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# Photopatternable Laminate BCB Dielectric

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## Abstract

Divinylsiloxane-bis-benzocyclobutene (DVS-bis-BCB, or BCB) is a well-known dielectric material that has been used in high volume manufacturing for many years (CYCLOTENE™ 3000/4000-series Advanced Electronic Resins). Typically, the application of these products has been by spincoating or spray coating of the dielectric material from a solvent-based formulation. However, for certain applications - for example, those involving large area, square substrates such as glass panels - it is desirable to be able to apply the BCB-based dielectric material using a dry film coating process, such as vacuum or hot roll lamination. In this paper, we describe the concept of creating a laminate film utilizing DVS-bis-BCB as the primary dielectric material component. In creating the laminate dielectric material, it is important to maintain the unique combination of thermal and electrical properties of DVS-bis-BCB, including high thermal stability, excellent copper barrier properties, low moisture uptake, low dielectric constant, and low dielectric loss. However, DVS-bis-BCB alone is too rigid to produce a high quality laminate film, therefore, it is necessary to modify the formulation to improve flexibility and lamination quality. As the flexibility of the film is increased, higher fracture toughness ($K_1C$) and higher elongation values should result. Novel formulation adjustments to the base DVS-bis-BCB polymer system have resulted in an experimental laminate dielectric product that will be the focus of this discussion.

Depending on the application, laminate films can vary in thickness from 2µm to 50µm or even thicker. A typical laminate film construct includes the BCB-based dielectric film with a base sheet of an optically-clear polyester (PET) film and a polyethylene (PE) cover sheet. The DVS-bis-BCB-based laminate can be tuned with appropriate additives to either pattern with UV exposure from a tool such as a Süss MicroTec Mask Aligner (50mJ/cm$^2$ – 100mJ/cm$^2$ exposure energy) or laser pattern with a tool such as a Süss MicroTec 248nm Excimer Laser. Aspect ratios of 1:1.5 have been achieved with a photopatternable DVS-bis-BCB film and aspect ratios of >1:1 are possible with a laser-patterned film. Beside the photopackage added to the film to enable UV patterning, toughening additives have also been incorporated to enhance the fracture toughness ($K_1C$) and elongation properties. $K_1C$ for the laminate has been improved to 0.55Mpa·m$^{1/2}$ vs. 0.35Mpa·m$^{1/2}$ for DVS-bis-BCB. Elongation has been improved to 13% for the laminate vs. 8% for DVS-bis-BCB. Electrical properties are similar to DVS-bis-BCB. An additional attribute of the laminate dielectric is the ability to tent over and protect vias. Vias >100µm diameter have successfully been tented with a 10µm thick film. A DVS-bis-BCB-based laminate has been demonstrated with continued optimization and evaluation to follow.

## Key words

Dielectric, Benzocyclobutene, Photopatternable, Laser Ablation, Laminate

## I. Introduction

Panel processing to reduce the cost of packaging electronic devices for consumer applications is currently the focus of significant R&D effort in the industry. The adoption of this technology requires the continued development of interesting interconnect solutions that reduce the size of signal routing and, therefore, impose new demands on the dielectric materials used to isolate the copper interconnects. Benzocyclobutene polymers have been used to isolate copper interconnects in packaging applications for more than 20 years, due in large part to the very low copper drift rate for this polymer platform [1-4]. In addition, the BCB platform has a number of other attributes that make it attractive for new material development including low dielectric constant, low moisture absorption, rapid low temperature curing without generation of by-products, minimum shrinkage in cure process, and proven reliability [5-8]. However, the relatively low degree of elongation and inherent stiffness of the BCB platform has limited its use in stress buffer applications. Therefore, it is highly desirable to improve the mechanical properties of the polymer platform while maintaining the good electrical and physical attributes of BCB polymer, enabling the development of both laser and photopatternable laminate BCB dielectrics.

## II. Overview of Photo and Laser Patternable Laminate Dielectric

### Mechanical and Electrical Properties of Dielectric Film

A dielectric film that is BCB-based and both photo and laser patternable has been developed for next-generation packaging needs. Toughening additives have enhanced the mechanical properties of the film while the electrical properties are similar to BCB.

