High Thermal Conductive Inter Chip Fill for 3D-IC through Pre-applied Joining Process

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Abstract

Three dimensional (3D) IC has been proposed for high performance and low power in recent years. Due to the narrow gap between stacked chips and fine pitch of bumps, new inter chip fill (ICF) which can be used for pre-applied ICF process is required. The heat generation of 3D-IC is higher than 2D, so that a high thermal conductive inter chip fill (HT-ICF) is simultaneously required to dissipate the heat from 3D-IC and for the purpose of pre-applied ICF and HT-ICF, highly active flux agent and thermal conductive materials such as filler and matrix have been called for at the same time.

In this study, some kind of materials were prepared, synthesized and optimized for the HT-ICF, and we evaluated its characteristic and confirmed applicability to pre-applied joining for 3D-IC.

Key words

3D-IC, High thermal, Inter chip fill, Pre-applied joining

I. Introduction

In the 3D-IC chip stacking, not only pre-applied inter chip fill (ICF) process but also high thermal conductive ICF (HT-ICF) are required because of both narrow gap between stacked chips and fine pitch of bumps [1]. Compared to the conventional capillary under fill (UF), pre-applied ICF would be required to include flux agent and furthermore requirement of flux agent for pre-applied process are written as follows:

1) Possible to mix flux with ICF compound
2) Removability of oxide from surface of solder
3) No need to clean

And to make thermal conductivity of pre-applied ICF advanced, high thermal conductive filler and matrix are strongly required.

Considering of HT-ICF for the pre-applied process, the conventional capillary UF could not be used [2], [3] in the 3D-IC chip stacking. So, to realize the real 3D-IC chip stacking, optimization and formulation of flux system and thermal conductive material for the pre-applied ICF are studied [4].

II. Experimental

To evaluate flux activity for pre-applied ICF, the mixture of matrix, flux agent and solder ball were put on the Cu substrate heated at 250°C to evaluate the solder joining. Both thermal conductive filler and matrix were mixed by a planetary mixer and then additives including cure agent and flux were introduced in the compound to prepare pre-applied ICF. It was coated on the test vehicle (TV) of Si chip with Pb-free (Sn/Ag) solder bump on Cu post. The TV coated with pre-applied ICF was joined to the Si interposer (IP) using flip chip bonder (FC bonder). After chip stacking, the joining quality was evaluated by a scanning acoustic tomography (SAT) and a cross-section of scanning electron microscope (SEM). The physical characteristics including thermal conductivity of pre-applied ICF were evaluated as cured thin film.

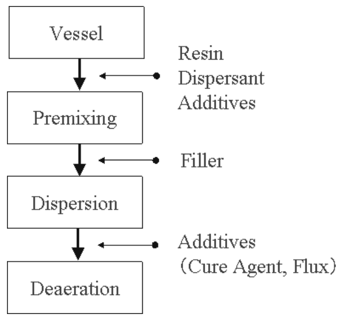


Figure 1 Preparation of pre-applied ICF

Flux evaluation

The 10g isopropyl alcohol and 0.1g flux agent were mixed and coated on the Cu plate. The Sn/Ag solder ball were put on the flux solution and heated at 100°C to evaporate the solvent, and then Cu plate was heated at 250°C for 10s to make solder joined to the plate.

Pre-applied ICF preparation

The pre-applied ICF compound was formulated at two steps, making filler dispersed into a matrix and then mixing compound with additives. Firstly, 5.5g epoxy based resin, 4.5g boron nitride (BN) powder and some kind of additives were put into a vessel and mixed for 5 minutes at 2000rpm utilizing a rotary and revolutionary stirrer shown in Figure 1. The filler size distribution was measured by the laser diffraction and diffusion analysis. Then, both 0.33g cure agent and 0.18g flux agent were added and mixed.

Physical property evaluation

The pre-applied ICF coated on the glasses (a surface treated by mold releasing agent) with a 500µm thickness silicone spacer, and then pressed and cured at 150°C for 2hours. The thermal diffusivity was measured by temperature wave analysis, and thermal conductivity was calculated by multiplication of the thermal diffusivity, specific heat and its density. Both glass transition temperature (Tg) and coefficient of thermal expansion (CTE) were measured by thermo mechanical analysis (TMA).

