Novel Low Temperature Curable Photosensitive Negative-tone Polyimide with Higher Resolution and Reliability

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Abstract

Hitachi Chemical DuPont MicroSystems (HDMS) has been developing photo sensitive negative-tone polyimides (PIs) as dielectrics for re-distribution layers (RDLs) in wafer level packages (WLPs) and as protection layers in semiconductor ICs. Photo sensitive negative-tone PIs can simplify the manufacturing process and ensure high reliability owing to their good mechanical properties, high thermal stability, and high electrical properties. On the other hand, since advanced packaging application such as Fan-Out WLP (FO-WLP) requires finer L/S design as well as higher reliability, lithographic performance of PIs has to be further improved and good cured film property should be achieved when cured at lower temperature (<230 °C). In order to meet these requirements, HDMS started the development of new PI which shows enhanced lithographic performance with good film property.

In this paper, we will demonstrate our novel low temperature curable photo sensitive solvent developable negative-tone PI. By adopting a new photo-package to improve lithographic performance, this PI can achieve 3 µm via opening at 5 µm cured thickness and 5 µm via opening at 10 µm cured thickness with smooth pattern profile after cure. In addition, this PI shows good film property when cured at 200 °C and no electrical failure is observed during 300h bias-HAST using 2/2 µm L/S pattern.

Key words

Polyimide, photo sensitive, low temperature cure, high resolution, insulation

I. Introduction

In recent years, photosensitive polyimides (PIs) have been widely used as protection layers for semiconductor ICs and as dielectrics for re-distribution layers (RDLs) in wafer level packaging [1]-[3]. By using photosensitive PIs, the fabrication process has been simplified because photoresist processing is not needed for patterning and the reliability of the package ensured due to the proven cured film properties of PIs.

Recently, a lot of attention has been given to Fan-out WLP (FO-WLP) from the viewpoint of both minimizing form factor and higher functionality [4]-[7]. FO-WLP does not need an interposer for packaging but instead adopts the embedded chip structure into molding compound and utilizes RDLs to rearrange the pad design of the IC chip to an outer area of the IC chip. However, due to the limitation of heat resistance of molding compound and controlling the warpage of FO-WLP, lower temperature curable PI is preferable for RDL application (<230 °C). In addition, since next generation FO-WLP requires finer L/S and smaller via in RDLs to cover the increasing I/O numbers of IC chips, higher resolution is strongly needed [8]-[16].

HDMS has provided a high reliable photosensitive negative-tone PIs since 1998 which need high temperature cure condition more than 300 °C. In parallel, HDMS has been developing low temperature curable photosensitive negative-tone PIs mainly for RDL application of FO-WLP and we already proposed 200 °C curable PI. Furthermore, in order to meet the requirements for next generation FO-WLP, we are focusing on the enhancement of lithographic performance as well as the reliability when cured at lower temperature.

In this paper, we will demonstrate a novel photosensitive negative-tone PI. This material has some improved features as below.

(1) 3 µm via opening at 5 µm cured film with smooth profile
(2) Good film property when cured at 200 °C
(3) Good insulation reliability (No electrical failure during 300h bias-HAST using 2 µm L/S pattern)

Details are described in the following sections.

II. Experimental

Preparation of photosensitive negative-tone PI varnish

Photosensitive negative-tone PI varnishes were prepared by mixing PI precursor, cross-linker, photo initiator and other additives in solvent.

Evaluation of lithographic performance

Photosensitive negative-tone PI varnishes were coated on 6-inch silicon wafers and baked at 105 °C/ 2 min + 115 °C/ 2 min (Tokyo Electron Act 8). The coated films (8 μm thickness) were exposed through a mask using an i-line stepper (Canon FPA-3000iW) and developed with cyclopentanone. Then the wafer was cured at 200 °C for 2 h (Koyo μ-TF). The resolution of the resulting patterns was measured by using an optical microscope. The cross section of the patterns was also measured by using FIB (Hitachi-hightech SMI-500).

Evaluation of Insulation performance

Photosensitive negative-tone PI varnishes were coated on test vehicle with a comb-type Cu electrode. Then the test vehicle was cured at 200 °C for 2 h (Koyo μ-TF). The electric resistance change under HAST condition (130 °C, 85 %RH) was monitored with applying 3.3V DC voltage between the anode and cathode. Schematic test vehicle structure is shown in Figure 1.

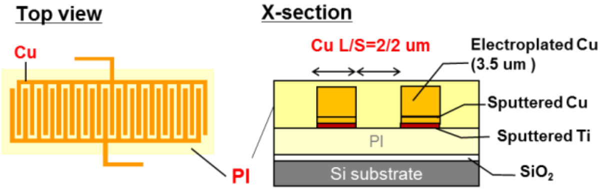

Figure 1. Top view and cross section of test vehicle.