*Table I. BCB Laminate Dielectric Material Properties vs. Various Dielectrics*

| Material Property | *BCB Laminate Dielectric* | CYCLOTENE™ 3000/4000 Dielectric | Polyimide | Epoxy/ Phenol | Acrylic | Poly-benzoxazole |
|---|---|---|---|---|---|---|
| Mechanical Properties | | | | | | |
| Cure Temperature (°C) | 200 - 250 | 200 - 250 | 350 | 190 | 200 | 175 - 225 |
| Tg (°C) | 250 | >350 | >350 | 210 | 180 | 250 |
| CTE (ppm/°C) | 63 | 42 | 34 | <30 | 80 | 70 |
| Tensile Strength (MPa) | 80 | 87 | 200 | 90 | <50 | 170 |
| Elongation (%) | 13 | 8 | 45 | 7 | 5 | 80 |
| Residual Stress (MPa) | 28 | 28 | 34 | 54 | <30 | 25 |
| Fracture Toughness (MPa m1/2) | 0.55 | 0.35 | NA | NA | NA | NA |
| Moisture Uptake (%) | 0.1 | 0.1 | 1.3 | 1.5 | 1.5 | 0.5 |
| Electrical Properties | | | | | | |
| Dielectric Constant (1MHz) | 2.57 | 2.57 | 3.2 | 3.5 | >3.5 | 3.1 |
| Dissipation Factor/Loss (≤1MHz) | 0.0032 | 0.0016 | 0.002 | 0.02 | 0.03 | 0.009 |
| Breakdown Voltage | 5.1MV/ cm | >5.3 MV/cm | NA | NA | NA | NA |

Table I summarizes the mechanical and electrical properties of the newly developed BCB-based laminate dielectric and Dow's BCB-based liquid dielectric CYCLOTENE™ series vs. industry standard dielectric materials. The BCB laminate film exhibits improved elongation (13% vs. 8%) and fracture toughness (0.55Mpa $m^{1/2}$ vs. 0.35Mpa $m^{1/2}$) vs. CYCLOTENE™ 3000/4000 Resin. The laminate film's electrical properties also compare favorably to the CYCLOTENE™ Resin dielectric properties. The combination of these electrical and mechanical properties makes this film an attractive candidate for high-performance dielectric applications.

### Lithographic Performance of Dielectric Film

A standard laminate thickness of 10µm was used to determine lithographic characteristics. Exposure energy of $50mJ/cm^2$ was sufficient to photopattern the film using a Süss MicroTec Mask Aligner. Being a negative-tone film, Dow's solvent developer DS2100 was used to dissolve the unexposed portions of the coating. The process conditions are described in detail in section IV.

*Table II. Lithographic Property Comparison Between BCB Laminate Dielectric and CYCLOTENE™ 4000 Resin Dielectric*

| Litho Properties | *BCB Laminate Dielectric* | CYCLOTENE™ 4000 Resin |
|---|---|---|
| Coating Type | Laminate | Spin-Coated |
| Film Thickness Range | 5 - 50µm | 1 - 15µm |
| Tone | Negative | |
| Via Resolution/Coating Thickness | 15µm in 10µm film | 20µm in 10um coating |
| Aspect Ratio | 1:1.5 | 1:2 |

Table II highlights the improved resolution of the BCB laminate dielectric film vs. the CYCLOTENE™ 4000 Resin. At an equivalent film thickness of 10µm, a 15µm wide via can be opened with the laminate as compared to a 20µm via with the CYCLOTENE™ 4000 Resin. Also of note is the improved photospeed of the laminate. Using a Süss MicroTec Broadband Mask Aligner, exposure energy of $50mJ/cm^2$ was sufficient to photopattern the laminate dielectric. As the CYCLOTENE™ 4000 Resin requires roughly $600mJ/cm^2$ exposure energy to photopattern the film at 10µm thickness, the laminate can be estimated to have 12X faster photospeed. Fig. 1 below shows cross-sections of a 10µm film on a silicon substrate, exposed at $50mJ/cm^2$ and developed with DS2100 to produce vias of varying diameters. The steeper sidewall angle (> 45°) vs. CYCLOTENE™ 4000 Resin will also yield finer pitch and higher density lithography.

