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BCB Polymer Dielectrics for Electronic Packaging and Build-up Board Applications

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Abstract

Dielectric polymer films produced from benzocyclobutene (BCB) formulations (CYCLOTENE* family resins) are known to possess many desirable properties for microelectronic applications; for example, low dielectric constant and dissipation factor, low moisture absorption, rapid curing on hot plate without reaction by-products, minimum shrinkage in curing process, and no Cu migration issues. Recently, BCB-based products for thick film applications have been developed, which exhibited excellent dissipation factor and dielectric constant well into the GHz range, 0.002 and 2.50, respectively. Derived from these properties, the applications are developed in: bumping/wafer level packaging, Ga/As chip ILD, optical waveguide, flat panel display, and lately in BCB-coated Cu foil for build-up board. In this paper, we review the relevant properties of BCB, then the application areas in bumping/wafer level packaging and BCB-coated Cu foil for build-up board.

Introduction

An extensive literature exists in applying benzocyclobutene (BCB) polymer as a dielectric layer for various electronic applications [1], for example, bumping/wafer level packaging [2-4], stress buffer/passivation [5], multilayer interconnects [6], Ga/As chips [7], waveguides [8], and build-up board [9]. In this paper, we will review the characteristics and properties of BCB as they apply to two application areas: bumping/wafer level packaging and BCB-coated Cu foil for build-up board.

BCB in Wafer Level Chip Scale Packaging (WL-CSP)

There are many design variations in the WL-CSP arena [10]. One example practiced by Fraunhofer IZM/TU Berlin is shown schematically in Figure 1. Photosensitive-BCB (Photo-BCB) formulations (CYCLOTENE* 4022, 4024, and 4026) are used in this application and they cover the film thickness range of 2.5 – 5, 3.5 – 7.5, and 7 – 14 μm, respectively. The important properties of Photo-BCB film that relate to WL-CSP manufacturing are shown in Tables I and II [11,12].

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Other advantages of BCB for WL-CSP manufacturers are: low cure temperature (210-250°C), rapid curing [13], compatibility with Cu metallization, high resistance to ion mobility [14], excellent chemical resistance [15], good planarization, and very low moisture absorption/rapid moisture desorption [16]. In a box oven, soft cure can be done within 30-40 minutes at 210°C, and hard cure in 60 minutes at 250°C. On a hot plate, the desired level of cure could be achieved in 20 seconds of contact time, by appropriately setting the hot plate temperature (Figure 2). Low moisture uptake at high humidity conditions (Table II) is beneficial in bumping/redistribution, as it is well known that uncontrolled outgassing of water vapor from underlying layers of dielectric can result in blistering and delamination of thin metal films [17]. Photo-BCB naturally gives a rounded via side walls with a positive side wall shape (Figure 3), which makes it easy to obtain good coverage either by sputtering or evaporation [18].

Adhesion is an important factor dictating the mechanical reliability of the products. Adhesion of BCB to the surfaces such as Si, SiN, Cu, and Al can be improved by using a spin-on primer, AP3000. It consists of 0.3 percent vinyltriacetoxisilane, which has been activated in water and diluted in Dowanol PM. The interfacial fracture energies for BCB from the aforementioned four surfaces are compared between using AP3000 and without (Figure 4). The results show that, by using AP3000, the interfacial adhesion energies increase to the level of cohesive energy of BCB bulk. Adhesion energies were measured by employing Edge Lift-off Test (ELT) described elsewhere [16]. Our recent data indicate that tape peel adhesion of BCB to metal surfaces (Cu and Al), after pressure cooker test (PCT) for 96 hours at 121°C and 14.7 psig, can be improved further by baking AP3000 for 30 seconds at over 75°C. On the other hand, adhesion of BCB to other surfaces (Si and SiN) passes the same PCT/tape peel test with the rating of 5B, without having to bake the promoter.

A number of companies are now using BCB as the dielectric material for their bumping and wafer level CSP. Table III shows a list of these companies. Figures 5-8 show some examples of bumped devices using Photo-BCB.

BCB-coated Cu Foil for Build-up Board Applications

Recently, polymer coated Cu foil build-up board technology has become popular due to its high productivity and adaptability to the infrastructure of the printed circuit board industry. It enables high-density wiring and high-speed signal transmission. Up to now, the resin has been mainly epoxy. High speed signal transmission calls for a dielectric with lower loss factor.

