Development and Evaluation of Photodefinable Wafer Level Underfill

Kazuyuki Mitsukura\textsuperscript{a}, Ryouta Saisyo\textsuperscript{a}, Tatsuya Makino\textsuperscript{a}, Keiichi Hatakeyama\textsuperscript{b}, Tomonori Minegishi\textsuperscript{a}, Teng Wang\textsuperscript{c}, Robert Daily\textsuperscript{c}, Fabrice Duval\textsuperscript{c}, Kenneth June Rebibis\textsuperscript{c}, Andy Miller\textsuperscript{c} and Eric Beyne\textsuperscript{c}

\textsuperscript{a} Tsukuba Research Laboratory, \textsuperscript{b} Packaging Solution Center, Hitachi Chemical Co., Ltd., Wadai 48, Tsukuba-shi, Ibaraki 300-4247, Japan
\textsuperscript{c} 3D System Integration Program, Interuniversity Micro Electronics Center (IMEC), Kapeldreef 75, 3001, Leuven, Belgium

Photodefinable wafer level underfill has been developed and its design concept has been verified, that is, the removal of underfill on the top of bumps enables the excellent quality of bump connection without underfill entrapment. The photodefinable composition using carboxylic type polyimide shows poor resolution, whereas the phenol type polyimide based Photo WLUF, CD3000B, has good patterning properties. CD3000B could form underfill patterns having 15 μm diameter holes on 25 μm Cu bumps through conventional photolithography processes. The bonded samples showed the seamless bump junction and passed moisture sensitivity level 2 and thermal cycling reliability test.

Keyword: 3D package, TSV, Underfill, Polyimide

1. Introduction

Three-dimensional (3D) integration technology offers benefits such as increased packaging density, heterogeneous integration, lower power and high bandwidth due to shorter interconnection length [1]. The applicable electrical interconnection pitch for 3D package such as flip chip, through silicon via (TSV) etc. becomes narrower.

Generally underfill materials are filled between organic/inorganic substrate and chip for stress relief. The conventional capillary underfill (CUF) is difficult to be applied to the package with fine pitch bumps because the capillary process after stacking is slow and damages the fragile low k. Pre-applied wafer level underfill (WLUF), which is formed to the whole wafer by lamination or spin coating, has been investigated. During the bonding process, WLUF material must flow not to be trapped between bump and pad. The underfill entrapment worsens the reliability of device by interfering the formation of intermetallic compound (IMC) between bumps. As the bump numbers increase and the pitch narrows furthermore in 3D package, it will be more difficult to push out the underfill on the top of bumps. Also it is needed to achieve good bump junction with lower bonding force to reduce the stress and adapt to chip-to-wafer and wafer-to-wafer stacking method. Thus we developed photodefinable wafer level underfill (photo WLUF) which has no possibility of underfill entrapment.

In this paper, photo WLUF design concept and the assembly results using IMEC fine pitch test vehicle are reported.
2. Experiment and Measurement

2.1. Materials

Photo WLUF solutions were prepared by mixing a polyimide, acrylates, photoradical initiator, thermally curing components and NMP. The solutions were coated on polyethylene terephthalate film with release layer and pre-baked at 80 °C for 20 min, then 120 °C for 20 min in an oven.

2.2. Photo WLUF patterning

Photo WLUF films with 20 μm thickness were laminated on Si wafer by vacuum laminator. The wafers were exposed with broadband light from high pressure Hg lamp. After the exposure, the wafers were baked at 80 °C for 30 s and then were developed with 2.38% tetramethylammonium hydroxide (TMAH) solution for 60 s.

2.3. Glass-transition temperature (Tg)

Each polyimide was coated on polyethylene terephthalate film to give 50 μm thick sample film. Tg was determined by the peak of tan δ from dynamic mechanical analysis.

2.4. Lamination Temperature

Photo WLUF films were laminated on Si wafers under various temperatures by vacuum laminator. Lamination temperature was determined by the inspection after removal of PET film.

2.5. IMEC test elementary group (TEG) for photo WLUF

TEG design is shown in Table 1. PTCM1 is the top wafer with 15 μm diameter bumps and PTCN1 is the bottom wafer with 25 μm diameter bumps. 8,250 bumps were designed in full area. Figure 1 shows schematic cross-sectional view of PTCM1-PTCN1 stacking sample.

2.6. Photo WLUF patterning on PTCN1

Photo WLUF was laminated on PTCN1 wafer at 60 °C for 60 s by vacuum laminator. The wafer was exposed with i-line stepper through the photo mask designed for bump-top opening. After the exposure, the wafer was baked at 80 °C for 30 s. Then the wafer was developed with a 2.38% TMAH solution for 60 s. The patterning property was evaluated by scanning electron microscope (SEM).

