Enhanced Cleanability Using Fluxes with Decreased Viscosity after Reflow

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ABSTRACT

A series of flux systems have been developed which would result in a reduced viscosity after reflow. This enables a high viscosity, high tack flux to be used to secure components at the component placement and reflow stage but ends up with a low viscosity flux residue after reflow, thus facilitating the flux residue to be cleaned. A technique for forming such special fluxes is to establish a temporary association force within the materials themselves, such as an acid-base association. This kind of association force can increase the apparent molecular weight and cause material viscosity to increase. After a heating process, one of the critical ingredients was evaporated, thus eliminating the association force, causing a decrease in the apparent molecular weight, and consequently a decrease in viscosity or an increase in mobility. The evaporation of one ingredient can be the result of one ingredient having a lower boiling point, or the decomposition of one ingredient during heating. A strong association force is desired to allow this acid-base combination approach to work. In this work, the volatile ingredient approach was less effective than a decomposable ingredient approach, presumably due to the formation of a bigger association cluster from the decomposable ingredient.

KEYWORDS

Flux, viscosity decrease, reflow, clean, SIP, flip-chip

INTRODUCTION

At assembly of flip-chip or SIP, many systems use a tacky flux to secure the chip during placing and reflowing the chips. On the other hand, it is critical to remove the flux residue after reflow in order to achieve high-reliability, particularly when underfilling is desired. A high viscosity thus tacky flux is required to secure the chip, while a low viscosity flux residue is critical for good cleanability, as illustrated in Figure 1. Unfortunately, the reflow process typically results in flux residue with a viscosity higher than the flux prior to reflow due to the removal of volatile ingredients at heating. This results in a severe challenge with the advancement of miniaturization, where the cleaning of flux residue under the chip is getting increasingly difficult. In this study, a novel flux system is developed, where the flux is high viscosity and tacky, but the viscosity of flux residue becomes low after reflow. This flux system can be engineered for either solvent cleaning or water cleaning, hence enabling the continuous miniaturization trend.

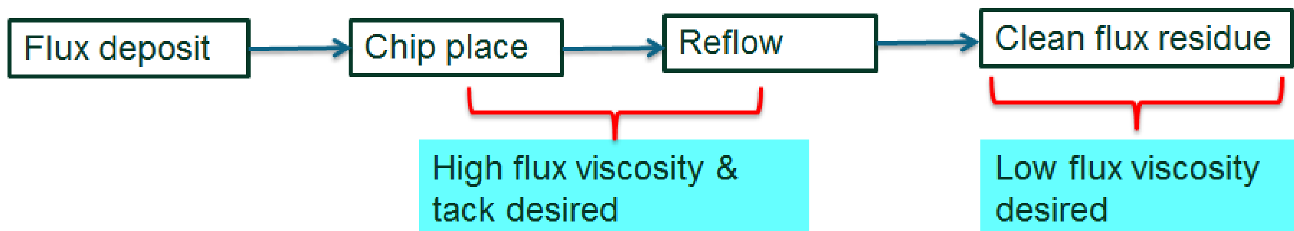

Fig.1. Desired flux characteristics at flip-chip and SIP Assembly.

I. APPROACHES

Materials having increased mobility after heating can be designed by engineering the association force between flux molecules. A technique for forming such materials is to establish a temporary association force within the materials, such as an acid-base association. This kind of association force can increase the apparent molecular weight and cause material viscosity to increase. After the reflow process, one of the critical ingredients is evaporated, thus eliminating the association force, causing a drop in the apparent molecular weight, and consequently a decrease in viscosity or increase in mobility. The evaporation of one ingredient can be the result of having a lower boiling point, or decomposing during reflow [1].

II. EXPERIMENTAL

The approaches described above can be demonstrated by using various combinations of the following chemicals, as described in Table 1. The boiling point, decomposition temperature, and viscosity of those chemicals are shown in Table 2.

Four acid-base flux designs were developed, as shown in Table 3. The acid types include VA, NVA, and DA, while the base types include VB, NVB1, and NVB2. Within each design, the amount of acids and bases used were represented in equivalent amounts of the functional group. The A/B equivalent ratio was calculated accordingly.