CYCLOTENE coated Cu foil and the relevant build-up board processes such as laser via formation and electroless plating have recently been developed to meet the high speed needs. The resin formulations were specially modified to satisfy the requirements of B-stage polymer coating on Cu foil. Those requirements consist of high flexibility and flaking resistance, low tackiness, and resin flow control in the hot press process [9]. Flexibility and flaking resistance was achieved by introducing flexible segments of polymer. Resin viscosity control was attained by incorporating flow control agent. Typical formulations for this application consist of solid content of 50-60 wt% in mesitylene with the viscosity range of 1000-1500 cSt.

Typical conditions for preparation of Cyclotene-coated Cu foil are 130-170°C for 5-15 minutes in air atmosphere, which reduces the residual solvent to less than 0.1%. Typical conditions for hot press process are 200-210°C for 1-3 hours in air atmosphere. It was confirmed that the properties of the FR-4 core board were not degraded by these conditions. Hot press time for 1 hours at 210°C provided sufficient Cu peel strength, >1 kg/cm (Figure 9).

Our results show that dielectric constant and dissipation factor for the CYCLOTENE formulation measured at a high frequency (1 GHz), are consistently around 2.5 and 0.002, respectively. Drill through hole and laser via can be formed on BCB layer with conventional laser conditions (Figures 10 and 11). The JIS test boards (Figure 12) were constructed and subjected to the reliability test per JIS C5021, and passed all the test items (Table IV).

Summary

BCB has been incorporated into several wafer level CSP processes. Properties such as very low moisture absorption, fast and low temperature curing, and compatibility with copper make BCB a low cost solution for WL-CSP manufacturers. Toughened BCB has been incorporated into build-up board. Low dielectric constant and dissipation factor (2.5 and 0.002) of toughened BCB at high frequencies over 1 GHz make this technology viable not only for high frequency PWB but also high density, high speed single or multi chip mini BGA or CSP packaging applications.

Acknowledgement

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Table I. Properties of Photo-BCB (CYCLOTENE™ 4000 series)

Property	Value
Dielectric constant (1 kHz – 10 GHz)	2.65 – 2.50
Dissipation factor (1 kHz – 10 GHz)	0.0008 – 0.002
Breakdown voltage (V/cm)	3×10^6
CTE (ppm/ºC) at 50 - 150ºC	52
Tg (ºC)	>350
Tensile modulus (GPa)	2.9 ± 0.2
Tensile strength (MPa)	87 ± 9
Elongation at break (%)	8 ± 2.5
Poisson's ratio	0.34
Residual stress on Si at 25ºC (MPa)	28 ± 2

Table II. Weight % Water Uptake in Photo-BCB at Various Relative Humidity at 23°C

CYCLOTENE	Film Thickness (μm)	Relative Humidity		
		30%	54%	84%
4024-40	5	0.061	0.075	0.14
4026-46	10	0.058	0.077	0.14
4026-46	20	0.005	0.082	0.14

Table III. Bumping / redistribution / WL-CSP programs utilizing photo-BCB.

Company	Technology	Feature	UBM	Dielectric
CHIPBOND	chipBGA™		Ti/Cu	BCB
FCT	UltraCSP™	Al redistribution, BON	Al/NiV/Cu	BCB
ASE	FCT licensee			
SPIL	FCT licensee			
Amkor	FCT licensee Unitive licensee			
California Micro Devices	FCT licensee	Low I/O passives		BCB
Unitive – U.S.		Al redistribution	Al/Ti/Cr-Cu	BCB
Unitive – Taiwan	Unitive-US licensee			
Dallas Semiconductor	Unitive licensee	Low I/O devices		BCB
Atmel	dBGA™			BCB
CS2 / IMEC		Cu redistribution		BCB
Hyundai Microelectronics	Omega CSP™			BCB on Elastomer
Fraunhofer IZM / TU Berlin		Cu redistribution	TiW/Cu/Ni/Au	BCB
National Semiconductor	MicroSMD™			BCB
Shellcase	ShellOP™	Glass encapsulation	Ni/Au	BCB, epoxy
Xicor	XBGA			BCB

