Preparation of solder pads by selective laser scanning

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We propose a new laser preparation technique to solder Sn-Ag3.5-Cu0.7 on a copper clad laminate (CCL). The experiment is conducted by selective laser heating and melting the thin solder layer and then preprinting it on CCL in order to form the matrix with solder pads. Through the analysis of macro morphology of the matrix with solder pads and microstructure of single pads, this technique is proved to be suitable for preparing solder pads and that the solder pads are of good mechanical properties. The results also reveal that high frequency laser pulse is beneficial to the formation of better solder pad, and that the 12-W fiber laser with a beam diameter of 0.030 mm can solder Sn-Ag3.5-Cu0.7 successfully on CCL at 500-kHz pulse frequency. The optimized parameters of laser soldering on CCL are as follows: the laser power is 12 W, the scanning speed is 1.0 mm/s, the beam diameter is 0.030 mm, the lead-free solder is Sn-Ag3.5-Cu0.7, and the laser pulse frequency is 500 kHz.

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Soldering using various lasers (Nd:YAG, diode, fiber laser, etc.) is a well-established technology in ball grid array (BGA), chip-scale package (CSP), and flip-chip pad preparation[1]. In a conventional laser soldering process, the solder balls need to be positioned on the substrate firstly, and then the laser head is moved to align the solder ball and is kept on until the solder ball melts. When the illumination is stopped, the temperature decreases, and the solder solidifies, a pad is formed on the substrate. Then the laser head is moved to another position to prepare the next pad. This process has been detailedly described[2,3]. In a conventional laser soldering process, the solder is usually a Pb-containing solder such as Sn-Pb. However, Pb and its compounds in the most common solder have been demonstrated to be highly toxic[4]. Meanwhile, the European Union has issued the Waste Electronic and Electrical Equipment (WEEE) mandate that aims to prohibit the use of Sn-Pb solder in 2006[4]. For environmental reasons and considering the pressure of trade competitions, manufacturers and research institutes started wide investigations on the substitutes for Sn-Pb solders. The solder Sn-Ag3.5-Cu0.7 is a good substitute for Sn-Pb solder and it is necessary to study the soldering technology of the solder Sn-Ag3.5-Cu0.7[5,6].

Laser beam, thanks to its excellent comprehensive properties such as high power density, high monochromaticity, and localized heating, has great advantages in solder ball placement[7]. The beam is focused on the solder ball whose size is usually in sub-millimeter level. A schematic diagram of the conventional laser soldering process is shown in Fig. 1[2,3]. As for the heat input is localized, the active regions of electronic components are not exposed to high temperatures. Therefore, assembly of heat-sensitive components can be accomplished[1,2].

Difficulties with the conventional laser soldering process arise when the bump size and interval become smaller. It is hard to position the solder ball and align it. So it is necessary to carry out a new process of laser scanning preparation to meet the need of packaging micro-miniaturization and low pitch trend.

In this letter, by combining a high-beam-quality fiber laser with two galvanometer scanners, the selective laser soldering of Sn-Ag3.5-Cu0.7 on a copper clad laminate (CCL) is investigated to obtain the matrix with solder pads.

Sn-Ag3.5-Cu0.7 solder and CCL were used for experiments. The copper layer of CCL was about 0.05 mm thick (see Table 1). A preprocess including pickling with 38% HCl solution, alcohol cleansing, and drying was applied to remove the oxide of CCL.

The apparatus used in the study included a 12-W

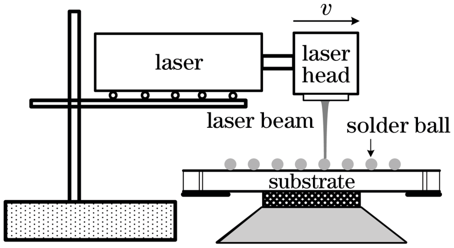

Fig. 1. Scheme of conventional laser soldering process.

Table 1. Experimental Parameters

Laser Type	SP-12P Fiber Laser
Laser Power (W)	12
Laser Wavelength (nm)	1075
Solder (wt.-%)	Sn-Ag-Cu 95.8-3.5-0.7
Focal Length of f-θ Lens (mm)	160
Copper Layer of CCL (mm)	0.05
Focal Beam Diameter (mm)	0.03

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pulsed fiber laser, a galvanometer scanning system, an f-θ lens, and a controlling computer. The wavelength of the fiber laser was 1075 nm and the focused beam diameter was 0.03 mm. The galvanometer system was used to deflect the laser beam to realize laser scanning function. An f-θ lens, providing a flat field of 160-mm focal length, was required as this kept the focal plane position constant irrespective of the angle of the beam being deflected from the scanning mirrors[8]. The laser scanning mode, pulsed laser power, and pulse frequency were computer-controlled. The system with a constitution as shown in Fig. 2 was used to run the soldering tests described below[9].

