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# Real-time Observation of Hydrogen Plasma Reflow Process with Lead-free Solder Pastes

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## 1. Introduction

In the field of semiconductor packaging, demand for flip chip bonding by lead-free solder bumps is growing rapidly. A flux is normally used in soldering process to remove initial surface oxides. However, the flux can lead to the corrosion of the circuit board due to the flux residues which should be cleaned after soldering. Chlorofluorocarbons are normally used as the cleaning agents, but they are believed to be damaging the earth's protective ozone layer. Furthermore, in the fine pitch flip chip package, cleaning of the flux residue is becoming difficult.

Recently, we have developed ultra-low residue and lead-free solder bumping process using stencil printing and hydrogen plasma [1, 2]. In this process the reduction of the hydrogen plasma, instead of the flux, will remove the surface oxides of the stencil printed lead-free solder paste. Plasma reflow method is strongly affected by the irradiation time and its timing. Sometimes, serious generation of voids inside the bumps and solder scatter to the surroundings have been observed [2,3].

To clarify these phenomena and optimum reflow conditions, in-situ observation of the reflow process is necessary. In this paper, we demonstrate in-situ observation of solder melting process by hydrogen plasma reflow with a CCD camera. The experimental results show that the excessive irradiation of hydrogen plasma on the melting bumps leads to the generation of voids inside the bumps.

## 2. In-situ Camera System in Hydrogen Plasma Reflow Process

The schematic representation and the photograph of the plasma reflow apparatus are shown in Fig. 1 and 2. In this reflow apparatus, printed chips are carried by the robot arm automatically from the load lock chamber into the plasma chamber.

In order to observe the reflow process, we installed the CCD camera system into the vacuum chamber. The magnification of camera is 245x. In order to prevent the heat damage of the camera, the camera system is water-cooled. Observation angle is 40 º and the focal distance is about 50 mm not to obstacle the hydrogen plasma by covering the upper part of sample with camera as shown in Fig. 1. The camera can move in the x, y, and z-direction by 10, 10, and 60 mm, respectably. By measuring temperature of the heater with the thermo-couple, heating can be done from pre-heat temperature (189 ºC) to peak temperature (225 ºC) in 90 seconds. In the chip side, the temperature raises 5 ºC by the plasma irradiation. The temperature distribution of the heater is about ±0.5 ºC on 12-inch wafers, which is small enough to be neglected.

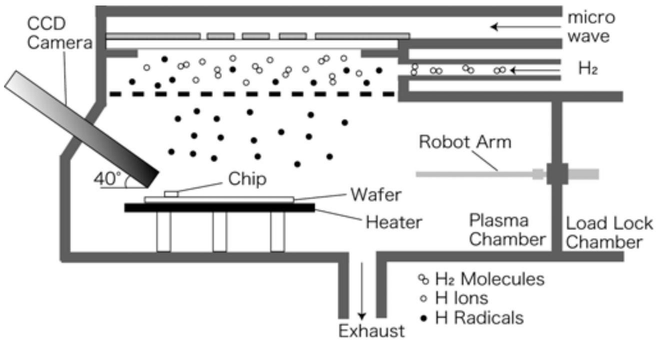



Fig. 1 Schematic representation of plasma reflow apparatus.

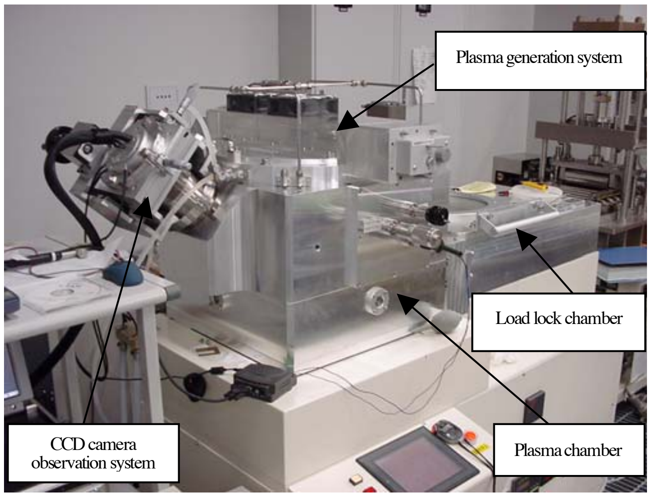



Fig. 2 Photograph of plasma reflow apparatus.

## 3. Stencil Printing on the Chip

As the economical way to produce solder bump, we used the stencil printing. Stencil printing of solder paste easily adapts to lead free solders, since the paste is available in a wide range of alloys. Solder paste is prepared by kneading M705 solder powder and NRB50 solder flux without highly activated elements, such as rosin and halogens. The M705 solder is composed of Sn-3.0Ag-0.5Cu. The diameter of the particle is 5~15 μm and the melting point is 220 ºC. The NRB50 flux occupies 9.5~11.0 wt% of the paste, and the viscosity is 200~400 Pa・s. The paste is printed on the chips with automatic solder printer (MK-838SV) made by Minami Co., Ltd. Pad pitch on the chip (20 mm square) is 200 μm and the diameter of under bump metallurgy pads is 100 μm.

