Laser Original**Development of a Rectangular Dual-Beam Optical Unit for YAG Laser Soldering of Fine Pitch Flat Package IC's****Hiroshi MIURA** , Kazumi ISHIKAWA*** and Keiji OKINO***

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We have developed a new optical unit for YAG laser soldering of high-density, super-multiple-pin LST's. The unit enables us to irradiate facing lines of LST's lead arrays simultaneously with two rectangular cross-section laser beams. We evaluated the unit by using an experimental assembled system composed of two rectangular robots, a belt conveyor, and a mounting system with pattern recognition capability. The following results obtained with 100 pin flat package IC's are summarized as follows (1) The most suitable solder amount was 2.5mg/cm—7mg/cm when solder paste was continuously dispensed across lead pad arrays and subsequently fused by rectangular laser beams. (2) Four lines of flat package IC lead arrays were soldered in 4 seconds, which is less than half of that for a previously developed conventional laser soldering method. (3) The photographs taken during laser soldering revealed that the flux in the solder paste evaporated in the first quarter of a unit soldering time; the dispensed solder then fused and flowed to leads and pads during the next quarter, and subsequently they got wet completely with the fused solder in the following half of the unit soldering time. (4) Suitable laser irradiation time for the FPIC's having different pitch and volume of leads was found to be approximately proportional, at a constant laser power to their lead volume per lead pitch.

Key Words : YAG laser, Optical fiber, Flat package IC, Reflow soldering, Surface mounting device.

1. INTRODUCTION

Adoption of high-density, super-multiple-pin, surface mounting LSI's (abbreviated as FPIC below) is nowadays remarkably increasing due to the strong demands for the improved device performance and assembling efficiency on the printed wiring boards¹⁾ (abbreviated as PWB below). These FPIC's are, however, necessarily heat sensitive, and must be assembled later, after conventional insertion type devices have

been assembled, utilizing a special soldering method capable of precisely localized heating.

We have previously reported the laser soldering system²⁾ for such FPIC's. In the previous system, however, a robot held a spherical lens unit, to which a laser beam was transmitted through an optical fiber, and the focused laser beam spot was subsequently scanned over two or four lines of FPIC's lead arrays for soldering. This robot could also hold a solder paste dispenser and a hand for mounting FPIC's

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owing to the light weight spherical lens. Consequently, single robot could perform all of these tasks, leaving PWB at the same position.

This made it possible to shorten necessary length of belt conveyor line, reduce system cost and construct a machining center of soldering FPIC's. Although this system is suitable for small batch wide variety production, however, it has such a disadvantage that it takes long time to solder all lines of FPIC's lead arrays due to the time consuming scanning method.

In order to solve this problem, we have developed a special optical unit, which can generate dual and parallel rectangular condensing beams. These beams can therefore simultaneously irradiate two facing lines of FPIC lead arrays and shorten the necessary laser soldering time. We have also constructed an assembling system composed of two rectangular robots, a belt conveyor and a FPIC's mounting unit having the pattern recognition capability to evaluate the developed optical unit. Soldering characteristics for both 80, 100 pin quad flat package IC's (abbreviated as QFP, below) and some kinds of small outline package IC's (abbreviated as SOP, below) have been investigated.

We would report here details of the newly developed optical unit and the experimental results, which include the most suitable solder amount for obtaining good laser soldering, the temperature rise characteristics during laser irradiation at FPIC lead and PWB slightly ahead from the edge of lead, the dependence of laser soldering characteristics on the laser power and laser irradiation time, the relationship between the laser irradiation time and the lead volume/lead pitch of FPIC's at a constant laser power.

2. DEVELOPMENT OF RECTANGULAR DUAL BEAM OPTICAL UNIT

Figure 1 shows the configuration of the newly developed rectangular and parallel dual beam optical unit. The laser beam from a YAG laser oscillator is coupled into a quartz optical fiber and is transmitted to the optical unit. A step index fiber is adopted to transmit the laser light, because the far field intensity profile of the beam transmitted through this type of fiber becomes more flattened³⁾ and can make the collimated laser intensity distribution along the line of FPIC lead arrays more uniform than that through a graded index fiber. The fiber core diameter and *NA* are 500 μm and 0.30, respectively. The laser beam passed through the optical fiber end is collimated by a spherical lens (focal length 60 mm), then truncated by the mask having a square slot. This mask also makes it possible to cut the peripheral part of laser beam and to generate uniform energy distribution at the irradiated plane.