III. Results and discussion

Design concept of negative-tone PI with higher resolution

It is well known that negative-tone PI has an advantage in film property and a disadvantage in lithographic performance compared to positive-tone PBO [14]. On the other hand, good lithographic performance of positive-tone PI applying the same photo-package of positive-tone PBO hasn't been achieved so far because dissolution rate of PI precursor to the developer is too fast to control. In addition, although positive-tone PI using pre-cyclized polymer with phenolic OH group was also studied, water absorption ratio was increased and chemical resistance were not good enough probably because phenolic OH group remained even after cure. From these backgrounds, improvement of lithographic performance of negative-tone PI becomes so important and many studies are being reported recently [17], [18].

There are three possible root cause of lower resolution of negative-tone PI as shown in Figure 2. The first one is swelling during development. To suppress swelling, it is important to strengthen crosslinked network or change developer. The second one is pattern collapse during development. In this case, it is effective to change developer or enhance the adhesion by using appropriate adhesion promoter or process optimization. The third one is footing at the bottom of unexposed area induced by the scattered light from the surface of substrate. Then, it is also essential to avoid unexpected reaction by additives or controlling UV transmittance.

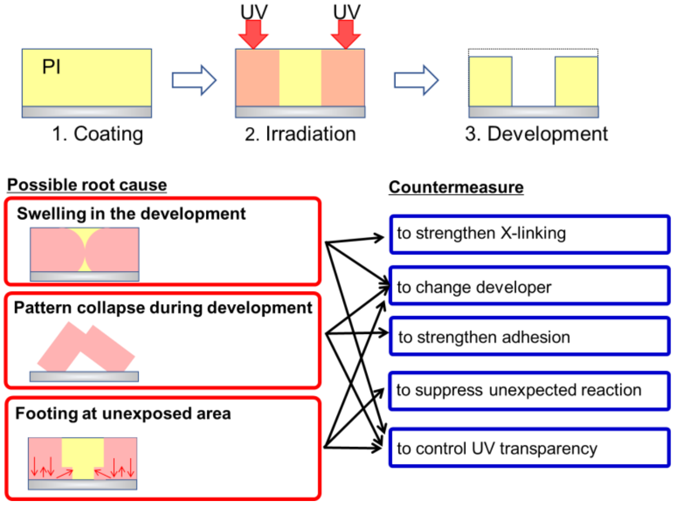

Figure 2. Possible root cause and countermeasure for high resolution.

As a result of investigation based on the countermeasures listed in Figure 2, we could achieve the improvement of lithographic performance of negative-tone PI.

Lithographic performance

The first low temperature curable negative-tone PI (PI 1) has already been set [14]. However, an improvement of lithographic performance was needed to meet current FO-WLP requirements and then a new negative-tone PI (PI 2) was developed through our study.

A comparison of the lithographic performance between PI 1 and PI 2 is shown in Table 1 and cross sections of a via opening pattern are also exhibited in Figure 3.

Table 1. Comparison of lithographic performance

Material	Irradiation (mJ/cm^2)	Thickness after cure (μm)	Substrate	Resolution of via (μm)
PI 1	500	5.0	Si	5
			Cu	10
PI 2	400	5.0	Si	3
			Cu	5

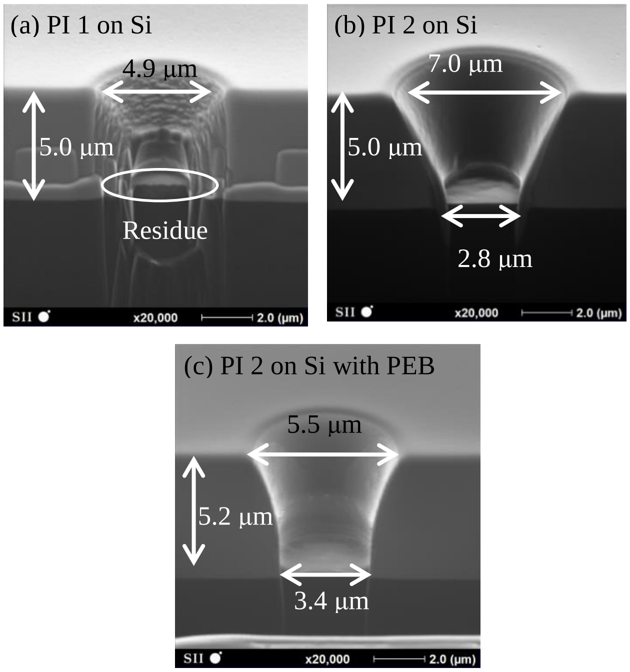

Figure 3. Cross sections of PI 1 and PI 2 after 200 °C cure.

Regarding the sensitivity, there was no significant difference between PI 1 and PI 2. However, due to the photo-package change, PI 2 could achieve ca. 3 µm bottom Critical Dimension (CD) on Si wafer with smooth pattern profile in contrast to PI 1. In addition, by treatment with Post Exposure Bake (PEB, 120 °C for 1 min), taper angle of via opening became steeper as shown in Figure 3 (c).