## 4. Experiments

A standard temperature profile in this study is shown in Fig. 3. The process is performed as follows; (i) pre-heating (189 ºC) for evaporation of organic acid and solvent in paste, (ii) first irradiation of plasma for the surface oxides removal using reduction of the hydrogen radicals, (iii) keeping temperature (225 ºC) at above melting point for bump formation, (iv) second irradiation of plasma for bump reshaping, and (v) atmospheric pressure compression for void reduction. The total profile consists of pre-heating for 10 min, first irradiation of plasma for 75 s, keeping temperature (225 ºC) for 185 s, second irradiation of plasma for 15 s, and atmospheric pressure compression for 60 s. As comparison, second irradiation of plasma for bump reshaping was performed for 900 s (225 ºC). We recorded the melting behavior of the solder paste during the reflow process. For more detailed observation, we used SEM (scanning electron microscopy). However, high-speed dynamic behavior can only be observed using real-time monitoring system with the CCD camera.

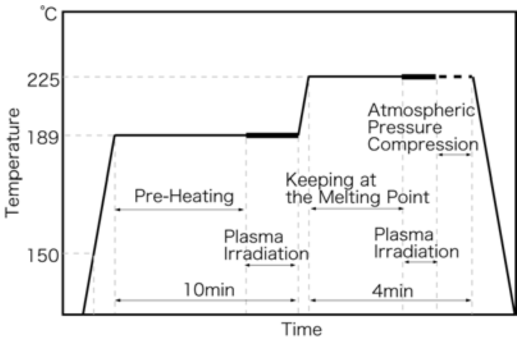
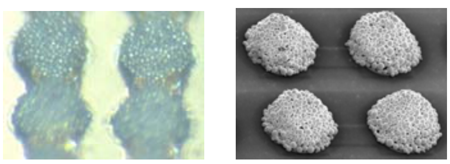



Fig. 3 Standard temperature profile.

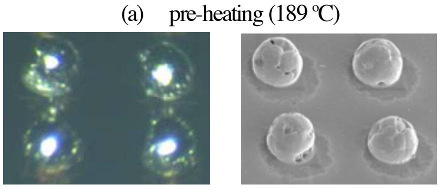
## 5. Results and Discussion

Figure 4 shows the observation results of the reflow process of solder paste. Figure 4(b) shows that the solder bumps begin melting at the melting point. However, a sufficient spherical shape could not be obtained. As seen in Fig. 4(c), the shape of the molten bumps after second irradiation of plasma was changed to a nearly spherical shape.

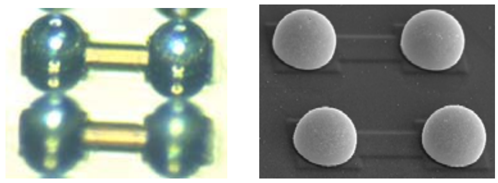
However, large-size voids were generated in the case of long-time irradiation of second plasma (900 s). We observed that the bumps were exploded many times because of the expansion of the internal gas [Fig. 4(d)]. X-ray transparent images are shown in Fig. 5. Table I shows the measured incidence of voids (the number of bumps with voids / the total number of bumps). Table I shows high incidence of voids (approximately 80 %) in the case of second irradiation of plasma for 900 s, while extremely low incidence of voids (1 %) in the case of standard reflow profile.



(a) pre-heating (189 ℃)



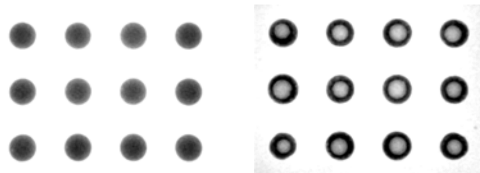
(b) keeping temperature at 225 ℃



(c) after second irradiation of plasma (15 s, 225 ℃)

(d) during second irradiation of plasma (900 s, 225 ℃)

Fig. 4 Photographs showing the shape change of the printed solder paste during reflow process (left; CCD camera, right; SEM).



(a) (b)

Fig. 5 X-ray transparent images, (a) standard reflow condition, (b) second irradiation of plasma for 900 s .

Table I Incidence of voids

| | incidence of voids | 0-10 μm | 10-20 μm | 20-30 μm | 30 μm- |
|---|---|---|---|---|---|
| standard reflow profile | 0.0115 | 0.0048 | 0.0066 | 0.0000 | 0.0000 |
| plasma irradiation (900 s) | 0.8160 | 0.0031 | 0.0305 | 0.0218 | 0.7607 |

Therefore, irradiation time of plasma should be controlled properly.

## 6. Conclusions

A real-time monitoring system for lead-free solder bumping process using stencil printing and hydrogen plasma has been demonstrated. It was possible to observe dynamic melting process in vacuum condition with a CCD camera. The hydrogen plasma reflow was as effective as flux in ball shaping. However, the excessive irradiation of plasma on the melting bumps led to the generation of voids.


## Acknowledgements

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## References


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