Electrocomponent Science and Technology, 1981, Vol. 8, pp. 21–25
0305-3091/81/0802-0021 $06.50/0

SOLDER PASTE PROCESS OF HYBRID CIRCUITS

HAYATO TAKASAGO, KOHEI ADACHI, YOUICHIRO OHNISHI and KAZUO TAZUKE

Mitsubishi Electric Corp., Manufacturing Development Lab., Amagasaki, Japan

This paper describes the critical factors required for the solder paste process and its applications to Hybrid Circuits (Solder Paste Process). It also describes the fine solder printing of substrate pads for flip chip IC and the simultaneously thick printing of solder paste for chip capacitors and/or other parts.

Through this "Solder Paste Process", assemblies of good quality and higher yields are achieved. The results of various evaluation and reliability tests were excellent. From this study, some new applications of solder paste are presented.

1. INTRODUCTION

1.1 Background

Solder paste (or solder cream) has been used in hybrid IC fabrication for relatively many years, so it is not a new material. But with the introduction of improved solder paste and automated machines the use [1] of the paste is growing rapidly. Recently it is being used for very severe environments such as in automobile electronics.[2,3]

The features of solder paste methods are well known.

Favourable features are that all parts are placed on a substrate and then simultaneously soldered, thus providing:

1) Labour saving in production
2) Good bonding characteristics

It emerged in practice that representative unfavourable aspects can also be listed, since a solder paste is a mixture of fine solder powder and flux. These are:

1) Good reflowing–soldering (reflowing) is difficult
2) Higher materials and processing cost result
3) Unstability

1.2 Objectives

The objective of the study is to utilize the favourable features of the solder paste method to develop a more mass productive and reliable process for hybrid circuits that contain a flip chip IC and several chip capacitors and inner leads on the same substrate; and to obtain significant improvements in the unfavourable aspects of solder pastes.

1.3 Study and Results

The main study is related to the following:

1) Solder paste and its printing techniques using optimum printing masks
2) Reflowing techniques for solder paste

2. SOLDER PASTE PROCESS

The process is shown in Figure 1 which is a typical and simple flow diagram for the solder paste method. The important factors relating to each stage are shown.

The factors are dependent on each other so that sometimes due consideration of trade-offs are required to specify optimum factors for the solder paste process.

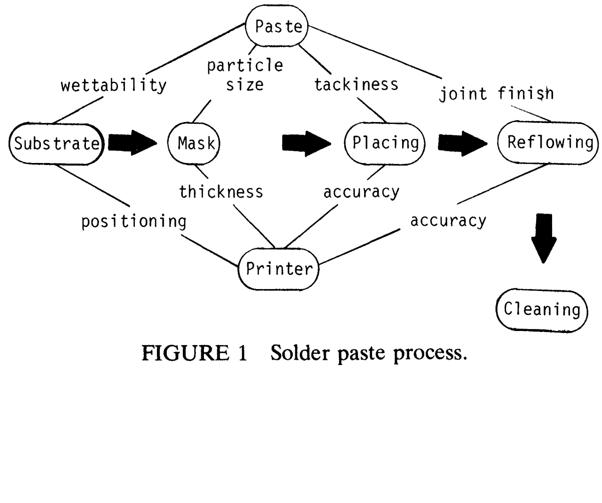

FIGURE 1 Solder paste process.

Important factors are reproducibility, productivity, higher yields and lower cost. These are common and essential factors in production but important in our process. For example, in solder printing the following are needed.

Paste Stable and low cost

Mask Easy mask positioning, cleaning and long life

Printer High speed and accuracy

During the development work the unfavourable aspects mentioned above emerged. The representative symptoms are listed in Table I.

TABLE I
Representative symptoms

Mask	Clogging the screen
Printing	Paste Spreading (after printing or drying)
Placing	Parts are run over to other conductor areas or excess "solder ball" (under or side of parts)
Reflowing	Voids Paste Spreading during reflowing
	Discoloration at the Cond./Solder boundary of conductor surface

3. SOLDER PASTES

Solder paste is a metal/chemical system that is a mixture of solder powder, flux, activator and solvents, etc.

An evaluation of the various factors is shown in Figure 1 for several solder pastes that are available in the market. These were based on 63Sn/35Pb/2Ag alloy from which closely formulated alloys were selected.

These materials were not useful in our solder paste process. The reason is that one or more of the representative aspects shown in Table I appeared. Therefore, it was necessary to design an improved solder paste. These design considerations and main characteristics of the new paste are as follows:

1) The rosin based, 63Sn/35Pb/2Ag alloy is the same, but

2) The size (mesh) of the solder powder is relatively large and the particle shapes are not spheres (as shown in Photo 1 (270 mesh pass)).

