Establishment of a Lead-Free Reflow Soldering Technology That Supports Components with Low Heat Resistance

Masahito Nozue　Takashi Obinata

Lead-free solders made of tin, silver and copper that have become the mainstream solders, have melting temperatures between 217 and 220°C, which is 30°C or more higher than conventional solders containing lead. Reflow ovens that support lead-free soldering commonly used in automated soldering processes adopt the convection fan method as the means for heating to maintain an evenly high internal temperature. For this reason components were exposed to high temperatures, which meant that components with a lower thermal resistance could not be used. Further, uniform heat transfer was difficult with multilayer and large scale, high density, package mounted substrates and ball grid array (BGA) terminal components that were used in sophisticated communications equipment and copying machines. Therefore, connection failure often occurred and common lead-free compatible reflow ovens could not be used.

These components needed to be replaced with alternative components with a high thermal resistance or mounted individually afterwards manually or by using special equipment.

At Oki Electric, we have been able to establish a fabrication method that resolves such problems related to lead-free soldering, by jointly developing a “component temperature rise controlled reflow technology” with the Furukawa Electric Co., Ltd. This technology adopts a new heating method, which realizes the automatic soldering of electronic components that have a low thermal resistance by inhibiting the temperature rise of components.

Status of lead-free conversion activities

There is a worldwide movement to regulate the use of lead, due to its harmful effects on the human body.

Particularly in Europe, with the restricted use of certain hazardous substances (RoHS), a regulation to stop the use of harmful chemical substances will begin from July 2006. The means to respond to the regulation restricting the use of solder containing lead is a major concern for corporate organizations dealing with electrical equipment and electronic devices.

At Oki Electric an environmental conservation activity program known as “OKI Eco Plan 21” was established, with a target to “totally abolish solder containing lead from major products by the end of fiscal 2003”. The establishment of technologies to attain this target has been promoted from the early stages.

The “component temperature rise controlled reflow soldering technology”, reported in this paper, is one result of such development.

Reasons for selecting Sn-Ag-Cu-type lead-free solder

High reliability is demanded of soldering materials that are used in communications equipment requiring a long product life. For this reason, comparison studies were made on items, such as those described in Table 1, keeping in mind that these materials need to have the following characteristics:

(1) Highly reliable materials
(2) Same material usable in all processes
(3) Industry standard materials
(4) Avoid factors that contribute to an increase in costs, such as patents

As a result, the Sn-3Ag-0.5Cu soldering material with its high connection reliability was selected.

Table 1　Lead-free solder selection result

Item	Lead-free conversion issues	Eutectic solder	Lead-free solder		
			Sn-Ag-Cu-type (JEITA) recommended composition	Sn-Ag-Cu-xx-type	Sn-Zn(-xx)-type
Solder melting temperature	Rise of melting temperature due to change of composition	183˚C	217 ~ 220˚C	210 ~ 217˚C	189 ~ 198˚C
Solder wetting characteristics	Deteriorated solder wetting characteristics due to reduced fluidity and increased surface tension	Good	Inferior (Melting temperature is high)	Good	Bad
Connection reliability	Alloy layer changes due to change in composition metals	High	High	Low	Low
	Liftoff arising from the difference in the melting points of composition metals	-	Rare	Often	-
Workability	Oxidation progression of composition metals	Good	Good	Good	Bad (rapid oxidation)
Effects of lead containing components	Connectivity when combined with existing components	-	Small	Medium	Large
Use in all processes Flow/reflow/manual soldering	Oxidation progression of composition metals	Possible	Possible	Possible	Reflow not possible

Since an aspect of the soldering material is its high melting temperature, soldering equipment that can heat uniformly at a high temperature will be required.

Necessity to support low thermal resistance components

(1) Aspects of reflow soldering

The common method for soldering components onto a substrate is by mounting components on a preprinted substrate and the heating the entire substrate to remelt the solder. This type of soldering method is called “reflow soldering” (Fig. 1).

If the melting temperature rises, such as with lead-free solders, then correspondingly, the temperature of the entire substrate also needs to be raised, making the component temperatures high at the same time. A reflow oven of about eight meters in overall length is used for heating with heaters above and below a conveyer that carries the substrates.

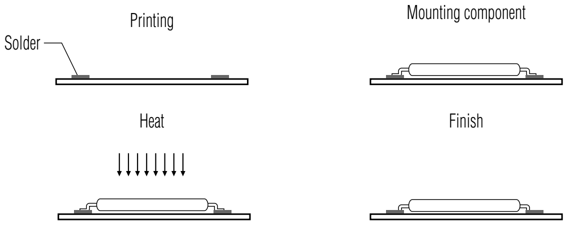


Fig. 1 Summary of reflow soldering

Heating methods vary among manufacturers in terms of types and the number of heaters used, the heating atmosphere, etc., however, the convection fan method is the common type used for lead-free soldering.

