Low Temperature Curable Photosensitive Dielectric Material with High Resolution

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Recently, semiconductor package with redistribution layer (RDL), such as fan-out wafer level package (FOWLP), has been developed to achieve downsizing for increasing pin counts and lowering cost. Dielectric material used for FOWLP needs to meet requirements such as low warpage, high reliability and adhesion strength with metals used as RDL. We developed low-temperature curable positive tone dielectric material, AH series, for FOWLP. AH-3000 has low residual stress to suppress substrate warpage, as well as high tensile strength and low CTE for more reliable FOWLP.

Keywords: Low-temperature curable, Reliability, Resolution

1. Introduction

In accordance with miniaturization of wiring, the size of package is becoming smaller and thinner. However, it is difficult to increase I/O counts with WLCSP since there is limitation of solder ball size. In order to increase I/O counts, FOWLP (Fig. 1) has attracted attention with capability of many I/O pins by redistribution of bump positions which can expand beyond the chip area. Since redistribution layer is formed after molding, dielectric material for FOWLP is required to have a variety of characteristics, such as low-temperature curability, low residual stress, thermal cycle resistance, and adhesion to copper.

In recent years, with the increasing number of redistribution layers for more pin counts, lower residual stress is required for next-generation dielectric material to suppress the warpage of substrate. Another requirement for dielectric materials is high resolution.

In order to achieve the requirements, polyimide (PI) or polybenzoxazole (PBO) have been developed [1,2]. They have excellent reliability, but residual stress is necessary to be lowered and resolution is necessary to be improved.

In previous study, we reported novel photo dielectric materials for redistribution layer with excellent resolution but its residual stress wasn’t low enough [3].

In this report, we present newly developed photosensitive dielectric material AH-3000, which shows low residual stress and high resolution.

In addition, we modified the base resin to improve thermal cycle resistance.

2. Experimental

2.1. Lithographic properties

AH-3000 was coated on a 6-inch Si wafer with a spin-coater (Mark-7, Tokyo Electron), then soft-baked at 120 °C for 3 min on a hot plate of Mark-7. The film was exposed with an i-line stepper (FPA3000iw, Canon) with xxx mJ/cm², then developed in 2.38% TMAH at 23 °C. The patterned wafer was cured in an inert gas oven (μ-TF, Koyo Thermo Systems) under N₂ atmosphere.

2.2. Mechanical properties

Mechanical properties of 10-µm-thick cured film were measured with a tensile testing machine (Lambda Ace, SCREEN Holdings).
2.3. Residual stress

The warpage of a 6-inch wafer was measured with a film stress measurement system (TENCOR FLX-2320, KLA-Tencor). Then, AH-3000 varnish was coated on the wafer and cured. The warpage of the cured wafer was evaluated in the same way and the residual stress of the cured film was calculated.

2.4. Thermal properties

Glass transition temperature ($T_g$) and coefficient of thermal expansion (CTE) of cured film were measured with thermomechanical analysis (TMA/SS7100 SII).

2.5. Adhesion on substrates

AH-3000 varnish was coated on various substrates and cured. Then an aluminum stud with epoxy resin was placed on AH-3000 film and heated at 150 °C for 60 min. Adhesion strength was evaluated by pulling the aluminum stud with a universal materials tester (ROMULUS IV, Quad group).

2.6. Chemical resistance

Cured AH-3000 film on copper-plated silicon was dipped in various solvents, propylene glycol monomethyl ether acetate (PGMEA), isopropanol (IPA), TMAH aq. (2.38%) HF aq (x%), mixture of CuSO$_4$ and H$_2$SO$_4$, (6/10(w/w)) and mixture of DMSO and Ethanol (3/7(w/w)), at 23 °C for 10 min, then the dipped AH-3000 films were observed with a microscope to find the generation of crack or delamination.

3. Results and discussion

3.1. Lithographic properties

High resolution is necessary for the dielectric material of redistribution layer to secure Cu interconnect. Lithographic properties of AH-3000 on Si and Cu substrate are showed in Table 1. AH-3000 of 10-µm-thick film showed excellent resolution on both Si and Cu substrate. 2 µm of square pattern was open.

| Substrate | Si          | Cu          |
|-----------|-------------|-------------|
| Pattern Image | ![Pattern Image](image1) | ![Pattern Image](image2) |

Pattern profile of AH-3000 after cure is possible to control by ramp-up during cure process. Its cross sectional images are shown in Table 2. Cure process with direct ramp-up generated smooth pattern edge. On the other hand, cure process with 2-step ramp-up profile made sharp edge. This is attributed the competitive process of cross-link reaction by cross-linker and the softening of the base resin by heating. Faster ramp-up causes the softening of the base resin dominantly before cross-link reaction progress. On the other hand, 2-step cure process promotes cross-link reaction to maintain the sharp pattern shape before the softening of the base resin.

