New Photosensitive Dielectric Material for High-Density RDL with Ultra-Small Photo-Vias and High Reliability

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Abstract

This paper presents an advanced ultra-thin photosensitive dielectric Film (PDM) newly developed with high resolution, low CTE and low residual stress for next-generation high-density redistribution layer (RDL), 2.5D interposer, and high-density fan-out package applications. For high-density RDL, photosensitive dielectric materials need to have low CTE to achieve high package reliability. The CTE of the material is 30-35ppm /K. While maintaining the low CTE, we successfully demonstrated the minimum micro-via diameter of 3um in the 5um thickness. Curing temperature of the PDM is 180^{0}C x 60 min. which is lower than most of the advanced dielectric materials which currently used in industry. Low-temperature curing process results in low stress. We have calculated residual stress in the cured PDM from a test result of warpage measurement on 4 inch wafer. As another benefit of the PDM material in curing process, the PDM can be cured in air oven. Most of advanced photo dielectric materials need to cure in N2 oven due to prevent an oxidation of the material. We have demonstrated copper traces of 2um lines and spaced on the PDM by using semi-additive process (SAP) with sputtered Ti/Cu seed layer. Thanks to the low CTE and low residual stress due to the low-temperature curing, it passed temperature cycle test (1,000 cycles) with daisy chain structure which has 400 vias in the structure. It can be concluded that the newly developed PDM is a promising dielectric material for highly reliable high-density redistribution layer (RDL) for 2.5D interposers and fan-out wafer level package applications.

Key words

dielectric materials, reliability, high-density substrate, interposer, fan-out package.

I. Introduction

A virtual reality technology and its market are growing rapidly in recent years It is easy to imagine that live-8K-VR streaming broadcast needs extremely high data bandwidth. An autonomous car technology also leaped in last half decade. An autonomous car equip a lot of sensors and these sensors gather a lot of data. Gathered data must be processed momentarily. These technologies require higher data bandwidth between logic and memory. The demand of higher data bandwidth drives ultra-high density packaging technologies, such as 2.5D interposers. These ultra-high-density packages require copper wires or traces below 5 µm and micro vias below 10 µm to realize high-density RDLs. Copper lines and spaces of 2um /2um is being established with Semi-Additive-Process (SAP). However, formation of small via is one of challenges. To form a via, CO2 or Nd-YAG laser drilling is frequently used but these lasers cannot make micro-vias below 10 µm [1][2].

Many publications have reported on the use of photolithography to form small micro-vias in recent years. Excimer lasers is often employed for ultra-small via fabrication on non-photosensitive materials [3], [4]. However, it requires a quite high initial cost of the equipment. On the other hand, photosensitive materials do not require expensive high power lasers. Hence, micro-via formation by photolithography using photosensitive dielectric materials is of high interest in the applications. Photosensitive polyimide (PI) and polybenzoxazole (PBO) are widely used to obtain ultra-fine vias. But, their high curing temperature limits several usages such as chip embed structures. In addition, curing with high temperature causes huge warpage that affects reliability of an IC-package. PI is known to have huge shrinkage during the curing process. [5]. Reduction of insulation layer thickness could be inflicted for a packaging designer, especially for thinner insulation layer structures. The relatively high cost of the materials (PI and PBO) is another challenge, and spin coating processes are not easy to apply in panel-scale production. Another challenge for high-density packaging is to maintain high reliability, since operation at high temperature might cause interfacial failure due to CTE mismatch between peripheral materials of a high density package. To achieve high reliability, the dielectric materials with low CTE can help to gain high thermal reliability. Adding fillers into matrix resin is one of the common methods to decrease CTE, and is a simple way for non-photosensitive materials which require laser ablation

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as they do not require good light penetration. However, this approach is not simply applied to photosensitive materials, as fillers can prompt excessive light scattering which degrades resolution performance. To obtain photosensitive materials with low CTE and high-resolution performance, elaborate filler design is necessary. Surface treated nano-sized inorganic fillers can help to achieve an optimum balance of high resolution and low CTE. Using the new filler, we have developed a photosensitive dielectric material, named PDM that has low CTE as well as high-resolution performance as reported earlier. [6] This paper reports on the feasibility study of the PDM for advanced applications such as 2.5D interposers and high-density fan-out packages. In this paper, we fabricate a test coupon with line and space of 2um / 2um on PDM and perform a BHAST using the coupon to demonstrate insulation performance. Also, a daisy chain test coupon was fabricated to demonstrate contact reliability of ultra-small photo-vias.