3) The solder alloy content is 88 to 90 wt%.

PHOTO 1. Solder particles.

4. MASK

Many kinds of masks have been used for hybrid ICs in the past years, stainless steel mesh, suspended metal mask, open metal mask, etc. We have considered the compatibility of solder paste printing with these masks from the view of conductor paste printing.[4]

Normally with a fine mesh screen, the printed paste thickness becomes much reduced, and in addition the mesh screen method will not give considerable change in deposited paste thickness due to the difference of pattern sizes, because it has a constant opening that is divided equally by mesh wires. In the case of conductor paste printing, fine patterns can be easily obtained but the printed thickness is normally of the order of 30 μm or so. This thickness is too thin for joining large chip capacitors or inner-leads. Even if this thickness is valid, the greater part of the solder particles will be trapped in the fine mesh screens. Photo 2 shows an example of the suspended metal mask. The mesh wires are observed in the opening of an etched foil.

An open metal mask has been tried before by P. Scharf for conductive epoxy printing[5] and by L. F. Miller for resistor paste printing.[6] The grain size of particles contained in solder paste are much larger than in conductive epoxy or resistor paste, so an open mask is believed to be best for our solder paste process.

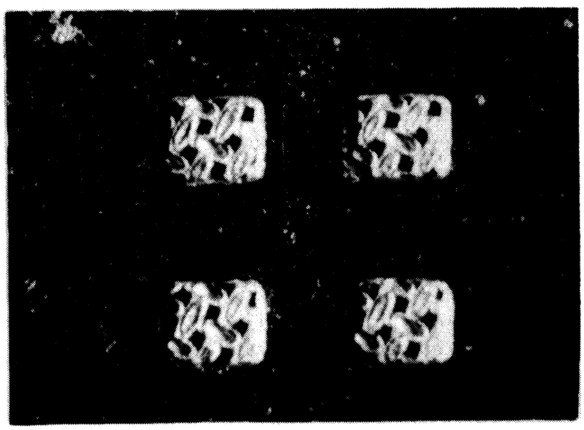

PHOTO 2. Suspended metal mask (120 mesh, 250 × 300 μm etched foil visible through holes).

5. PRINTER AND PRINTING

A high speed, high accuracy automated printer was used that had a six-divided rotary index table and an automatic unloading system.

Important printing factors for open metal masks are the squeegee angle of attack, the squeegee pressure, the snap-off distance, etc. For open masks squeegee results were obtained at about 40°. Squeegee pressure must be set properly for solder paste printing. If having squeegee pressure was applied at a contact printing or near the contact region, the pastes were dispersed and caused a failure of "solder ball" generation. If much lower pressure was applied the solder thickness was increased too much. Also this caused a "solder running" failure because of insufficient contact between solder pastes and conductor surfaces.

Figure 3 shows printed thickness curves of changing the snap-off distance, where the upper line is the thickness for a chip capacitor pads and the lower is the thickness for flip chip IC joining pads. These pads were simultaneously printed through the mask. As shown in Figure 2 our pattern sizes for chip capacitors are large (about 1 × 2 to 3 × 2 mm) and for flip chip IC pads are very small (about 250 μm square). In Figure 3 the open mask has no mesh, so that at the near contact region the printed solder thickness for chip capacitors is almost equal to the metal thickness (in this case is 0.16 mm), but for a flip chip IC this is about 75% of the thickness. Taking a larger snap-off distance the thickness of paste for chip capacitor is linearly increased but the thickness for flip chip ICs remains almost constant. At further distances very thick solder pastes are obtained for chip capacitors, but thickness reproducibility becomes rather lower.

With these results, even if some deviation of printing condition occurs, the solder thickness for a flip chip IC remained relatively constant. (See Photo 3.)