The process of laser scanning preparation includes three main steps. The first step is solder paste stencil printing. Put the solder on the stencil which is previously positioned on the CCL, and then level the solder using a scraper. The thickness of the solder paste layer depends on the thickness of stencil. The second step is laser scanning. Adjust the laser processing parameters and set the laser scanning path to form a matrix scanning mode, and then scan the solder by laser. The solder pads are formed by the laser melting. The third step is cleaning. General washing and ultrasonic washing with clean water is applied to remove the residual solder paste. Thus the matrix with solder pads is obtained. The process is schematically shown in Fig. 3.

The solder bumps were arranged as a regular square matrix as shown in Fig. 4(a). A 10 × 10 matrix of solder bumps with 1-mm interval was set as the laser scanning mode in the experiment. It took 3.90 s to scan all the 100 bumps. The speed of laser scanning was 1 mm/s, and the jump speed from bump to bump was 3000 mm/s. This meant that each solder pad was irradiated for about 39 ms. The length of laser scanning on each pad was equal to the focused beam diameter, that is, 0.03 mm. With the laser heating and the following cooling, the solder melted, contracted, and formed into a pad under the action of surface tension. So the solder pad emerges a disk-like configuration rather than an oval one.

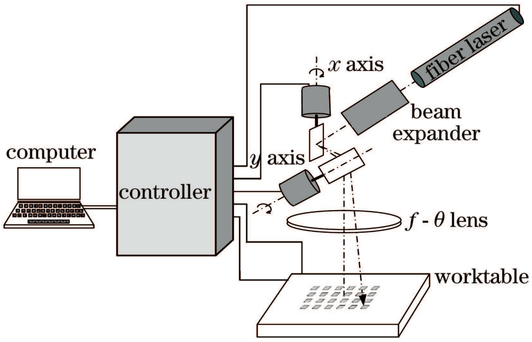


Fig. 2. Principle of the selective laser soldering system.

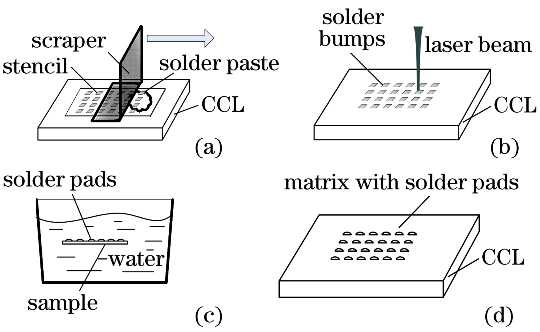
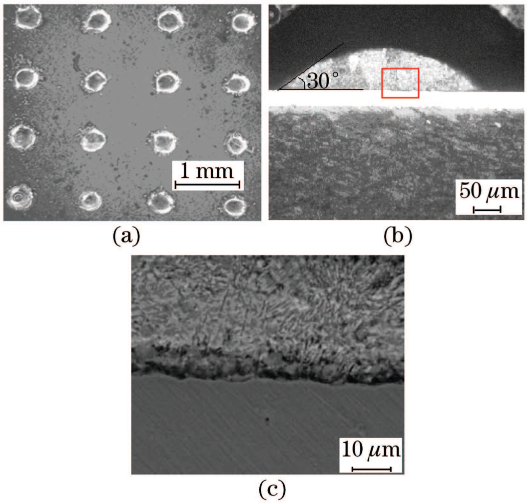


Fig. 3. Technological process of laser soldering. (a) Solder paste layer printing; (b) laser scanning; (c) cleaning; (d) soldering finished.



(a) (b)

(c)

Fig. 4. Results of fiber laser soldering on CCL at 500-kHz frequency. (a) Macro photograph; (b) metallograph; (c) scanning electron microscopy (SEM) photo for the area in the square of (b).

With the high power density, short pulse duration, and small spot area, the peak power density can reach 10^8 W/cm^2. The solder temperature increases rapidly when laser irradiates the solder. The temperature's rising speed can reach more than 10^4 °C/s. Because the copper conducts well, most of the energy can be carried away quickly. The solder temperature would decrease quickly when the laser irradiation is stopped. The temperature's decreasing speed is very high but less than the rising speed. The solder temperature does not decrease too much when another laser pulse irradiates it. At the same time, the temperature of the CCL increases. The temperature trend is shown in Fig. 5.