2.7. Stacking of PTCM1 and PTCN1

PTCN1 wafer with the patterned WLUF was diced and picked up as a chip from dicing tape. Each PTCN1 chip with photo WLUF was bonded with corresponding PTCM1 chip by flip chip bonder.

2.8. Stacking quality test

The void and delamination were inspected by scanning acoustic microscope (SAM) and then the bump junction was observed by cross-sectional SEM.

2.9. Reliability test

The stacked samples passed through the reflow furnace three times after 85 °C/60 % RH for 168 h (JEDEC MSL 2). Also their stacking quality was checked after thermal cycling test (TCT) from -55 to 125 °C, 1000 cycles.

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Table 1. Design of PTCM1 and PTCN1

| Item                | PTCM1               | PTCN1               |
|---------------------|---------------------|---------------------|
| Use                 | Top die             | Bottom die          |
| Die size (mm²)      | 5.1 x 5.1           | 8.1 x 8.1           |
| Bump array          | Full area           |                     |
| Number of bumps     | 8250                |                     |
| Bump diameter (μm)  | 15                  | 25                  |
| Bump pitch (μm)     | 50                  |                     |
| Bump height (μm)    | 9.5                 | 10                  |
| Bump composition (μm)| Sn/Ni/Cu (3.5/1/5) | Cu (10)             |

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Figure 1. Design of PTCM1 and PTCN1
3. Results and Discussion

3.1. Photo WLUF patterning

At first, to investigate the relationship between the patterning aspect ratio and polyimide rigidity, we synthesized some kinds of polyimide by changing the ratio of rigid diamine A with carboxylic group and flexible diamine B. The schematic polyimide structure is shown in Figure 2. As shown in Figure 3, increasing rigid diamine A provided higher Tg polyimide and significantly got worse the resolution property. For investigation of the reason, we prepared a solution of polyimide having 140 °C Tg along with thermally curing components. It was coated on polyethylene terephthalate film with release layer and pre-baked at 80 °C for 20 min, then 120 °C for 20 min in an oven. The film was dipped in NMP for 10 minutes and consequently 80 % of the film was insoluble. On the other hand, all films using phenol type polyimide and thermally curing components dissolved to NMP completely. These results show that the crosslinking reaction between carboxylic group and thermally curing components proceeded during the thermal treatment for film preparation. Therefore, it was difficult to satisfy both thermal resistance and resolution properties using carboxylic type polyimide.

We also prepared some phenol type polyimides by changing the ratio of rigid diamine C with phenol group and flexible diamine B. Figure 4 shows the relationship between Tg of phenol type polyimide and patterning aspect ratio. The resolution of phenol type polyimide based films is much better than carboxylic type polyimide based film. Other compositions were optimized as an appropriate photo WLUF. Here, we name the optimized material as CD3000B. As shown in Figure 5, CD3000B can make 15 μm via holes using 20 μm thick film.
3.2. Stacking and Reliability

Next, we evaluated patterning property on TEG and stacking quality of CD3000B. Figure 6 shows the top view of photo WLUF patterned on PTCN1. The underfill over Cu bumps is removed and all bump tops are revealed properly by patterning process.

![Top of Cu bump](image)

Figure 6. Top SEM image of patterned WLUF on PTCN1

PTCN1 chip with photo WLUF bonded with PTCM1 chip by flip chip bonder. The cross sectional SEM images of the stacked sample and SAM picture are shown in Figure 7 and Figure 8, respectively. The bump junction is excellent without any underfill entrapment and the gap caused by patterning is filled with CD3000B completely.

![Cross sectional SEM images of stacked sample](image)

Figure 7. Cross sectional SEM images of stacked sample

![SAM](image)

Figure 8. SAM inspection of stacked sample

Finally, the reliability of the stacked samples was evaluated and the results were summarized in Table 2. No change has happened in the electrical yield, resistance and SAM pictures during thermal cycling test. Furthermore, the samples pass JEDEC moisture sensitivity level 2 (MSL2) as well.

| Table 2. Reliability test results of stacked samples |
|----------------------------------------------------|
| **Yield (%)** | **After Stacking** | **After TCT 1000cycles** |
| **Resistance (Ω)** | 317 | 315 |

4. Conclusion

In this paper, the development of photo definable wafer level undefill (Photo WLUF) and the stacking demonstration were studied. Photo WLUF based on phenol type polyimide shows good resolution due to no thermal reaction during film preparation. The stacking samples using photo WLUF afford void-free bump junction without underfill entrapment and pass moisture sensitivity level 2 and thermal cycling reliability test.

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