Chip stacking

The TV that was 7.3mm square size and 725µm thickness with bumps (80µm pitch, 30µm height Cu post with 15µm height Pb-free (Sn/Ag) solder bump (peripheral array) was used in evaluation. The pre-applied ICF (10µL) was dispensed onto the Si chip. Then, TV was set, aligned and joined to the Si interposer using FC bonder in operating temperatures 40 to 250°C within 60 seconds shown in Figure 2 and Figure 3.

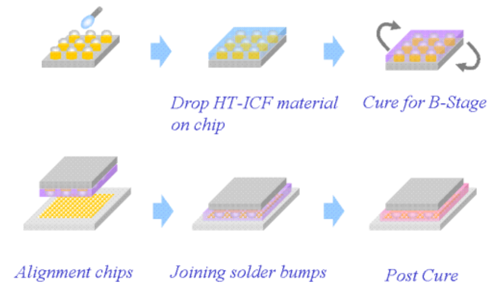


Figure 2 Schematic pre-applied ICF joining process

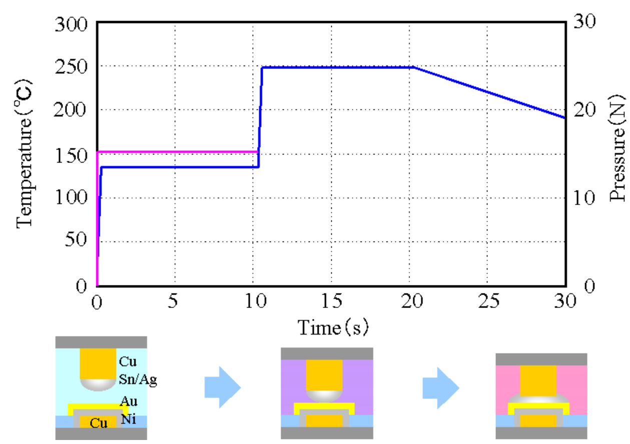


Figure 3 Bonding profile for pre-applied ICF

Joint evaluation

The solder joint was evaluated by an electrical connection of daisy chains, SAT and cross section of SEM after curing at 150°C for 2hours.

Reliability test

The jointed chips were at first treated with the condition of JEDEC Level 3 (35deg.C/60%RH/192hrs + 260deg.C reflow, 3times) and then treated with a deep thermal cycle test (-55 to 125 deg.C /2-cycles/hour). After treated in that condition, visual inspection, measurement of electric resistance and SAT evaluation were performed.

III. Result and Discussion

To optimize pre-applied ICF for 3D-IC joining, it is necessary to add a proper flux agent in the ICF to get rid of tin oxide from the surface of solder. Figure 4 showed a potential-pH equilibrium diagram of Tin which was major component of solder and it is desirable to remove tin oxide in lower pH written in equation (1), (2) [5].

$$Sn + O_2 \Rightarrow SnO_2 \quad (1)$$
$$SnO_2 + 4H^+ \Rightarrow Sn^{4+} + 2H_2O \quad (2)$$

There are various fluxes proposed for solder joining, but some of them are rosin type and they are not adequately effective because of its low activity and they are also difficult to be applied to inorganic type due to halogen contamination.

So, to investigate the fundamental characteristics of organic acid (OA), some of OA are selected in the point of liquid phase stability and its pKa shown in Figure 5.

In case of OA-A, OA-B and OA-F, each pKa showed under 3 (acidic) and they could remove tin oxide from solder. But those OAs tended to be decomposed or vaporized under 200°C and they could not be used in pre-applied ICF because of voids. On the other hand, acidity of OA-D and OA-E was not strong, but they were stable over 250°C at liquid phase. Figure 6 showed the flux activity of OA-D on Cu plate and it showed good activity at 250°C for 10s.

