Development of Positive-tone Photodefinable Material for Redistribution Layer

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Recently semiconductor packages with redistribution layers are gathering attention because of its electrical performance and low energy consumption. Dielectric materials for these packages require low-temperature curability to avoid thermal damage of devices and thermally unstable materials in the packages. Low-temperature curable positive-tone photodefinable material AH-3000 was developed and its reliabilities were evaluated. AH-3000 kept good mechanical properties after reliability test. AH-3000 is also applicable to slit coating, which is required for next-generation panel level package.

Keywords: Low-temperature curable, Photodefinable, Reliability, Resolution

1. Introduction

Semiconductor devices have progressed along with the decrease of package size and the increase of I/O counts. Therefore semiconductor packages which have redistribution layer are gathering attention. By the application of redistribution layers, devices are possible to increase I/O counts and show high performance with low energy consumption. These packaging techniques require dielectric materials which can be cured at low temperature with high resolution. In addition, since the number of redistribution layers is increasing, dielectric layers need to have low residual stress to avoid device warpage.

Polyimide (PI) and polybenzoxazole (PBO) have widely been used as dielectric layer materials for semiconductors [1]. However, there are several disadvantages such as thermal damage of device and wafer warpage with typical PI and PBO which need to be cured at high temperature. Low temperature curable PI and PBO have been developed to satisfy the requirements from recent packages [2,3].

We have focused on low-temperature curable photodefinable material utilizing phenol resin. In previous study, we reported positive-tone photodefinable dielectric material AH-1170 for redistribution layer [4]. In this paper, we report a novel photodefinable dielectric material AH-3000, which is positive tone, aqueous developable and low-temperature curable with improved reliability.

2. Experimental

2.1. Lithographic properties

AH-3000 was coated on a 6-inch Si wafer with a spin-coater (Mark-7, Tokyo Electron) and soft-baked at 120 °C for 3 min on a hot plate of Mark-7. Then the film was exposed with an i-line stepper (FPA-3000i, Canon) with a photomask having via patterns, then developed in 2.38 % TMAH at 23 °C. The patterned wafer was cured in an oven (INH-9CD-S, Koyo Thermo Systems) under N2 atmosphere.

2.2. Mechanical properties

Elongation, tensile strength and Young’s modulus of the 10µm thick cured film were measured using a tensile testing machine (AGS-100NH, Shimadzu).
2.3. Residual stress
The initial warpage of a 6-inch wafer was measured with a film stress measurement system (KLA-Tencor). Then, AH-3000 was coated on the wafer and cured. The warpage of cured wafer was measured with the system and residual stress was calculated.

2.4. Measurement of thermal properties
Glass transition temperature ($T_g$) and the coefficient of thermal expansion (CTE) of cured film was measured with a thermomechanical analysis (TMA/SS7100 SII).

2.5. Adhesion strength with Cu
AH-3000 was coated on a Cu-plated wafer and cured at 230°C. Then the wafer was treated with thermal cycle (-65°C to 150°C for 200 cycles) and HAST (135°C/85%RH/96 h). 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 an universal materials tester (Romulus, Quad Group).

2.6. Coating on panel substrate
A diluted version of AH-3000 was coated on a panel substrate with a knife coater (SNC-350, Yasuiseiki) and soft baked at 120°C for 10 min in a conventional oven to obtain 12.9µm thick film. The coated substrate is exposed by broad band exposure (ML-320FSAT, Mikasa) at 500 ml/cm² with a photomask having 20 µm via patterns, then developed in 2.38% TMAH. The patterned substrate was cured in an oven (CLH-21CD(III)-S, Koyo Thermo Systems) under N₂ atmosphere.

3. Results and discussions
3.1. Lithographic properties
The lithographic properties of AH-3000 are shown in Table 1. Film retention after development was more than 90%. This is attributed to the strong interaction between the base resin and photoactive compound, which results in the dissolution inhibition of the unexposed area at development. The high film retention enables patterning of thick film. The resolution of 10 µm and 20 µm thick AH-3000 is 3 µm.