II. Material

A. Chemical Components and Dry Film Structure of PDM

PDM mainly consists of carboxylic acid resin, photo sensitive-multi functional acrylate resin, epoxy resin and inorganic fillers. These ingredients were mixed uniformly then coated on PET film followed by drying. Finally, covered by PP film. The dry film structure is show in Fig. 1.

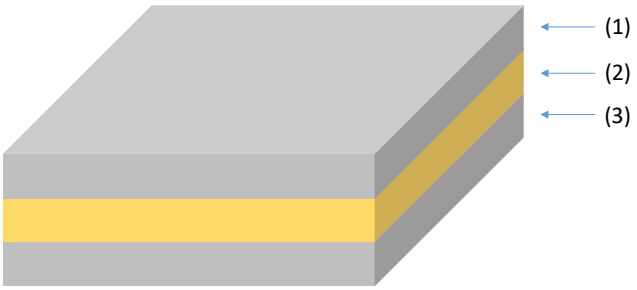


Figure 1. Dry Film Structure of PDM (1): Cover Film (PP), (2): PDM-1, (3): Carrier Film (PET)

B. Material Properties of PDM

Various material properties of the PDM were measured. The glass transition temperature (Tg) and CTE of the PDM-1 were analyzed through thermomechanical analysis (TMA). Tensile strength, elongation and elastic modulus were measured by tensile test. Dielectric properties were observed by a network analyzer with split post dielectric resonator (SPDR) fixture. The water absorption rates of PDM were also measured by dipping PDM into boiling water for 60 minutes. The properties of PDM are summarized in Table 1.

Table 1 Material Properties

Properties	Unit	PDM
Tg (@TMA)	(deg.C)	**180 - 185**
CTE alpha 1	(ppm)	**30-35**
Elastic Modulus	(GPa)	**3.5 - 4.0**
Tensile Strength	(MPa)	**90 - 95**
Elongation	(%)	**5.5 – 6.0**
Dk (10GHz)		**3.3**
Df (10GHz)		**0.019**
Water absorption	(%)	**0.84**

C. Ultra-Small Photo via of PDM

To confirm a small via opening performance of PDM, the cover film was removed from the sandwich structure and the PDM was laminated on electrically-plated copper. Then 200 mJ/cm2 of 365 nm wavelength was dosed. Before development process, carrier film was removed and PDM-1 was developed by 1.0 wt % aqueous sodium carbonate. After development, 2.0 J/cm2 of UV light with broad spectrum was exposed to cure the remaining photo curable resin completely. At the end of the process, we did a thermal cure with 180 deg.C for 60 min. After that we observed vias image using Scanning Electron Microscope (SEM). As the minimum micro-via diameter, 3 um in the 5 um thickness is observed. Observed SEM image is shown in Figure 2.

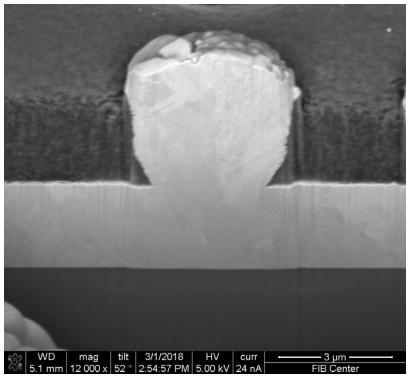


Figure 2 Cross Section Image of 3 um Diameter Copper Filled Via on Electro Plated Copper

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III. Daisy Chain Test Coupon Design and Fabrication Processes

A. Daisy Chain Test Coupon Design

Figure 3 shows flat pattern of over all the daisy chain test coupon. The test coupon is consists of 10 row and 20 column of discontinuous copper lines and each line is connected with a total of 400 vias. The point A to point B is connected electrically. Large pad (indicated in yellow) is located at the side of the daisy chain. The large pad is used to measure a resistance by 4-terminal method.