Table IV. Results of JIS test board reliability evaluation

Item	Conditions			Results	
Solder Dip	260 C float, 10sec, 3 times			passed	
Chemical Resistance	10 vol% of 36 % HCl, 1hr			passed	
	10 vol% of 95%H2SO4, 1hr			passed	
	5wt% of NaOH,			passed	
Cu Foil Peel Strength	1hr18um Cu foil			> 1.0 Kg/cm	
Flame Retardancy	UL			94 V-0	
Resistivity of Internal Layer	100 V, L/S = 0.08 mm 240 hrs, 40°C, 90 – 95 %	L1	0 hr	>10E+11	passed
			240 hrs	>10E+10	
		L2	0 hr	>10E+11	passed
			240 hrs	>10E+10	
Through-hole Reliability (Resistivity Change %)	Oil dip (260°C, 5sec← Air, 15sec→20°C, 20sec) 100 Cycles			1.0 mm TH	passed
				0.35 mmTH	passed
	Thermal Cycle (125°C, 30min ←→ -65°C, 30 min) 100 cycles			1.0 mm TH	passed
				0.35mm TH	passed

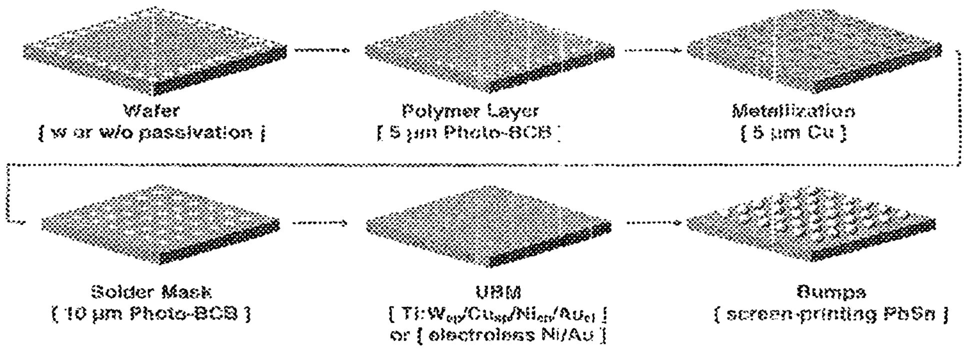

Figure 1. Redistribution/WL-CSP using BCB (Fraunhofer/TU Berlin)

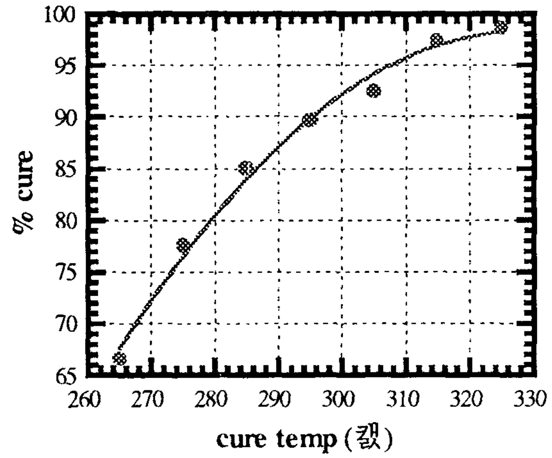

Figure 2. Cure level vs. hot plate temperature. Cures were 20 seconds (contact time).

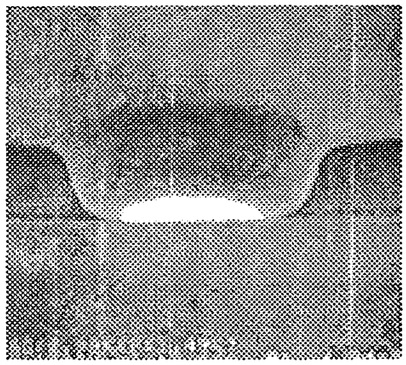

Figure 3. 35 µm via (mask dimension) in a 10 µm thick film of CYCLOTENE 4026, exposed using a broad band mask aligner at 10 µm gap.