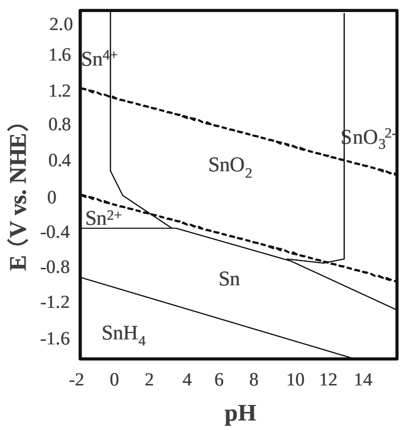


Figure 4 Potential-pH equilibrium diagram of Tin

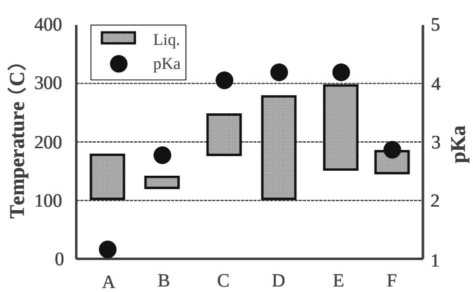


Figure 5 Characteristics of various OA

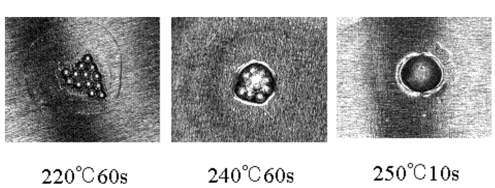


Figure 6 Flux activity depended on temp. and time

And then, to understand the effect of the raw materials (filler and matrix) on thermal conductivity, the simulation was performed by means of Bruggeman's formula shown in Figure 7 [6]. It should be noted that application of high thermal conductive filler at a high concentration was key to develop the HT-ICF. Major characteristics of some ceramic filler are shown in Table 1. In consideration of thermal conductivity, density, dielectric constant and its stability, we selected BN as one of major fillers and applied it to the HT-ICF.

Figure 8 showed the SEM view image of the selected BN filler and its crystal orientation is hexagonal [7]. The hexagonal crystal of BN (h-BN) has only a few functional groups at the edge. To identify the functional groups, it is essential to make the BN filler disperse in the matrix solution and it is important to select the dispersant. The IR spectrum was measured by means of surface diffusion FT-IR. The absorption spectra of $-NH_2$ and $-OH$ were detected at $3224cm^{-1}$ and $3400\text{-}3600cm^{-1}$, respectively. The absorption spectrum area of -OH was at least two times larger than that of $-NH_2$ and it appeared that -OH was major functional group in the h-BN.

In accordance with the result of the FT-IR analysis of the h-BN, an amine derivative was selected as dispersant. To apply the HT-ICF to the fine pitch of bumps and narrow gap, maximum filler size should be controlled within one third of gap. Figure 9 showed BN filler size variation by planetary mixer. In the condition of mixing at 30rpm at 50°C, maximum filler size distribution could be controlled under 10μm.

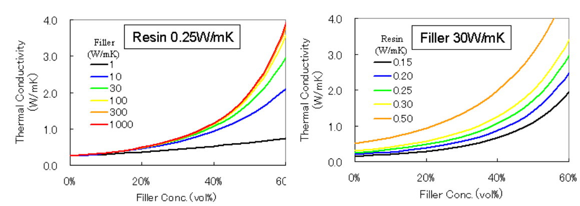


Figure 7 Simulation of Bruggeman's formula

Table1 Characteristics of major ceramics

	BN	Al_2O_3	AlN	SiO_2
Density (g/cm3)	2.3	3.9	3.4	2.1
Thermal Conductivity (W/mK)	410(a-b) 2(c)	30	300	1.4
Dielectric	3.9	8.8	9	3.8

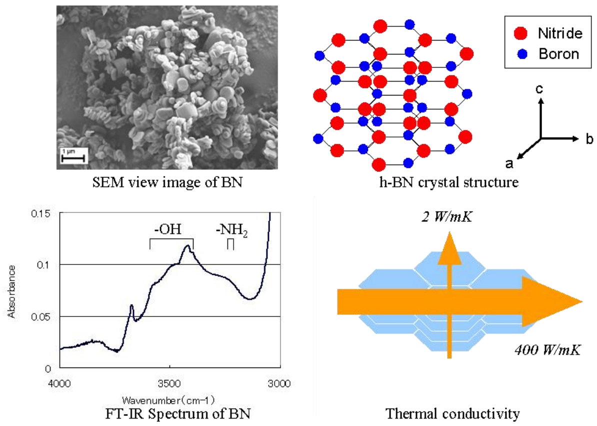


Figure 8 Characteristics of BN

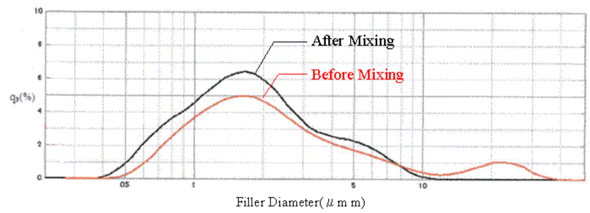


Figure 9 Filler size distribution

Figure 10 showed thermal conductivities of 500µm cured thin film depended on kind of filler and its concentration. In the case of silicon dioxide (SiO_2) filler, it could not be possible to be over 1W/mK as high thermal conductive ICF. The thermal conductivity of boron nitride (BN) and aluminum oxide (Al_2O_3) was at least two times higher than that of SiO_2. At the same concentration of filler, BN filler could attain high thermal conductivity compared to Al_2O_3. Figure 11 showed that the CTE was strongly related to not kind of filler but its filler concentration in the compound. In case of chip joining, CTE of Si substrate was about 3.5ppm/K so that CTE of ICF should be kept less than 30ppm/K by controlling filler concentration [8].