3.2. Film properties
Mechanical properties and thermal properties of AH-3000 are shown in Table 2. The elongation and tensile strength of AH-3000 is comparable to that of AH-1170. The residual stress of AH-3000 falls to 16 MPa and $T_g$ rises to 243°C. This is attributed to modification of base resin and optimization of cross-linker content.

3.3. Mechanical properties after reliability tests
To achieve high reliability, it’s necessary to keep mechanical properties under reliability test conditions. Table 3 shows mechanical properties after reliability tests. After thermal cycle or unbiased HAST (uHAST) treatment, AH-3000 kept its elongation and tensile strength, suggesting that the cured film was not degraded. This is attributed to the improved oxidation resistance of base resin of AH-3000. Adhesion strength to Cu was evaluated by stud pull test. After cure, AH-3000 showed adhesion strength 500 kg/cm² or higher, and its failure mode was cohesive failure of the epoxy resin, suggesting that adhesion strength to Cu is strong enough. Adhesion strength of AH-3000 after thermal cycle or uHAST treatment kept over 500 kg/cm² and their breaking modes were cohesive failure of epoxy resin.

3.4. Coating on panel substrate
To reduce manufacturing cost, the application of panel substrate is considered for next-generation fan-out packages. In the case of large panel size,
spin coating is not applicable. Film lamination or slit coating is necessary to apply dielectric layer for the panel level packaging. As feasibility study of slit coating, AH-3000 was coated with a knife coater for panel substrate. Table 4 shows comparison of process between knife coating and spin coating. Diluted version of AH-3000 was applied for this evaluation, since slit coating requires lower viscosity of varnish. Coating gap of knife coating is 50 µm since diluted varnish was applied. As a result, larger amount of varnish was required to achieve 13 µm thick, thus prebake condition was longer than spin coating.

Table 3. Mechanical properties after reliability test

| Properties                  | Units       | After cure | After temp. cycle$^{(a)}$ | After uHAST$^{(b)}$ |
|-----------------------------|-------------|------------|--------------------------|----------------------|
| Elongation                  | [%]         | 46         | 45                        | 43                   |
| Tensile strength            | [MPa]       | 110        | 107                       | 105                  |
| Young’s modulus             | [GPa]       | 2.7        | 2.7                       | 2.7                  |
| Adhesion strength to Cu$^{(c)}$ | [kg/cm²]   | >500       | >500                      | >500                 |

$^{(a)}$ -65 °C to 150 °C for 200 cycles. $^{(b)}$ 135 °C /85 %RH/96 h. $^{(c)}$ Evaluated by stud pull test.

Table 4. Comparison of process flow for knife coating and spin coating

| Process          | Unit   | Knife coating | Spin coating |
|------------------|--------|---------------|--------------|
| Spin coat        | [rpm]  | -             | 1500         |
| Coating gap      | [µm]   | 50            | -            |
| Pregake          | [°C/min] | 120 / 10     | 120 / 3      |
| Prebake film thickness | [µm] | 12.9          | 11.9         |
| Exposure         | [mJ/cm²] | 500          | 500          |
| Cure             | [°C]   | 200           | 200          |
| Cured film thickness | [µm] | 9.2           | 10.0         |

Figure 1 shows film thickness after development and via size measured with a profilometer. It was confirmed that knife-coated AH-3000 could form 9.2 µm-thick film with good uniformity. Lithographic properties were evaluated with a photomask having 20 µm via patterns. Via holes of diameter 20 µm were obtained in accordance with the mask pattern size on AH-3000 film, suggesting that if properly prebaked, coating method is not affect to resolution.

![Optical microscope observation](image1)

![Profilometer measurement](image2)

Fig. 1. Surface observation and film thickness of AH-3000 on panel substrate.

4. Conclusion

AH-3000 showed excellent resolution in the wide thickness range from 5 µm to 20 µm. AH-3000 kept good mechanical properties even after reliability test, suggesting that it has good thermal cycle and HAST tolerance.

AH-3000 is also applicable to slit coating for panel substrate with good thickness uniformity and fine resolution.

References

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