Table 1. Chemicals used in demonstration

Chemical Type	Symbol
Volatile Acid	VA
Non-volatile Acid	NVA
Decomposable Acid	DA
Volatile Base	VB
Non-volatile Base 1	NVB1
Non-volatile Base 2	NVB2

Table 2 Boiling point (BP), decomposition (DEC), temperature, and viscosity of the chemicals used for demonstration

Chemical Type	Boiling Point	Viscosity (cp)
VA	bp 162°C	1.3
NVA	bp 237°C	5.2
DA	Solid, dec 132°C	□
VB	bp 158°C	0.5
NVB1	bp very high	140
NVB2	bp 350°C	540

The viscosity of each flux at 23°C was measured at 10rpm by a corn-plate viscometer (Brookfield DV-II+). Five grams of the flux was sent through a forced air convection oven (BTU VIP70) using a profile with a peak temperature specified and a 6-7 minute transition time from room temperature to peak temperature. This profile is suitable for a specified corresponding solder alloy shown in Table 3. After reflow, flux residue was put into a dry box to cool down to room temperature, and the viscosity at 23°C was measured.

Table 3 Flux system designs and its effect on viscosity upon reflow

	Equivalent of Acid and Base			
Chemical Type	Design 1	Design 2	Design 3A	Design 3B
VA (bp 162°C)		0.227 (1.3cp)		
NVA (bp 237°C)	0.465 (5.2cp)			
DA (dec 132°C)			0.577 (∞)□□□	0.228 (∞)□□
VB (bp 158°C)	0.276 (0.5cp)			
NVB1 (bp v high)			0.0936 (140cp)	0.117 (140cp)
NVB2 (bp 350°C)		0.146 (540cp)		
A/B Equivalent Ratio	1.68	1.55	6.16	1.95
Reflow peak (°C)	180	180	245	245
Target solder alloy	Low temp	Low temp	SnAgCu	SnAgCu
AB Association force	Strong	Weak	Strong	Strong
Note	Visc increased after A+B	Visc decreased after A+B	Visc increased after A+B	Visc increased after A+B
Visc (10 rpm, before reflow)	21cp	408cp	1600cp	530cp
Visc (10 rpm, after reflow)	7cp	215cp	105cp	103cp
Visc (non-Volatile A or B)	5.2cp	540cp	140cp	140cp

Flux Design 1

In this design, excessive non-volatile acid NVA was blended with volatile base VB, as shown in Figure 2. The association of acid NVA and base VB formed a bulky complex structure which is high in viscosity, 21 cp, at ambient temperature. Upon reflow, the base VB molecule escaped from the complex structure and vaporized. The remaining acid NVA was smaller than the complex structure and exhibited a lower viscosity, 7 cp, which is close to the viscosity of raw NVA, 5.2 cp.

Flux Design 2

In this design, excessive volatile acid VA was blended with non-volatile base NVB2, as shown in Figure 3. The mixture exhibited a viscosity of 408 cp at ambient temperature, which is lower than that of NVB2, 540 cp, indicating a negligible association formed between VA and NVB2. Upon reflow, a good portion of the acid VA molecule escaped from the weak association and vaporized. The remaining flux of NVB2 plus a small portion of VA thus exhibited a lower viscosity, 215 cp, which is less than one half of the viscosity, 540 cp, of raw NVB2.

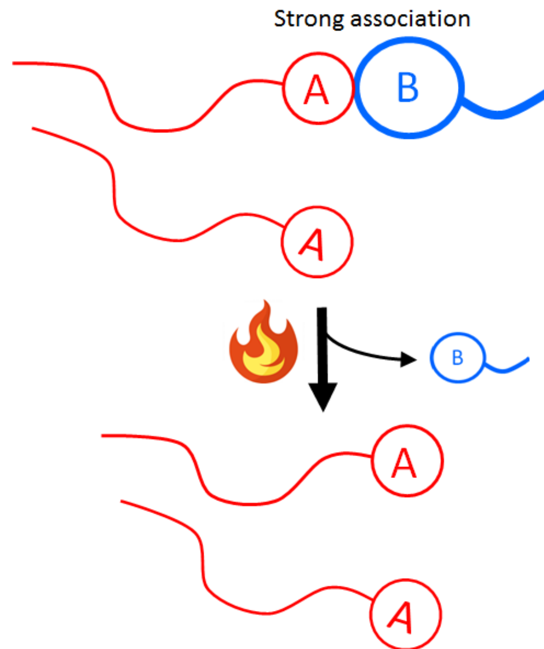

Fig.2. Schematic display of flux composition changes caused by reflow of flux design 1. Flux B vaporized at reflow.