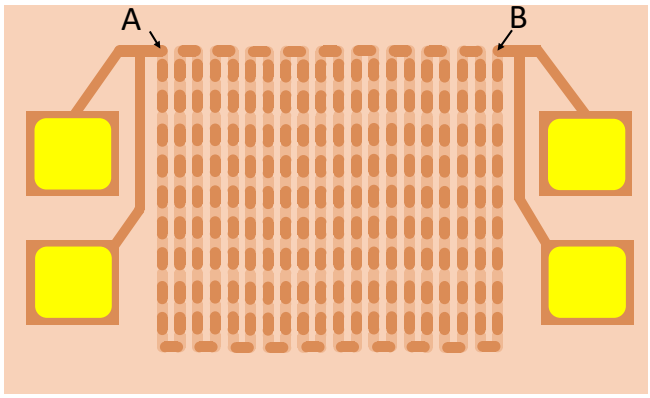


Figure 3 Flat Pattern of Over All of the Daisy Chain Test Coupon

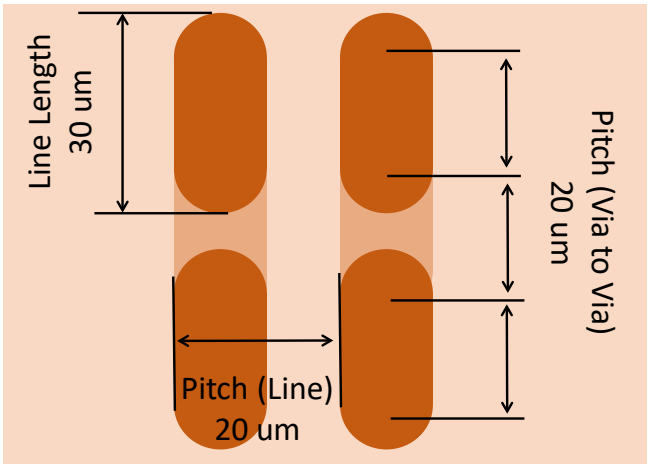


Figure 4 Enlargement Schematic of the Test Coupon

Figure 4 indicates an enlarged schematic of the test coupon. Pitch of each copper line is 20um and Pitch of each via is also 20um. Length of each copper line is 30um. Figure 5 shows cross-sectional image of the daisy chain and figure 6 is its magnification image. Height of copper trace is 5 um for each copper layer. 1st copper layer and 2nd copper layer is connected with 3 um diameter and 5 um height via.

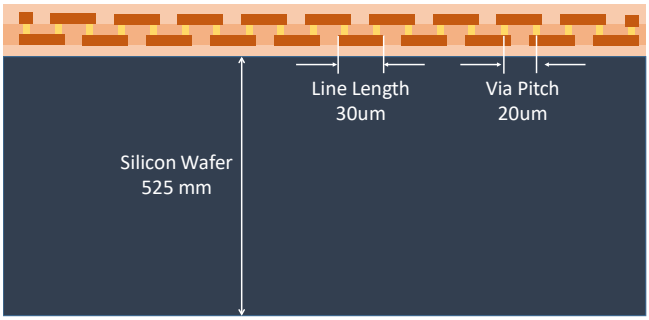


Figure 5 Cross Section Image of the Test Coupon

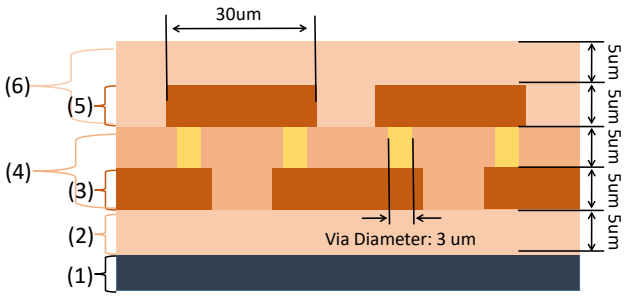


Figure 6 Magnification Schematic of Cross Section
(1): Silicon Wafer, (2): 1st Layer PDM, (3):1st Layer Cu, (4): 2nd Layer PDM, (5): 2nd Layer Cu, (6): 3rd Layer PDM (Passivation Layer)