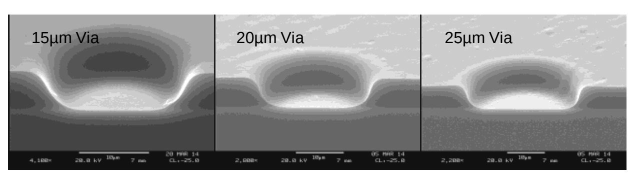


*Figure 1. Cross-section SEM images of vias photopatterned in the BCB laminate dielectric film*

**Laser Ablation Patterning of BCB Laminate Dielectric**

To evaluate the laser patterning performance of the film, a 10µm coating of BCB laminate dielectric was applied to a silicon substrate, blanket UV exposed (50mJ/cm$^2$), soft cured (200°C for 100mins.), and then ablated with a Süss MicroTec 248nm Excimer Laser. The ablation energy was 650mJ/cm$^2$ per pulse for 52 pulses. The images below show that 6µm line/space structures with an improved aspect ratio of 3:1 can be achieved using laser ablation.

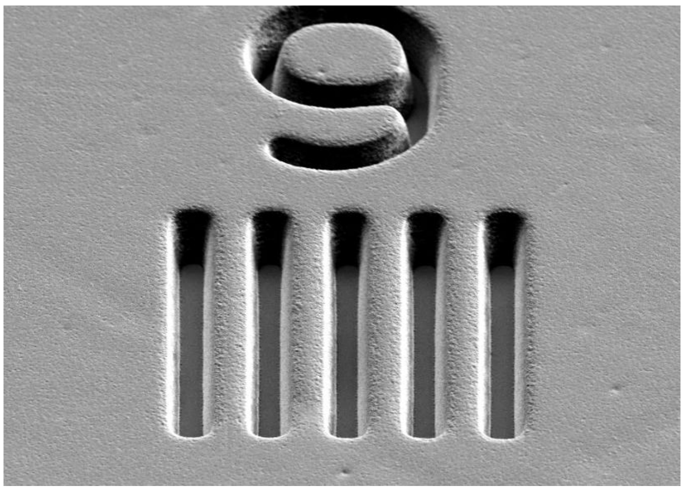

*Figure 2. 6µm line/space pattern in 10µm thick film (image courtesy of Fraunhofer IZM)*

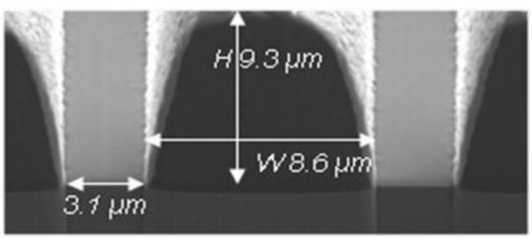


*Figure 3. Cross-section image of 6µm line/space pattern shown from above in Fig. 2. (image courtesy of Fraunhofer IZM)*

Fig. 3 above shows that there is some top-loss associated with the laser ablation process as a 10µm film has been reduced to 9.3µm thickness. The laser fluence used has resulted in a 3.1µm trench width for a 3:1 aspect ratio. In this case, higher resolution is possible when using laser ablation vs. standard photolithographic processing.

**Tenting Performance of BCB Laminate Dielectric**

The ability of the BCB laminate dielectric to tent and protect vias having a diameter of at least 100µm is unique to this format as compared to a spin-on dielectric that will not have the ability to span openings present on glass or silicon substrates. The following images show a 10µm film applied over 100µm vias with hot roll lamination. The film was processed through hard cure (250°C for 60mins.) with no degradation or openings in the tents.