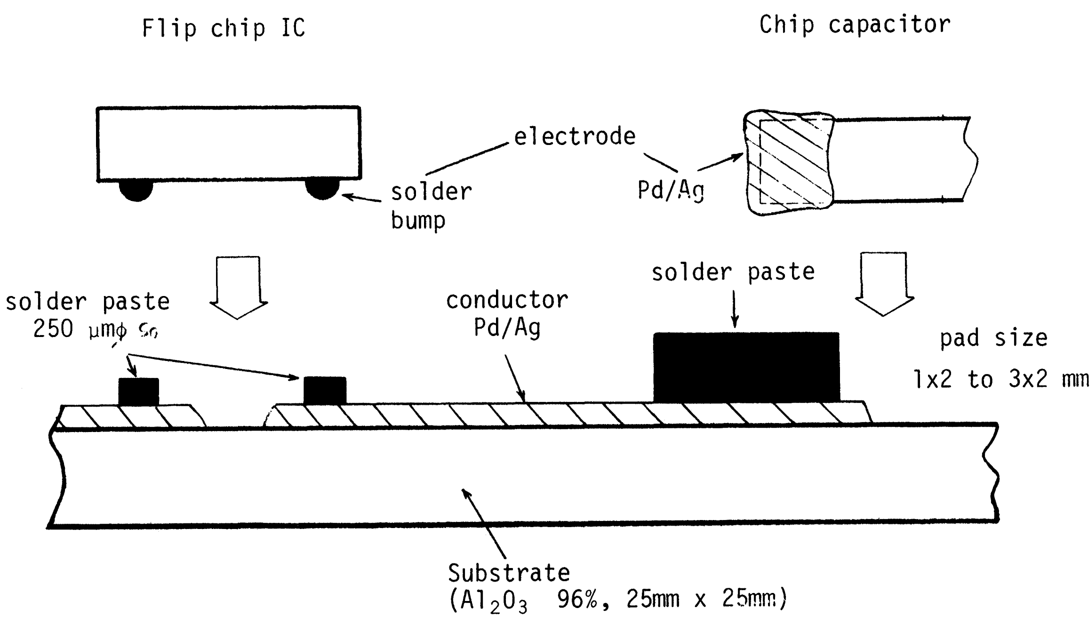

FIGURE 2. Hybrid circuit using solder paste process.

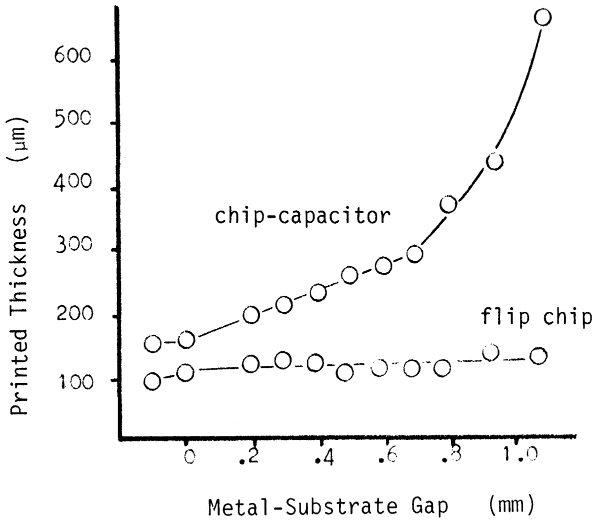

FIGURE 3. Paste thickness vs. snap-off distance.

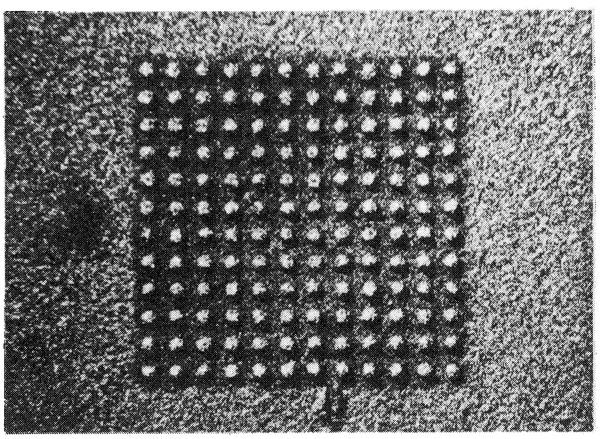

PHOTO 3. Example of fine solder paste printing (before reflowing) (100 μm, diameter balls 12 lines × 12 columns).

6. PLACING

With regard to placing, one must control the placing accuracy, placing pressure and drying condition of the solder paste.

In the case of placing accuracy, we noted that a conventional chip capacitor is satisfactorily self-aligned even when incorrectly displaced by about ±0.5 mm. Successful placing of a flip chip IC however requires more precise matching accuracy.

Excessive placing pressure causes solder paste to protrude and considerable "solder balls" are formed under or around the assembled parts.

After solder paste printing, the printed paste is sometimes dried in order to facilitate handling. In our results, moderate drying brings better reflowing characteristics. However, we can simplify the process only by keeping the substrate for a certain time at ambient temperature without drying, after printing. When assembling the "Mini-Mold" transistor, having a SOT-23 package, this tends to stand on its lead because of the unfavourable surface condition of the lead. But we can solve this problem by heating the mounted substrate for 5 to 10 minutes in an oven. By such a process we can simultaneously fix every mounted component without using a special operation and a placer.