B. Fabrication Process

5 um thickness of PDM was laminated on 4-inch wafer using a vacuum laminator and then cured completely. To fabricate copper wires on PDM, a standard semi-additive process (SAP) was used. As the first step of SAP, titanium and copper seed layers were deposited on the PDM surface with thicknesses of 50 nm and 300 nm respectively using RF sputtering. Then, a photo resist was coated on the seed layer using a spin coater. The photo resist was exposed through a glass mask which had a 1st layer copper pattern followed by development. Then Electro copper plating was done until the copper height reached to 5 um. After photoresist stripping, the seed layers were etched. After etching process, Annealing was done by 180deg.C for 1hour. Next, 10 um thickness of PDM was formed on 1st copper layer using vacuum laminator. Then the 2nd layer PDM was exposed by an i-line dose of 200 mJ/cm2 for small via patterning, followed by development with 1.0 wt% Na_2CO_3. Then 2.0 J/cm2 of UV light with broad spectrum was exposed followed by thermal cure at 180 deg.C for 60 min. Then after surface cleaning by Ar plasma, titanium and copper seed layers were deposited on the 2nd layer PDM surface as well as vias with thicknesses of 50 nm and 300 nm respectively. Same process as 1st copper layer, 2nd copper layer was formed. As passivation layer, 3rd PDM layer was formed on

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2nd copper layer. As a surface finish, Electro less nickel immersion gold (ENIG) was applied. Overall process flow is shown in figure 7.

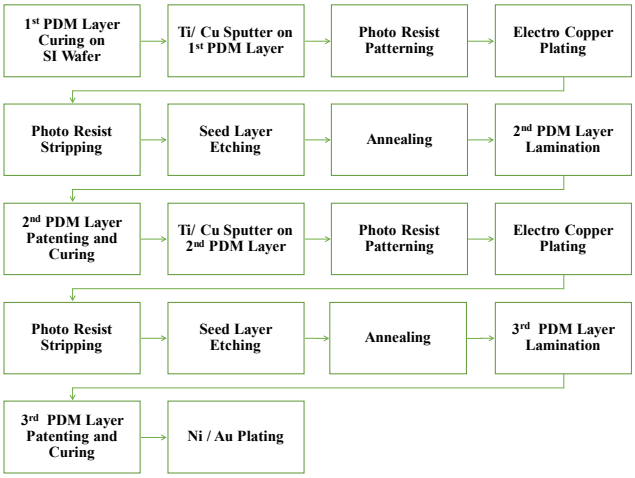


Figure 7 Process Flow for Test Coupon Fabrication

IV. RESULTS AND DISCUSSION

To evaluate via connection reliability, temperature cycling was performed. Prior to the temperature cycle test, the test coupon was dried with 125deg.C for 24hours. After drying, the sample was put into a thermos hygrostat chamber and treated with 60deg.C, 60 %R.H. for 120 hours (JEDEC Soak condition Level 2a). After preconditioning, temperature cycle was done with condition B. (low temp.-55 deg. C High Temp.; 125 deg. C). The resistance was measured every 100 cycles with 4 terminal method. Each measured resistance was plotted in figure 8. This result means a total of 400 ultra-small vias (3um) are being connected even after the temperature cycle test.

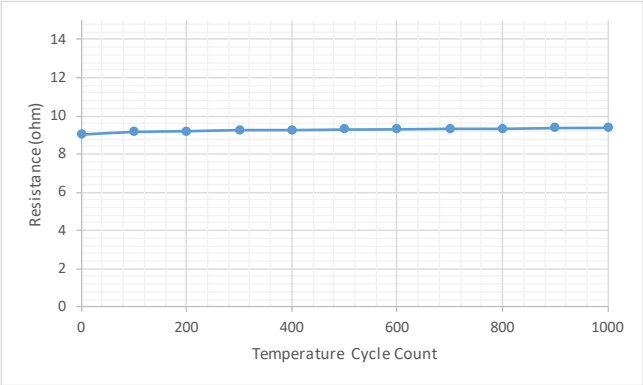


Figure 8 Plots of Resistance at Every 100 Cycles.

V. Conclusion

A high resolution photosensitive dielectric material was developed. The PDM can form 3 um diameter via in 5 um thickness. The daisy chain test coupon was fabricated to evaluate a reliability of the ultra-small vias. As a result very stable via connection was confirmed even after 1,000 cycles of temperature cycle test. We can conclude that the PDM reported in this paper is expected to be a suitable dielectric material for 2.5D interposer and high-density fan-out package applications.

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