Fig. 1 Schematic diagram for the rectangular and broad-area dual-beam optical unit.

The mask slit size is 23mm $\times$ 23mm, which is large enough to solder the maximum lead array length of 100 pin QFP. The laser beam, transformed to almost uniform intensity distribution, passes through the cylindrical lens (focal length 200mm), and enters onto the prism base. The laser light reflects totally at the two sides of prism so that the apex of the prism behaves as a beam divider, thereby it splits into two parts.

Next, each laser beam reflects at the total reflection mirror located directly on a pulse motor axis, and passes through the second slit, driven by another pulse motor. This slit adjusts the irradiation length in the range of 0 ~ 23mm to be able to solder various kinds of FPIC's having different lead array lengths.

Each pulse motor is controlled by a computer (NEC personal computer PC8801mk II).

Figure 2 shows the irradiation form of a condensed laser beam. The optical unit having fiber

Laser irradiation form (unit: mm)

Fig. 2 Shape and dimension of the rectangular and broad-area dual-beams.

with 500 μ m core diameter, a 60mm focal length collimator lens, and a 200mm focal length cylindrical lens makes the irradiation width about 2mm at the focal point. This width is measured by the burn pattern method⁴⁾ using an acrylic plate doped with black color material. This width is wide enough to heat both the QFP leads and pads. The distance between two parallel beams is also adjustable in the range of 0 ~ 40mm by varying the total reflection mirror angle.

This optical unit is held by a robot arm at the rear stage of the assembling system arranged to evaluate the unit as described in the next chapter. The robots moves and locates the optical unit accurately above the two lines of a SOP or QFP lead arrays to be soldered. The optical unit can be rotated 90° to be able to solder another two lines of QFP lead arrays. To prevent from warping of each FPIC leads, the FPIC is pressed during laser soldering by a pusher which is attached to the base of the optical unit at the center of the two parallel beams.

Figure 3 shows the periphery of the rear stage robot including the dual beam optical unit.

Fig. 3 Photograph of the rear stage of a belt conveyor and a robot hand with the dual-beam optical unit.

3. ASSEMBLING SYSTEM ARRANGEMENT TO EVALUATE THE DEVELOPED OPTICAL UNIT

An assembling system was constructed to evaluate the soldering performance of the developed optical unit. This system can handle a number of PWB's on which several kinds of FPIC's are assembled.

Figure 4 shows the schematic layout of the constructed assembling system. The PWB's stacked in the loader, are sequentially fed onto the belt conveyor. Tasks such as the solder supplying, FPIC's mounting and FPIC's soldering by the developed optical unit were shared be-

tween the two robots deployed along the belt conveyor.

A syringe held by the front robot squeezed the solder paste above each pad successively on the PWB in sequence of movement according to the robot teaching program as reported previously²⁾ to shorten the necessary time for solder paste supply. After supplying solder paste, this front robot mounts both 80 and 100 pin QFP's on a PWB.

QFP's are packed in a flat resin tray which is divided into 12×5 boxes and can contain 60 pieces of QFP's. The QFP cassette loader can contain ten stages of such trays. Therefore, 600 pieces of QFP's can be supplied successively.

Fig. 4 Layout of the system.

In order to mount QFP's precisely on the PWB's pads, the robot must get accurate position information regarding QFP leads and PWB pads.

In the present system, the 80 or 100 pin QFP picked up by the robot hand was monitored using two one-dimensional CCD cameras so that the accurate information about QFP lead position can be got.

A μ PD799D (NEC 2048-bit CCD image sensor) is used as a position sensor, whose specifications are shown in Table I. The reflection of the circular light from the lead array is detected by the camera at the magnification ratio 1 : 1. The CCD camera can have the field of view equal to the span of 28mm. Therefore, the FPIC, which is centered by a robot pick up hand within the accuracy of $\pm 0.4\text{mm}^2$) and carried by a robot onto the CCD camera within robot repetition accuracy of $\pm 50\text{ }\mu\text{m}$, can be easily positioned within the sweep of the CCD camera.

The data for the lead position information can be obtained by storing the picture element addresses of the CCD camera, in whose next addresses, light/dark states of the elements have changed to dark/light states, corresponding to the lead edges. Then these data are transmitted to the computer, which calculates the difference from the initialized data, and calculates the displacement of X, Y direction and, as a result, the rotation angle of the picked up QFP.