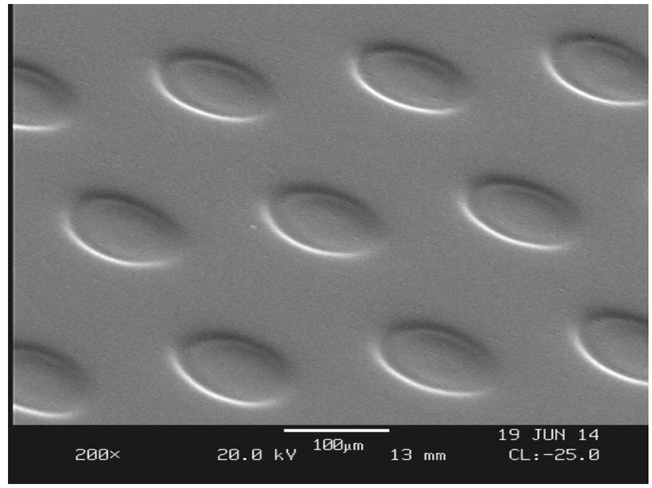


*Figure 4. BCB laminate dielectric applied over 100µm vias*

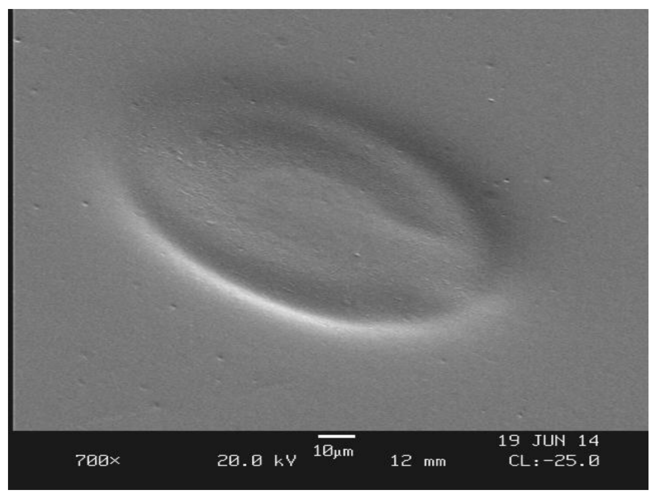


*Figure 5. Magnified image of BCB laminate dielectric applied over 100µm via*

An advantage of the tenting ability of the film as compared to a standard spin-on resist is the ability to exclude plating from non-conductive vias.

## III. BCB Laminate Dielectric Construction

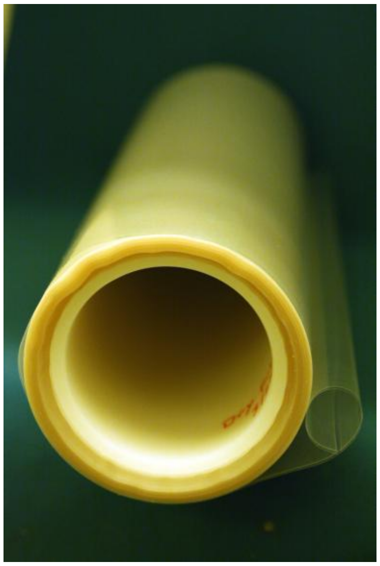

*Figure 6. BCB laminate dielectric on plastic core*

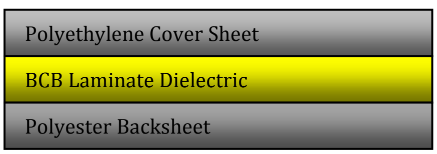


*Figure 7. BCB laminate dielectric film construction*

As this is a thin film coating, high quality polyethylene is used as a cover sheet to prevent gels from imprinting holes or voids into the coating. Optically clear polyester is also critical as exposing radiation will be passing through the backsheet and distortion should be limited.