(2) Thermal resistance of components and 230°C limitation

Substrates for communication equipment produced by Oki Electric have the following features:

1) Substrates have a long product life cycle.
2) Wide range of substrates produced in a small volume.
3) Many components have a thermal resistance of 230°C or lower.
4) Large sizes, multiple layers and high densities (with many mounted BGAs).

For these reasons, it is extremely difficult to take steps, such as changing components or substrate design, when conducting high temperature reflow for lead-free soldering.

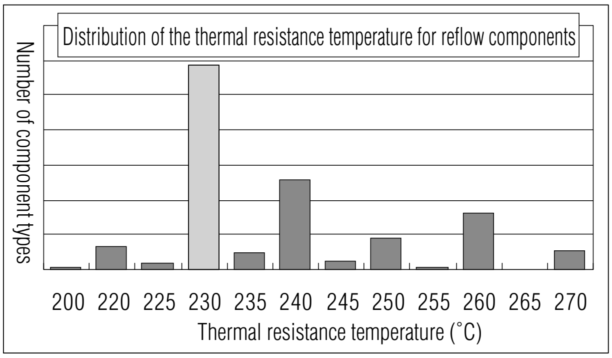


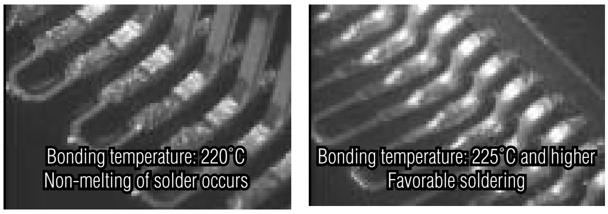
Fig. 2 Reflow thermal resistance temperature and number of component types

A survey of the thermal resistance temperature of components used, resulted in a finding that about 45% of all component types had a thermal resistance temperature of 230°C or less, as indicated in Fig. 2. Since most of these components are ICs, which are difficult to switch to alternative components, the component temperatures must be kept at or below 230°C to conduct reflow soldering.

Although manual soldering is one of the fabrication methods that can be used instead of reflow soldering for components with a low thermal resistance, it would lead to a deterioration in quality due to variations arising from the work and, since also may be a contributing factor to a rise in costs, it would not be a realistic approach.

Securing heating process margin

While conventional eutectic solder reflow a variance of up to 47°C can be tolerated in the substrate heating temperature, between the thermal resistance of components to 230°C and the solder melting point of 183°C. On the other hand, with lead-free soldering only 10°C can be tolerated between the thermal resistance of components to 230°C and a solder melting temperature of between 220 and 217°C (Photo 1 and Fig. 3).



Phot. 1 Reflow temperatures and conditions of soldering

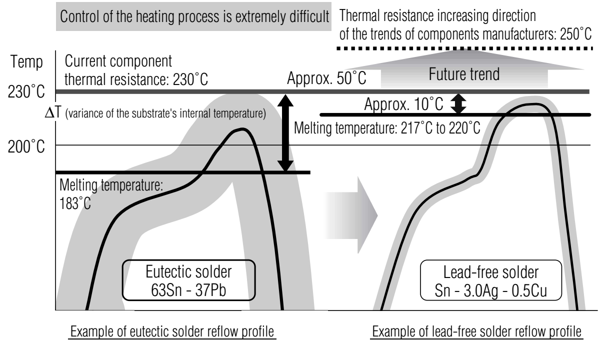


Fig. 3 Comparison of temperature margins of lead-free solder and eutectic solder

Current levels and target setting

As part of a study into the process for lead-free soldering, the performance of reflow ovens, manufactured by various companies, was investigated using substrates for communication equipment. As a result it was found that although the variance of the substrate's internal temperature for conventional reflow ovens supporting eutectic solders (high temperature portions: Component bodies; low temperature portions: Temperature difference at soldered sections) was 18°C, commonly available reflow ovens for lead-free solders had a substrate internal temperature variance of 12°C (Fig. 4).

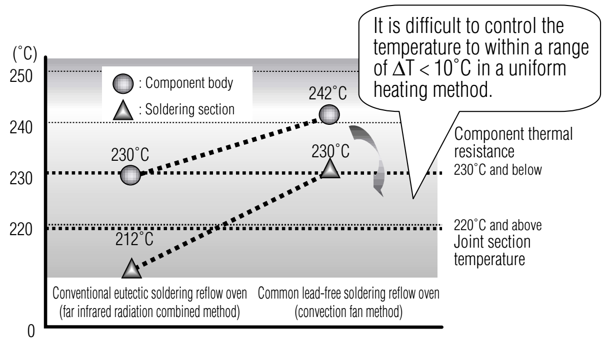


Fig. 4 Comparison of the temperature variance between substrates

Keeping in mind that the temperature margin of lead-free soldering must be 10°C or less, the actual development target was set with a substrate internal temperature variance of 10°C or less. For this reason, in order to inhibit the rising temperature of components and by taking an inverse action, the temperature variance was intentionally created on the top and bottom surfaces of the substrates, resulting in a heating method that makes it possible to bring about:

- Component temperature < soldering section temperature.