To improve thermal conductivity at lower CTE, we had been trying to make thermal conductive path in the matrix shown in Figure 12. By addition of the third component (TC) in the matrix, it is expected that special restriction would occur and increase the possibility of filler connection called thermal path. And in addition, thermal conductivity of TC is higher than that of matrix it could be possible to make thermal conductivity of matrix itself increased. In case of the BN filler, thermal conductivity was 0.4W/mK on ICF-A, but it could be attained 0.9W/mK at 30vol% because of its high performance at lower concentration on ICF-B. But at that condition, CTE was larger than 30ppm/K and it could not be applied for 3D-IC joining shown in Table 2. To solve this problem, we did optimization of ICF-C using both BN and TC, and we could achieve not only thermal conductivity but also CTE at the same time.

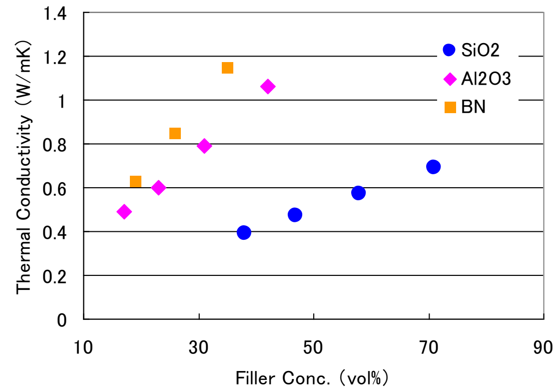


Figure 10 Thermal conductivity depended on filler conc.

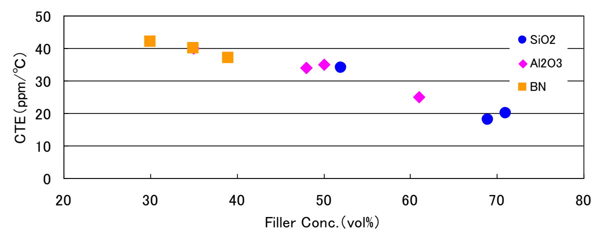


Figure 11 CTE related to filler concentration

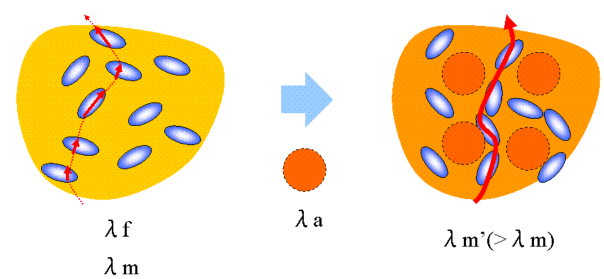
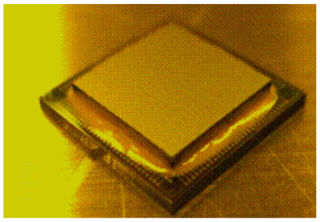


Figure 12 Thermal conductive path

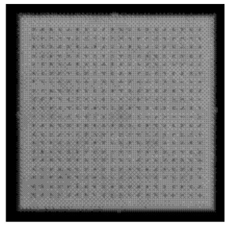
Table 2 Optimization of λ and CTE

Characteristics		ICF-A.	ICF-B	ICF-C
BN	(vol%)	12	30	12
λ	(W/mK)	0.4	0.9	0.9
CTE	(ppm/K) -10～40℃	54	42	28

Figure 13 showed the result of Si chip joined to Si interposer in the pre-applied process as illustrated in Figure 2. There was no void detected by means of SAT. Figure 14 showed the cross section view of the interconnection between solder bump and pad, and Cu post was connected to the pad by the medium of solder. Electrical connection was evaluated by daisy chain and the resistance was almost same as connection without ICF.