## IV. Processing Conditions for BCB Laminate Dielectric

*Table III. Processing Conditions of BCB Laminate Dielectric vs. CYCLOTENE™ 3000/4000-Series Dielectrics*

| Process Step | *BCB Laminate Dielectric* | CYCLOTENE™ 3000/4000 Dielectric |
|---|---|---|
| Adhesion Promoter | Current version self-priming | AP3000 |
| Application | Hot roll or vacuum laminator | Spin-coated |
| Post-Application Bake Step | Not Required | 90C/90s (assume 10µm tks) |
| Thickness | 5 - 50µm | 1 - 15µm |
| Exposure Type and Energy | i-line or Broadband (BB), exposure depending on film thickness (50mJ/cm2 for 10µm film) | i-line or BB, exposure depending on film thickness |
| Post-Exposure Bake | 90C/90s | 80C/90s |
| Develop | Puddle or spray with Dow's DS2100 solvent developer | |
| Post-Develop Bake | 90C/60s | Spin dry |
| Hardcure | 250C/60min. in Nitrogen-purged environment | |

Table III summarizes the processing conditions for the BCB laminate dielectric as compared to the CYCLOTENE™ 3000/4000-series Dielectric.

### Substrate Surface Preparation

The current version of the laminate is self-priming. For some applications, an adhesion promoter designed for use with BCB-based dielectrics such as Dow's AP9000M or AP9000S may be used, if needed. Prior to film lamination, the adhesion promoter is applied to the substrate by dispensing either statically or dynamically. The substrate is then spun dry at 2000rpm for 10- 20s and baked to remove the solvent carrier for 30sec. at 90-150°C.

### Film Application

The film may be applied by hot roll lamination with a tool such as the Western Magnum XRL-120 Hot Roll Laminator. The polyethylene cover sheet is peeled away while the BCB laminate dielectric is adhered to the substrate surface at a speed of 2fpm and a temperature of 107°C. The polyester backsheet is left to cover the laminate coating through exposure for protection against both physical damage and oxygen inhibition during free radical polymerization. Vacuum lamination is another possible method of applying the BCB laminate dielectric. Advantages of a BCB laminate dielectric versus a spin-on coating include enhanced thickness control, availability of multiple film thicknesses with the ability to coat very thick layers, and the absence of a baking step to eliminate solvent. This results in a lower VOC process.

### Exposure and Post-Exposure Bake

In this description, the Süss MicroTec Mask Aligner was used to cure the film. Exposure energy will depend on film thickness. At a film thickness of 10µm, 50mJ/cm$^2$ was sufficient to cure the film. A 90°C/90s bake step is used post-exposure to complete the free radical polymerization.

### Development and Post-Develop Bake

Dow's DS2100 Solvent Developer was used to dissolve the unexposed portions of the film and create the intended pattern. In this description, a puddle develop step of 180s was used which was followed by a spin step at 1000rpm to remove the dissolved portions while spraying with fresh developer to clean out finer features. A final 2000rpm spin step is used to remove the developer. To dry the wafer, a post-develop bake step of 90°C for 60s is used.

### Laser Ablation

As an alternative to UV exposure and development, laser ablation can be used as a means to open features in the laminate dielectric. A Süss MicroTec 248nm Excimer

Laser was used with an exposure energy of 650mJ/cm$^2$ per pulse and requiring 52 pulses to transfer the pattern. For this experiment, a 5µm sacrificial layer was applied over the laminate dielectric to capture particles produced by the ablation process. Post-ablation, the sacrificial layer was stripped to reveal a clean, patterned layer.

### BCB Curing Step

Post-patterning, the laminate can be either soft cured at 200°C for 100min or hard cured at 250°C for 60min, depending on the amount of BCB polymerization required. The laminate is oven-cured in an $N_2$ atmosphere as BCB is susceptible to oxidation at elevated temperatures.

## V. Conclusion

This paper summarizes the development of a BCB-based laminate dielectric with performance advantages as compared to CYCLOTENE™ 3000/4000-series Dielectrics and other current dielectric materials. Improved mechanical properties, similar electrical properties, and the ability to tent vias are seen as properties suited for the next generation of electronic devices. Enhanced lithographic resolution and faster photospeed are additional benefits that will enable higher density patterns and faster manufacturing throughput. Laminate products demonstrate the ability for improved thickness control, the introduction of a wide range of available thicknesses, and the exclusion of VOC-producing steps such as the bake process following liquid dielectric application. Further processing advantages can be realized when laser patterning is employed, including improved resolution and the elimination of UV exposure and developer tools.

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