Determining a basic structure for a component temperature rise controlled reflow oven

Fig. 5 shows the structure of the reflow oven[1] that was developed. Fig. 5 is a vertical section diagram of a view in the direction of the substrate flow in the reflow oven.

Component mounted substrates are transported on rails between heaters that are installed on the top and bottom in the direction of the arrow in the center, as shown in the diagram. Heaters at the entrance of the conveyer have a relatively low temperature, but the oven is designed in such a way that the temperature of the heaters closer to the exit are higher.

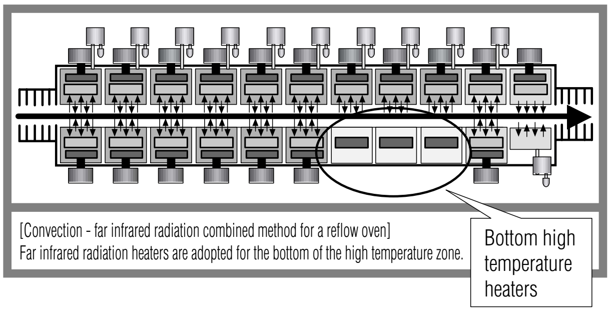


Fig. 5 Structure of a reflow oven (cross section diagram)

Heaters commonly used for reflow ovens are hot air heaters, but in this instance far infrared radiation heaters were adopted for the bottom heaters. By combining the two different types of heaters, temperature interference was kept to a minimum to gain the effect of broadening the temperature variance inside the component mounted substrates.

Realizing non-uniform top and bottom heating

When hot air heaters are used for both the top and bottom sections of a reflow oven, it is difficult to create a temperature variance between the heaters on the top and bottom, since they both directly blow hot air towards the other and equalize the temperature.

On the other hand, by using far infrared radiation heaters at the bottom, there is no direct application of hot air from the bottom whose temperature is higher than that of the top section, to the top side. Additionally, a circulating structure that absorbs and cools the hot air that it generates was adopted for the hot air heater on the top section, to inhibit a rise in temperature. It was possible through these methods to maintain to a minimum the temperature interference of the facing heaters, which succeeded in controlling the temperatures of the top and bottom heaters individually and realized a non-uniform heating method that inhibits the temperature rise of components on the component side of the substrates (patent pending) (Fig. 6).

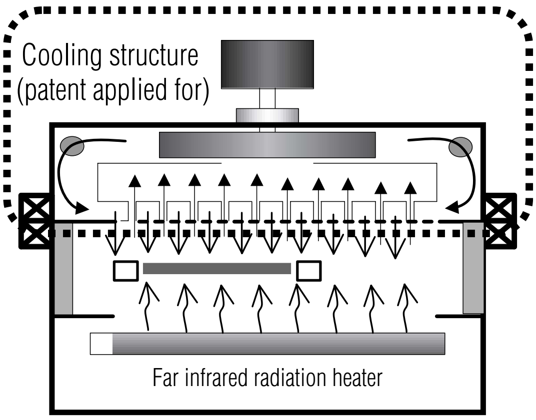


Fig. 6 Structure of a reflow oven (front view)

Verification results

The substrate for study of the process (Fig. 7) was used to conduct performance verifications of the developed reflow oven.

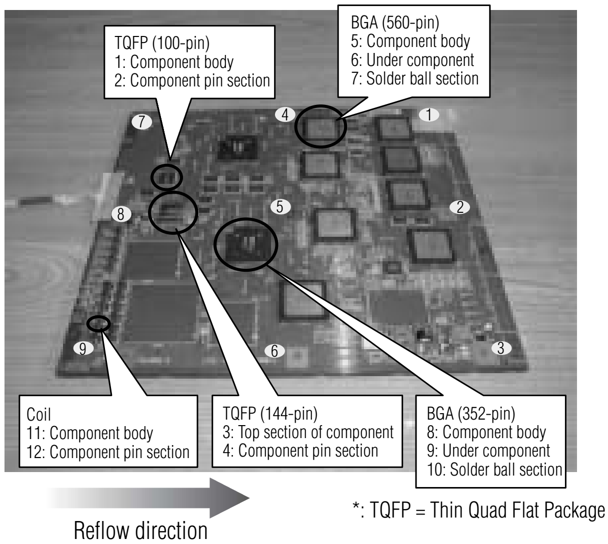


Fig. 7 Substrate used for the verification of effects and measurement locations

A verification result is shown in Fig. 8. Although the conventional common convection method, causes the temperature of component bodies to rise higher than soldering sections, the developed reflow method made it possible to reverse this temperature tendency, thereby allowing the control of both the soldering temperature and the rising temperature of components.