Si Chip joined with
Si Interposer



SAT view

Figure 13 Chip stack joining in pre-applied process

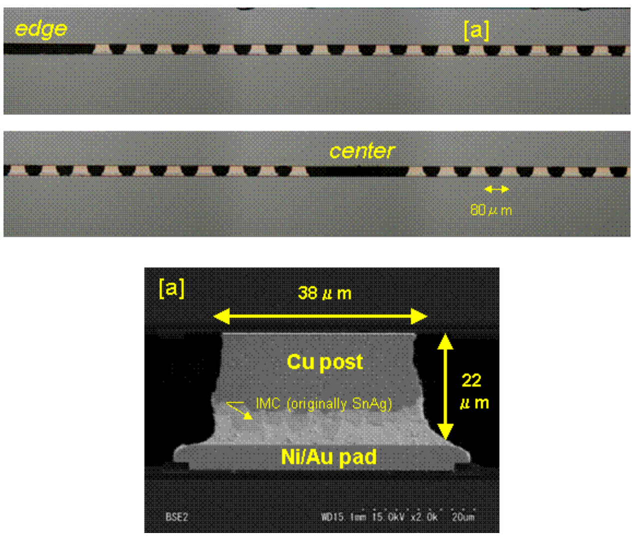


Figure 14 Cross section of joining

Table 3 Characteristics of the pre-applied ICF

Characteristics		ICF-D	ICF-E
λ	(W/mK)	0.6	1.0
CTE	(ppm/K) -10～40℃	28	28
Notice		pre-applied ICF	pre-applied HT-ICF

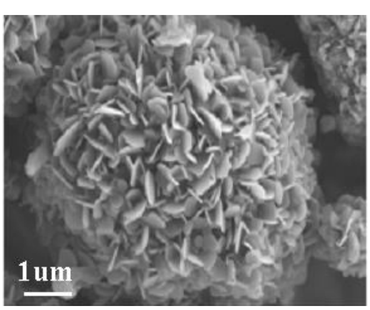


Figure 15 Spherical BN

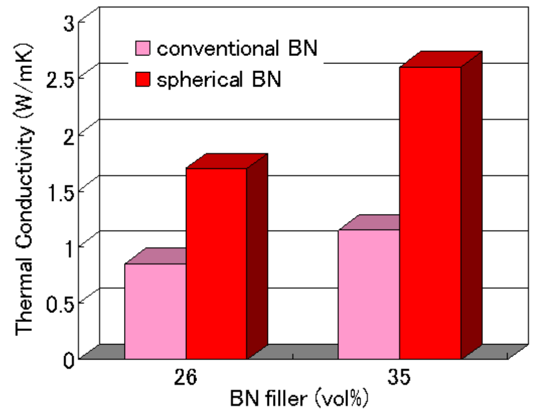


Figure 16 Thermal conductivity of Spherical BN

The characteristics of pre-applied ICF were shown in Table3. Thermal conductivity of ICF-D was 0.6W/mK and physical properties were measured as cured thin film and Tg was 104°C and CTE was 28ppm/K (in case T<Tg). And we did the reliability test of JEDEC level 3 and deep thermal cycle test, and we'd confirmed 2000 cycles passed at that condition.

We had tried to apply various kinds of BN filler to pre-applied ICF, but thermal conductivity of ICF was still under 2W/mK , so that we had researched and developed new type of BN filler called 'spherical BN'. Figure 15 showed the SEM view image of the new spherical BN and maximum filler size was under 10um. Figure 16 showed a thermal conductivity dependence on filler concentration. At 26vol% of spherical BN filler, thermal conductivity was 1.7W/mK, and at the 35vol%, thermal conductivity of 2.6W/mK was attained.

IV. Conclusion

We developed new pre-applied HT-ICF which consisted of thermal conductive filler, epoxy based matrix and organic flux. In the pre-applied ICF, flux was one of the key materials and it could be selected in the point of pKa and its stability at high temperature. The BN filler was effective for thermal conductivity at lower concentration, but CTE was strongly related to its concentration. To solve this problem, we had developed thermal conductive path formation by addition of TC and we could achieve high thermal conductivity and lower CTE in pre-applied ICF at the same time. And also the chip joining without voids in the ICF and reliability was confirmed.

In addition, new high thermal conductive filler was also studied. We had synthesized new spherical BN (diameter <5um) and applied it to pre-applied ICF. Thermal conductivity was almost two times higher than conventional BN. Thus pre-applied HT-ICF which is optimized will be applicable and effective for the next 3D-IC joining.

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