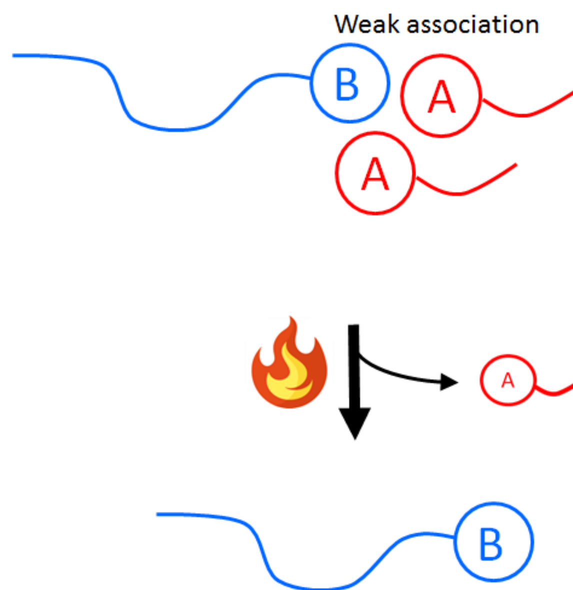

Fig.3. Schematic display of flux composition changes caused by reflow of flux eesign 2. Flux A vaporized at reflow.

Flux Design 3A

In this design, a much excessive decomposable acid DA was blended with a non-volatile base NVB1, as shown in Figure 4. Association of acid DA and base NVB1 formed a large cluster complex structure which is high in viscosity, 1600 cp, at ambient temperature. Upon reflow, the acid DA molecule decomposed and the fragments escaped from the complex structure and vaporized. The remaining base NVB1 is smaller than the complex structure, and exhibited a lower viscosity, 105 cp, which is close to the viscosity of raw NVB1, 140 cp.

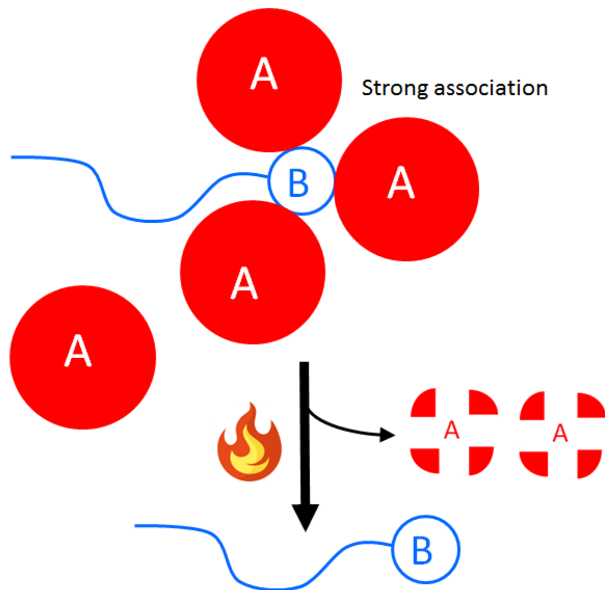

Fig.4. Schematic display of flux composition changes caused by reflow of flux design 3A. Flux A decomposed at reflow

Flux Design 3B

In this design, an excessive decomposable acid DA was blended with a non-volatile base NVB1, as shown in Figure 5. The association of acid DA and base NVB1 formed a small cluster complex structure which is high in viscosity, 530 cp, at ambient temperature. Upon reflow, the acid DA molecule decomposed and the fragments escaped from the complex structure and vaporized. The remaining base NVB1 is smaller than the complex structure, and exhibited a lower viscosity, 103 cp. Again, this is close to the viscosity of raw NVB1, 140 cp.