We also evaluated aspect ratio of PI 1 and PI 2 at 5µm and 10µm cured thickness. Results are shown in Figure 4.

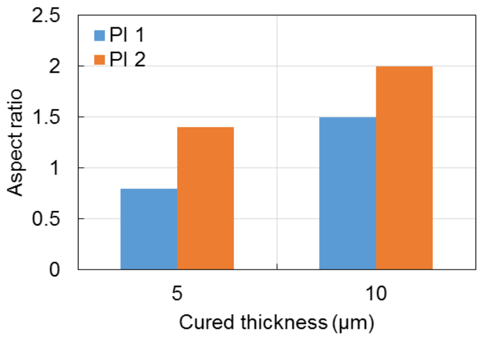

Figure 4. Aspect ratio with different cured thickness.

Regardless of cured thickness, PI 2 could be patterned at higher aspect ratio than PI 1. Especially, aspect ratio of PI 2 was almost twice as high as that of PI 1 when cured thickness was 5 µm.

We also checked cross section of PI 2 via opening at 10 µm cured thickness. Result is shown in Figure 5. As similar to the 5µm cured thickness, smooth pattern profile was obtained.

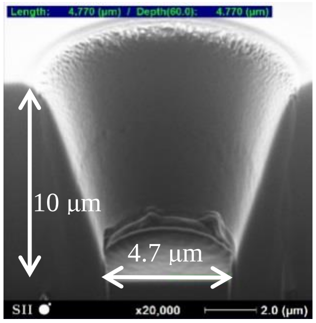

Figure 5. Cross section of PI 2 after 200 °C cure (10 µm^t).

Our further study on photo-package is in progress. Cross sections of PI 3 and PI 4 (slightly modified PI 2) are shown in Figure 6. It should be noted that PI 3 achieves 3 µm bottom CD with nearly vertical taper angle and PI 4 can provides 2 µm via opening.

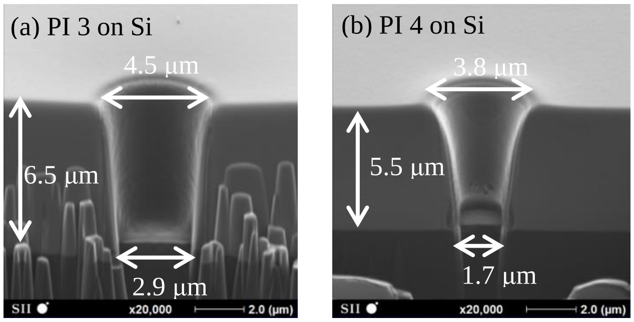

Figure 6. Cross sections of PI 3 and PI 4 after 200 °C cure.

Now, we are still investigating the improvement of lithographic performance of negative-tone PI to overcome the limitation.

Cured film properties

Table 2 summarizes the cured film properties of PI 1 and PI 2. We found that PI 2 showed comparable film property to PI 1 and change of photo package did not affect film property.

Table 2. Comparison of cured film properties

Item	PI 1	PI 2
Cure temp. (°C)	200	200
Tensile strength (MPa)	175	170
Elongation (%)	40	50
Modulus (GPa)	3.2	3.1
Tg (°C)	230	210
CTE (x10^{-6}/°C)	65	70
5 % weight loss temp. (°C)	330	345

Insulation reliability

The insulation reliability of PI 2 was evaluated by bias-HAST using 2 μm L/S pattern. As shown in Figure 7, PI 2 showed no short circuiting during 300 h testing and this result means good insulation reliability of PI 2.

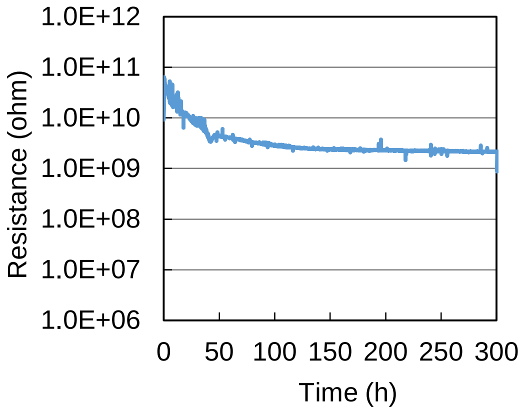

Figure 7. Bias HAST result of PI 2 cured at 200 ^{o}C. Test condition: 130 ^{o}C/ 85 %RH/ 3.3 V DC.

IV. Conclusion

By adopting new photo-package, our new negative-tone PI shows better lithographic performance. 3 μm via opening is successful at 5 μm cured thickness and the pattern profile is smooth. In addition, good film property can be obtained when cured at 200 ^{o}C and its insulation reliability looks good. From now on, we will continue to develop a photosensitive PI to meet future requirements.

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