The PWB's position information was retrieved by the same method reported previously²⁾.

Table I The specification of the CCD camera (μ PD799D).

Number of picture element	2048
Pitch of picture element	$14\mu\text{m}$
Size of picture element	$9 \times 14\mu\text{m}$
Span of the detection area	$28672\mu\text{m}$

The computer sums the displacements of the QFP's and the PWB, and corrects the mounting position before QFP is finally mounted on PWB.

The robot controller (NRC 400 II) and the computer are connected via a RS232C communication cable.

After QFP's and SOP's are mounted, a PWB is fed into the rear stage of the belt conveyor. At this stage, the SOP's packed in a plastic stick, were fed by a vibratory part feeder. The mounted QFP's and SOP's are then soldered by the developed optical unit held by the rear robot. The rear robot also holds a spherical lens unit which can focus the image of the $500\text{ }\mu\text{m}$ core diameter fiber, with 1 : 1 ratio. The soldering speed of the newly developed method was compared with that of the scanning method²⁾ using the spherical lens unit having the resultant minimum spot diameter of 0.5mm .

The laser beam is switched automatically between the two optical fiber by the fiber switching unit⁵⁾ coupled to the YAG laser head emitting the maximum output power of 300 W.

Figure 5 shows a PWB used for system performance evaluation. In the figure, the paste-solder is supplied continuously along the lines of FPIC's pad arrays on the PWB.

Fig. 5 Printed wiring board for evaluating the system performance.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Solder Paste

The most suitable amount of the solder paste which would generate neither solder bridge between leads nor detaching, has been determined for the developed optical unit for 100 pin QFP's.

The soldering pad is made of tin-lead plated copper foil layered on the glass epoxy PWB. The QFP lead are also tin-lead plated. The pitch between the pads on the PWB is 0.65mm and the pad width is 0.3mm. The solder paste material is the same as reported previously²⁾.

The amount of solder paste was controlled by regulating the compressed air pressure, the needle inner diameter and the dispensing speed.

Figure 6 shows the dependence of the probability (per one lead, percent) that a solder bridge or a detaching will happen, on the amount of the supplied solder paste. The total laser power is 185 W and the irradiating time is

Fig. 6 Dependence of the probability for a solder bridge or a detaching on the amount of supplied solder paste. (per lead, percent), Laser power, 185 W ; Irradiating time, 3 s.

3 s for both sides of lead arrays. It was found from this figure that the solder amount from 2.5mg/cm to 7mg/cm is most suitable for this QFP.

4.2 Laser Soldering

Figure 7 shows the experimental temperature rise characteristics measured by the non-contact thermometer, for two points of 100 pin QFP leads and the point on the PWB 1 mm ahead from the edge of the relevant laser soldering leads. The measured area is about 1 mm diameter. The laser power is 180 W and the irradiation interval is 4 seconds. The peak temperature for the lead irradiated directly by the laser beam was 260°C, and the period in which the lead temperature is above 230°C, is 1.3 s. This peak temperature and the period are respectively higher and longer than those of the scanning method²⁾. This results from the larger input energy and longer irradiation time of the developed soldering method compared with these

Fig. 7 Temperature rises observed at two points of 100 pin QFP lead and a point on the PWB 1mm ahead from the edge of the lead during laser irradiation. Laser power, 180 W ; Irradiation time, 4 s.

of the scanning method.

Figure 8 shows the dependence of laser soldering characteristics of 100 pin QFP's on the laser power and the irradiation time.

At the region (I), some QFP's leads were oxidized because the laser energy is too high. At the region (III), the solder paste was not fused because the laser energy was too low. At the region (II), the QFP's are soldered satisfactorily. The minimum soldering time was found to be 1.5 s per two lines of QFP lead arrays for a laser power of 260 W.