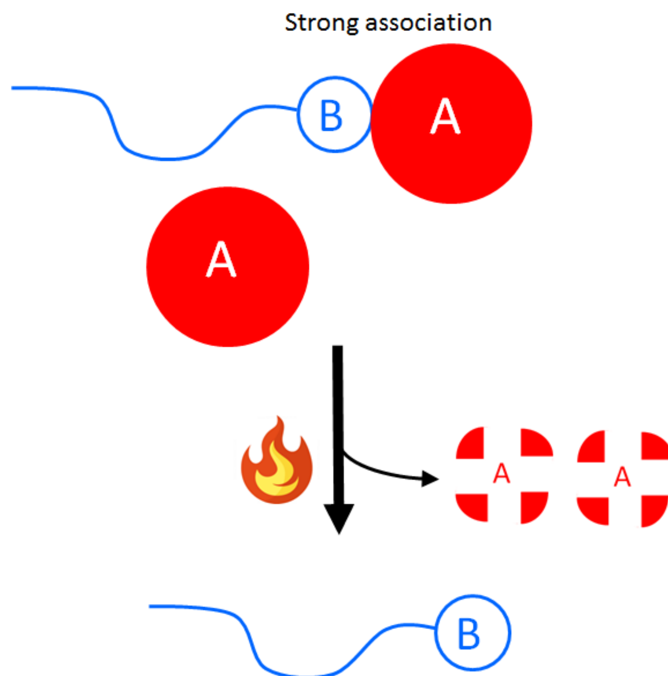

Fig.5. Schematic display of flux composition changes caused by reflow of flux design 3B. Flux A decomposed at reflow.

III. DISCUSSION

A. Volatile Acid or Base

The use of a volatile base resulted in a viscosity drop to 1/3 of the original system viscosity, as shown in Design 1 in Table 3. Although this is a fairly significant reduction in viscosity, the extent of the decrease could be partially compromised by some permanent chemical reaction between the acid and base. This permanent chemical reaction would result in a higher molecular weight, thus a higher viscosity. This appeared to be true for FLUX DESIGN 1, where the viscosity of flux after reflow, 7 cp, is higher than the viscosity of the ingredient VB, 5.2 cp.

However, for FLUX DESIGN 2, the mixture exhibits a viscosity, 408 cp, which is lower than the viscosity of NVB2, 540 cp. Apparently, the association force between VA and NVB2 is not high enough to form a higher viscosity complex, and after reflow, the dilution effect of remaining VA resulted in a viscosity, 215 cp, lower than that of NVB2, 540 cp.

B. Association Cluster Size

Use of decomposable acid resulted in a viscosity drop of 1/5 to 1/16 of the original system viscosity, as shown in Design 3A and Design 3B in Table 3. For Design 3A, more of the acid molecules may have associated with one base molecule, as shown in Figure 4, thus resulting in a much higher viscosity, 1600 cp. For Design 3B, much less of the acid molecule may be associated with one base molecule, thus resulting in a lower viscosity of 530 cp, as shown in Figure 5.

C. Association Force Matter

Flux Design 2 had a mixture viscosity of 408 cp, which is lower than the viscosity of the ingredient NVB2, 540 cp. This is attributable to the weak association force between this acid-base pair. In other words, a strong association force is desired to allow this acid-base combination approach to work.

D. Solvent Clean or Water Clean

Depending on the nature of the non-volatile acid or base, the flux can be customized to be water cleanable or solvent cleanable.

E. Alternatives to Acid-Base System

Although examples described in this study are all reliant on the acid-base association forces, any other association force which can bond a volatile/decomposable ingredient with a non-volatile ingredient could also promise similar results.

IV. CONCLUSION

At assembly of flip-chip or SIP, the use of a tacky flux is necessary to secure the chip during handling and reflowing of the chips. On the other hand, it is critical to remove the flux residue after reflow in order to achieve high-reliability. A series of flux systems have been developed which could result in a reduced viscosity after reflow. This enables a high viscosity, high tack flux to be used to secure components at the component placement and reflow stage but ends up with a low viscosity flux residue after reflow, thus facilitating the flux residue to be cleaned. A technique for forming such special fluxes is to establish a temporary association force within the materials themselves, such as an acid-base association. This kind of association force can increase the apparent molecular weight and cause material viscosity to increase. After a heating process, one of the critical ingredients was evaporated, thus eliminating the association force, causing a decrease in the apparent molecular weight, and consequently a decrease in viscosity or an increase in mobility. The evaporation of one ingredient can be the result of having a lower boiling point or decomposition during heating. A strong association force is desired to allow this acid-base combination approach to work. In this work, the volatile ingredient approach was less effective than the decomposable ingredient approach, presumably due to the formation of a bigger association cluster from the decomposable ingredient.

V. REFERENCES

1. US Patent 10,010,981 Materials having increased mobility after heating.