus increases.
Durability of soldering connections in case of parallel US vibrations above on 1.5–2.0 time, than at the longitudinal.

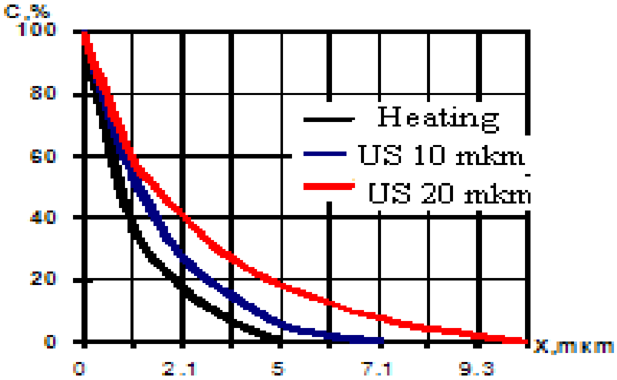

Fig. 4. Concentration profiles of diffusion Al.

Optimum time of US influence lies with 15-20 s. At smaller time oxide films have not time to collapse and bad wetting takes place, at high time - erosion of soldered material and solder oxidation is possible.
HF heating in frequency band 1000 – 2000 kHz has the greater dependence on size of capacity and electrophysical characteristics of materials. At capacity of heating of 1–1,2 kW intensity of a field makes (4,5–5,0)•104 A/m, and time of the soldering of magnetic materials is 5–7 s (Fig 5).

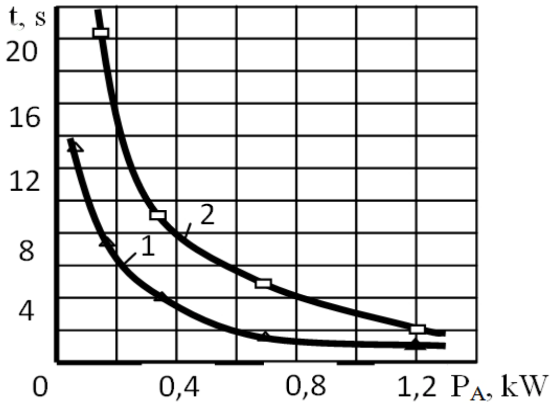

Fig. 5. Soldering time vs. HF heating power: 1– inductor with magnetic core, 2¬–usual inductor.

The maximal heating speed (till 60 0C/s) is observed at frequency 325 kHz. Optimum parameters of HF heating process are: voltage on inductor is 165–180 V, an anodic current is 0,80–1,2 A.
After solder fusion intensity of HF-heating is reduced subject to required temperature mode of the soldering process that allows to avoid solder overheating as well as to lower a product heating. Last stage is HF-voltage cutoff and product cooling.
Basic disadvantage of IR heating is non-uniform temperature influence on the component package and on the printed-circuit board (PCB) (Fig 6).
The difference between temperature under a microcircuit package and on a PCB surface makes to 50ºC, that at infringement of soldering parameters can lead to occurrence of a considerable gradient of internal pressure.

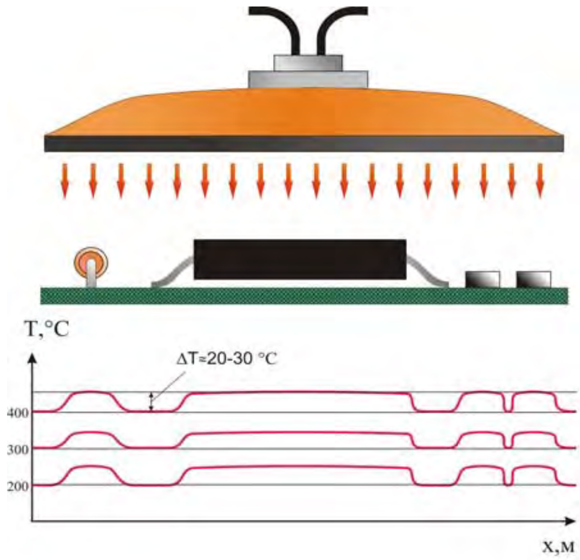

Fig. 6. Temperature profile IR heating at electronics module soldering.

To reduce a gradient of mechanical pressure and to eliminate printed-circuit board deformation apply bilateral IR heating by means of an additional heater which settles down under the printed-circuit board.

4. Conclusion

Frequency bands optimization of electromagnetic fields energy influence on soldering processes of electronic components has allowed defining conditions of formation of reliable soldering connections with low transitive electric resistance and high mechanical durability. It allows to recommend these soldering processes for assembly of a wide range of the electronic modules including powerful semi-conductor devices, laser diodes, integrated microcircuits, multilayered ceramic condensers, etc.

LR vibrations allow receiving a demanded level of heat-transfer resistance between chip and package. Activation US vibrations allow to realize flux-free soldering difficult solderable metals, such as aluminum, titan, molybdenum, etc.

Modeling and investigation of electromagnetic heating in soldering processes has allowed to optimize heating speed in local zones of formation of soldering connections and to improve their quality.

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