Therefore, although the conventional heating process could only support 45% of component types when lead-free soldering was used for existing products, it has become possible to apply the reflow process to up to

93% of component types. This leaves 6% of components that have been dealt with individually in the past by manual soldering, and 1% of components, which have to be either individually dealt with or changed, to make lead-free soldering possible (Fig. 9).

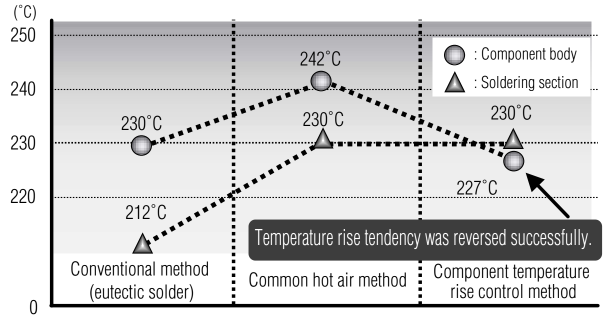


Fig. 8 Verification results of effects

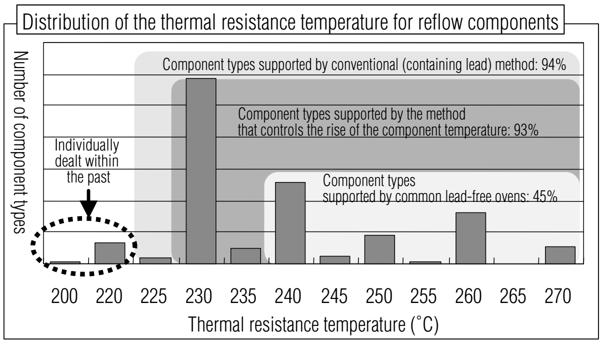


Fig. 9 Reflow thermal resistance temperature and number of component types (result after applying the temperature rise controlled method)

Component arrangement standard for component mounted substrates

As described thus far, a method was developed that controls the rise of the component temperature by creating a temperature variance between the heaters on the top and bottom. This was achieved by setting the top heater temperature to cool the components, but it was also necessary to consider the rise in temperature from the bottom of the substrate.

The limitation conditions of the component thermal resistance temperature for each substrate process are shown in Table 2. A method that controls the rise of the component temperature is extremely effective for substrates that could be handled with a conventional eutectic soldering process for reflow / flow component mounting (component side is reflow mounted, while the solder side is mounted with flow soldering). However, for reflow / reflow component mounting (substrates on which reflow component mounting is performed on both the component and solder sides), it is necessary to design manufacturing processes and component arrangements assuming that the required component thermal resistance will rise by approximately 10°C on the solder side.

Further, it is possible to heat with a uniform temperature, similar to that of common lead-free soldering reflow ovens, as processes selectable with this equipment.

Table 2 Limitations of component thermal resistance (Selectable)

	Process	New heat reflow oven		Common convection reflow oven
1	Reflow / flow component mounting	Component side: 230°C and higher (Solder side: 250°C and higher)	New heating	Component side: 240°C and higher (Solder side: 250°C and higher)
2	Reflow / reflow component mounting	Component side (2): 230°C and higher Component side (1): 250°C and higher	New heating	Component side (2): 240°C and higher Component side (1): 240°C and higher
		or, Component side (2): 240°C and higher Component side (1): 240°C and higher	Conventional heating (Selectable)	

Conclusion

Support for lead-free soldering has been slow in developing but the reflow soldering technology that controls the rise of the component temperature will bring about great advantages to highly dense and large substrates. It is believed to be extremely effective for medium size substrates as well, for which the adoption of alternative components with thermal resistance has not been progressing.

The lead-free soldering process that uses this reflow oven is being applied not only to Oki Electric products, but also to products of the Electronics Manufacturing Service (EMS) business as well, which started in fiscal 2002.

In the future, we intend to further expand the range of products to which this technology can be applied, promote additional steps for reducing the burden on the environment and contribute to the expansion of the EMS business with this core technology of the Manufacturing Service Company of Oki Electric.

References

1) "Soldering equipment that supports lead-free soldering", The Soldering Subcommittee of the 35th Microjoining Commission, p.61, Jul. 2003

Authors

Masahito Nozue: Manufacturing Service Company, EMS Business Div., Quality Assurance Dept., General Manager

Takashi Obinata: Manufacturing Service Company, EMS Business Div., Quality Assurance Dept., Production Engineering Team, Assistant Manager