Different frequency of the laser beam makes different pad quality. The frequencies of laser pulse used in the experiments were from 20 to 500 kHz. Through a series of experiments, we found that the 12-W laser could solder the pads successfully at 500 kHz. For the laser frequency

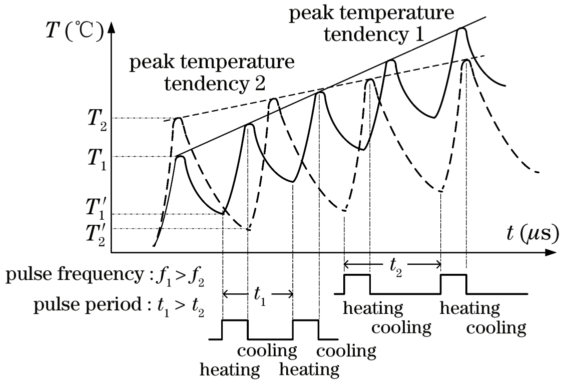


Fig. 5. Solder temperature T versus laser heat time t.

less than 500 kHz, the experiment failed. We hypothesize that the experiment would success if we had the laser with much higher frequency, much higher power, or much smaller laser spot.

When the duty cycle of the laser pulse is less than 1%, it can be calculated that each pulse outputs 0.024-mJ energy during its 10 ns duration. Obviously, the energy of laser pulse is too puny to melt the solder, while lots of laser pulses could successfully melt a solder bump. Because the pulse intermittence occupies most of time (more than 99%) in a 2-μs pulse period, the effective cooling in the pulse intermittence makes the solder temperature decrease. The longer the pulse intermittence, the lower the solder temperature. The cooling time (the pulse intermittence) will decrease if the pulse frequency increases, and so the solder temperature decreases slowly. In the experiment, the solder was fully melted at 500-kHz frequency and a metallurgical combination was obtained at the interface. On the contrary, the cooling time (the pulse intermittence) prolongs when the pulse frequency decreases. In a pulse period, the solder temperature decreases too much to melt the solder and to form a metallurgical combination interface. The principle of the different frequencies affecting the solder temperature is also shown in Fig. 5.

As shown in Fig. 4(a), we can see clear surface and sound pads. The metallograph of the vertical section of the solder pad is shown in Fig. 4(b). We can find that the wetting angle is about 30°. Such a wetting angle is generally beneficial to the formation of perfect pads. As shown in Fig. 4(c), the solder pads obtained by selective laser soldering with the above parameters have excellent microstructure, which consists of mostly Ag3Sn/β-Sn dendrite eutectic structure and a little β-Sn primary structure. It also can be seen in Fig. 4(c) that the solder pad appears compact microstructure. Because the laser beam has rather high energy density and irradiates the solder locally, the laser soldering is a rapid heating and rapid cooling process, which leads to the fine homogeneous eutectic structure of the solder pads and a metallurgical combination between solder pad and Cu substrate.

Because the pulse frequency is so high, supersonic cavitations can occur in the solder, which crush the oxide film on the interface between solder and bonding pad at 500-kHz pulse frequency[10]. The solder is wet and spreading on the CCL, and then laser soldering is realized on the CCL with Sn-Ag-Cu lead-free solder by pulsed laser scanning.

In conclusion, the laser soldering technique by fiber laser can realize high speed scanning soldering with lead-free solder Sn-Ag3.5-Cu0.7 on CCL. The solder pad is of good microstructure and good binding performance with the substrate. This technique is suitable for preparing solder pads of lead-free solder by fiber laser. In the process of laser soldering, different frequency of the laser pulse makes different pad quality. High frequency pulse is beneficial to the formation of better solder pad. The 12-W fiber laser with 0.030-mm beam diameter can successfully solder Sn-Ag3.5-Cu0.7 on CCL at 500-kHz frequency.

References

1. K. Kordás, A. E. Pap, G. Tóth, M. Pudas, J. Jääskeläinen, A. Uusimäki, and J. Vähäkangas, Opt. Lasers Eng. **44,** 112 (2006).
2. Y. Tian, C. Wang, and X. Zhang, Mater. Sci. Technol. (in Chinese) **10,** 136 (2002).
3. H. Dürr, R. Pilz, and N. S. Eleser, Computers in Industry **39,** 35 (1999).
4. Y. Shang, “Study on the microstructure, properties and interfacial reaction of Sn based lead-free solder” (in Chinese) PhD Thesis (Jilin University, June 2007) p.3.
5. L. Yao, S. Xue, P. Wang, and L. Liu, Trans. China Welding Institution (in Chinese) **26,** (10) 90 (2005).
6. S. Xue, L. Yao, Z. Han, and L. Liu, Trans. China Welding Institution (in Chinese) **26,** (12) 39 (2005).
7. Y. Chen, Y. Miao, L. Li, and L. Wu, Chinese J. Lasers (in Chinese) **34,** 1716 (2007).
8. N. H. Rizvi and P. Apte, J. Mater. Process. Technol. **127,** 206 (2002).
9. W. Shi and Y. Yang, Laser Technol. (in Chinese) **32,** 308 (2008).
10. Y. Tian and C. Wang, Welding and Joining (in Chinese) (6) 5 (2002).