7. REFLOW

This stage is very important in order to obtain a good solder bonding.

After preliminary experiments, we decided to use a three zone tunnel belt furnace where the substrates are heated from their upper side. From our experimental results it became clear that the reflow profile of the paste has a great effect on the solder, particularly with regard to the inclusion of voids, solder bump absorption and so on.

The causes of the voids are occlusion of the outgassing organics of the paste or expanded air trapped on the conductor surface. In fact, when the substrate as printed is rapidly heated the centre portion of the printed paste swelled up. Therefore, adequate preheating time is needed for the solder paste process.

Good solder texture is obtained by quick cooling after reflowing. However, since quick cooling results in thermal shock to the mounted components, one cannot in practice cool too quickly.

In the reflowing profile, solder paste begins to melt in the region which is about 2/3 to 1/2 of the total distance from the exit of the main heating zone, and boiling of the flux does not occur until just before the entrance to the cooling zone. The total time for melting of the solder is 15 sec.

8. CLEANING

The difficulty of cleaning has been believed to be one of the problems in utilizing solder paste. This is substantial for solder paste, since the paste consists of powdered solder and no cleaning is permitted before the reflow stage. In particular, the adhered "solder balls" and fluxes under the chip components are not easily cleaned and can give some trouble.

As described in an earlier section, an improvement of paste compositions and processes was made in order to reduce the occurrence of "solder balls".

In addition, it was found that a solvent mixture of trichlorethylene/ethanol (5:1 by vol.%) gave a very good cleaning effect.

9. OTHER IMPORTANT FACTORS IN THE SOLDER PASTE PROCESS

There are two distinct regions in solder paste processed circuits, one of which is where the conductor is solder coated and the other where the conductor is exposed, since paste is usually only deposited on a restricted portion of the conductor where components are to be bonded.

This results in a thickness change at the boundary between the solder coated conductor and the plain conductor, and sometimes at this step cracks appear during the heat cycle tests.

Thus the conductor pattern suitable for the solder paste process must be controlled. For example, in order to prevent the occurrence of "solder balls" or cracks in the periphery of the reflowed solder, the size of pad or width of conductor should be larger than that of the solder coated area.

Sometimes a black discoloration in the boundary region of conductor/solder was observed. In these regions particularly, the wettability of solder was poor. The solder we designed does not show this discoloration.

10. CONCLUSIONS AND SUMMARY

1) Yields of assembled circuits using the new solder paste process method are extremely good except in such rare cases as incompletely printed thick film conductors, poor snap-edged substrates or defective chips loading. The yields of the process for printing the paste and the related bonding is almost 100%.

2) The cost of the solder paste is substantially the same as that of dipping solder.

3) Properties obtained from this method such as bond-strength, solder leach, variation of solder thickness, and productivity are superior to those of dip soldering.

4) The reliability of hybrid circuits constructed using this process is high in terms of the heat cycle test ($-40°C \sim +150°C$, 1000 cycle), heat resistance (175°C, 1000 Hr), and humidity and bias test (85°C, 85% Rh, 1000 Hr).

5) The process satisfies the requirements for reliable production.

6) The process can probably be extended to give 100 μm patterns (see Photo 3) by using fine solder powder.

With the tendency towards high density or small packaging, the development of chip components and automated machines, the solder paste process will play a significant role from now on. A more suitable solder paste is expected for new applications.

ACKNOWLEDGEMENT

The authors would like to thank Katsuhiko Fukumi for this contribution in the preparation of this paper.

REFERENCES

1. Alfred R. Kroehs, "Bonding Alloy Placement and Device Attachment by the Use of Metal/Chemical Systems", pp. 71–80, *International Microelectronics Symposium, (U.S.)*, (1969).
2. Leoncio Y. Ang and Larry D. Leadbetter, "A Hybrid Circuit for Anti-Lock Braking Application in Heavy Truck Environment", pp. 276–279, *International Microelectronics Symposium, (U.S.)* (1978).
3. D. A. Bianchi, "A Mass Production of Thick Film Car Voltage Regulators", *Electronic Component Science and Tech.*, **5**, 45–48 (1978).
4. Dietrich E. Riemer, "The Direct Emulsion Screen As Tool For High Resolution Thick Film Printing", pp. 463–467, *Electronic Component Conf. (U.S.)*, (1971).
5. P. Scharf, T. Coleman and K. Avellar, "Flip Component Technology", pp. 269–274, *Electronic Component Conf. (U.S.)*, (1967).
6. L. F. Miller, "Paste Transfer in the Screening Process", *Solid State Technology*, 46–52, June 1969.