Table 2. Pattern profile of AH-3000 after cure

| Pattern shape | Smooth | Sharp |
|--------------|--------|-------|
| Cross sectional image* | ![Cross sectional image](image3) | ![Cross sectional image](image4) |

*Mask size : 5 µm

3.2. Thermal and mechanical properties

The comparison of AH-3000 with AH-1170, the previous version, in cured film properties is shown in Table 3. The elongation of AH-3000 is over 60% to enable good reliability for thermal cycle test. AH-3000 shows lower residual stress and is expected to enable lower warpage even of multilayer redistribution structure.

Table 3. Mechanical properties of AH series

| Properties         | Unit | AH-1170 | AH-3000 |
|--------------------|------|---------|---------|
| Cure Temperature   | °C   | 230     | 200     |
| Elongation         | %    | 50      | 60      |
| Tensile strength   | MPa  | 100     | 106     |
| Young’s modulus    | GPa  | 2.0     | 2.4     |
| $T_g$              | °C   | 207     | 205     |
| CTE                | ppm/K| 58      | 56      |
| Residual stress    | MPa  | 23      | 16      |

The residual stress of multi-layered AH-3000 is shown in Table 4. AH-3000 of 15 µm-thick-film was coated and cured as each layer and its residual stress was measured. Residual stress of triple-layered film was 21 MPa, suggesting that even multi-layered film could show low warpage.

Table 4. Residual stress of multi-layered AH-3000

| Substrate | Si          | Cu          |
|-----------|-------------|-------------|
| Pattern Image | ![Pattern Image](image5) | ![Pattern Image](image6) |
Table 4. Residual stress of multilayered AH-3000

| The number of layers | Thickness of total film [µm] | Residual stress [MPa] |
|----------------------|-------------------------------|-----------------------|
| 1                    | 15                            | 16.3                  |
| 2                    | 30                            | 18.4                  |
| 3                    | 45                            | 21.0                  |

3.3. Adhesion of AH-3000 to various substrates

Adhesion strength to various kinds of metal substrates is required for dielectric material used for FOWLP.

Adhesion strength of AH-3000 before and after PCT was evaluated by stud pull test. Results are summarized in Table 5. AH-3000 before PCT showed adhesion strength over 600 kg/cm² and breaking modes were cohesive failure of epoxy resin. The strong adhesion of AH-3000 should be due to the phenolic hydroxyl group of the base polymer.

Table 5. Stud pull test results of AH-3000 film

| Substrate | Before PCT [kg/cm²] | After PCT [kg/cm²] |
|-----------|---------------------|---------------------|
| Si        | 666                 | 651                 |
| SiO       | 716                 | 707                 |
| SiN       | 725                 | 736                 |
| Cu        | 672                 | 681                 |
| Ti        | 701                 | 695                 |
| Al        | 711                 | 712                 |
| Au        | 651                 | 653                 |
| Pd        | 711                 | 718                 |

After PCT treatment, adhesion strength of AH-3000 was kept over 600 kg/cm² and breaking modes were still cohesive failure of epoxy resin, suggesting high resistance against PCT.

3.4. Chemical resistance

Through Cu redistribution process, dielectric material is exposed to various chemicals such as photoresist, developer, stripper and plating agents, and it needs to be resistant to the chemicals. However, dielectric materials cured at low temperature could generally cause cracking or delamination during the process due to possible insufficient cure.

Chemical resistance of AH-3000 is shown in Table 6. No cracking or delamination after dipping in the chemicals was found, indicating that curing degree is enough.

Table 6. Chemical resistance of AH-3000

| Chemical                  | Film thickness | Film Appearance |
|---------------------------|----------------|-----------------|
| PGMEA                     | Unchanged      | Unchanged       |
| IPA                       | Unchanged      | Unchanged       |
| TMAHaq (2.38%)            | Unchanged      | Unchanged       |
| Buffered HF               | Unchanged      | Unchanged       |
| CuSO₄ / H₂SO₄ (6/10)      | Unchanged      | Unchanged       |
| DMSO / Ethanol amine (3/7)| Unchanged      | Unchanged       |

4. Conclusions

We have developed AH-3000, which is low-temperature curable photosensitive dielectric material with high resolution. AH-3000 has good lithographic property on Cu substrate and its pattern profile is possible to control by curing process. AH-3000 shows good adhesion to various substrates. AH-3000 shows low residual stress and is expected to suppress warpage even of multilayer redistribution structure. AH-3000 has good chemical resistance for Cu redistribution process. AH-3000 is applicable to Cu redistribution process as dielectric materials due to the properties.

References
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