The comparison of soldering capabilities between the dual beam method and scanning method was made. In the latter case, the spherical lens unit equipped at the rear stage robot was used for soldering. In this case, the laser beam irradiation diameter was adjusted to be about 4 mm by a vertical defocusing movement of the robot. A good solderability for a 100 pin QFP could be obtained at the laser power of 30 W and the scanning speed of 8mm/s. This condition enabled to solder four lines of 100 pin lead arrays in 13 s. At the laser power of 40

W and the scanning speed of 10mm/s, it was possible to solder the same lead arrays in 10 s. However the complete wetting of solder to the leads and the pads was impossible for scanning speeds higher than 10mm/s, even for a laser power in excess of 40 W. On the other hand, the dual beam optical unit could solder four lines of 100 pin QFP lead arrays in 6 s which includes the 90 degree rotation of the unit to solder another two lines of lead arrays at the laser power 180 W, and in 4 s at 260 W.

This concludes that the reduction of the soldering time by more than half is possible, by utilizing the developed optical unit instead of the scanning method.

Figure 9 shows the photographs for QFP leads and their neighborhood on the PWB sequentially taken during laser soldering. Thirty photographs were taken successively during the 3 s of the laser irradiation period. The photographs (a)~(f) were taken at the time of 0, 0.7, 1.2, 1.3, 1.4, and 3.0 s after the on-set of the laser irradiation. During the initial period of 0.6 s, the solder was never fused, though the flux in the solder paste was evaporated. At 0.7 s, as shown in (b), the solder between the leads, which have less heat capacity than that around the leads and pads, begins to be fused. These solder have been pulled and flowed to the leads by the surface tension of the fused solder until 1.2 s from the being of the solder fusion, shown as (c). But even at 1.2 s, the solder around the edge of the lead did not get wetted. This phenomenon can be explained as it takes long time for the solder around the lead to be wetted because the temperature rise at this area is lower than that of the leads during the laser soldering from the results in Fig.8. After 1.4 s from the on-set of the laser irradiation, as shown in (e) of Fig.8, the solder around this area has been pulled and flowed to the leads and pads by

Fig. 8 Dependence of the laser soldering characteristics on the laser power and the laser irradiation time at a constant solder amount.

Solder amount : 5mg/cm

Fig. 9 Sequential photographs of 100 pin QFP during a laser soldering by the dual beam optical unit.

(a) photograph was taken at the starting of a laser irradiation, (b) at 0.7 s, (c) at 1.2 s, (d) at 1.3 s, (e) at 1.4 s, and (f) at 3.0 s after the on-set of laser irradiation.

Laser power : 185 W

Unit irradiation time : 3 s

the surface tension of the fused solder. In the following 1.6 s all solder was wetted completely.

This experimental result revealed that the

flux in the solder paste is evaporated in the first quarter of the unit soldering time, the dispensed solder is fused and pulled to the leads

Fig. 10 Dependence of the laser irradiation time for the three different FPIC's to be soldered satisfactorily by the two rectangular parallel beam optical unit, on their lead volume and lead pitch.

Laser power : 180 W

and the pads in the next quarter, and the fused solder wets to the leads and the pads completely in the remaining half of the unit soldering time. The delay of the soldering around the edge of the leads will be decreased by improving the laser intensity profile at this area.

Figure 10 shows the dependence of the laser irradiation time on the lead volumes and the lead pitches for three different FPIC's to be soldered by the developed dual beam optical unit. The laser output power was 180 W. From these results, the irradiation time for FPIC's to be soldered satisfactorily was found to be roughly proportional to the lead volume per the FPIC's lead pitch.

5. CONCLUSIONS

We have developed the rectangular and broad area dual beam optical unit for a surface mounting LSI package and got the following results.

- (1) The solder paste amount from 2.5mg/cm to 7mg/cm was found to be most suitable for 100 pin QFP soldering when the newly developed optical unit is used as a reflow heat source.
- (2) The peak temperature in the lead during laser soldering was 260°C and the period, during which the lead temperature is above 230°C, was 1.3 s at the laser power 180 W. These are respectively higher and longer than those of the previously reported scanning method.
- (3) The newly developed dual beam optical unit could solder two lines of 100 pin QFP lead arrays in 1.5 s and four lines of lead arrays in 4 s at the laser power 260 W. This processing time is reduced to less than half from that of the previous scanning method.
- (4) The sequential photographs of the lead during the laser soldering revealed that the flux in the solder paste is evaporated in the first quarter of the 3 s-long unit soldering time and the dispensed solder is fused and pulled to the leads and pads in the next quarter and wetted completely in the remaining half of the unit soldering time.
- (5) The laser irradiation time for good soldering is roughly proportional to the lead volume per the lead pitch of FPIC's.

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