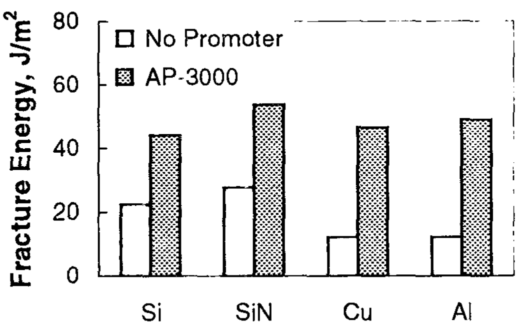

Figure 4. Comparison of interfacial energy of CYCLOTENE 4024 film to other surfaces, between using AP3000 and without a promoter.

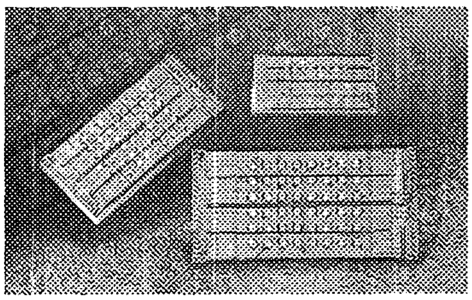

Figure 5. UltraCSP™ (FCT)

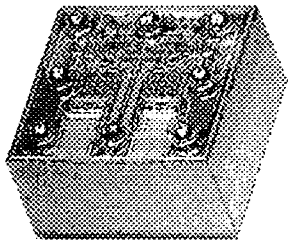

Figure 6. Micro-SMD™ (National Semiconductor)

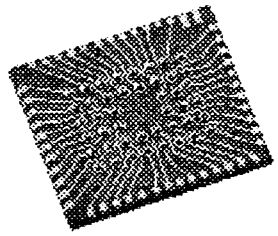

Figure 7. ShellOP™ optoelectronic CSP (Shellcase)

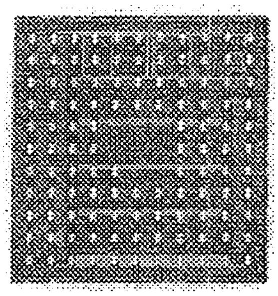

Figure. 8. Bumped ASIC controller (Unitive)

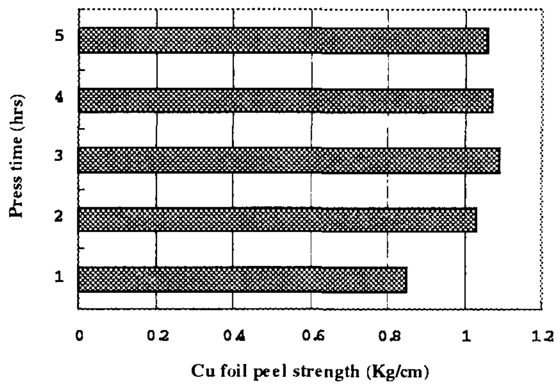

Figure 9. Peel strength of Cu foil from BCB vs. hot press time at 210°C

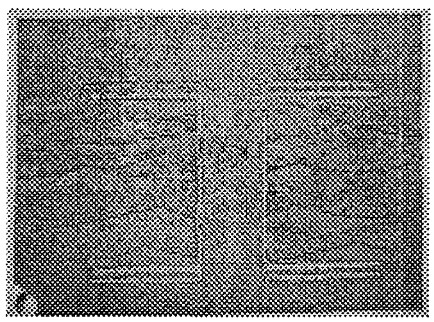

Figure 10. Cross section showing BCB coated Cu foil on FR-4 board, with 0.35 mm drill through hole

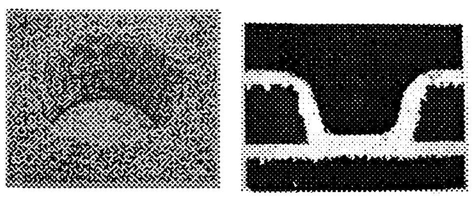

Figure 11. 0.15 mm laser via on BCB after Cu foil strip, and Cu plated via.

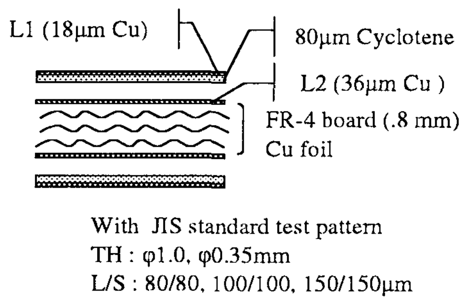

Figure 12. Schematic of JIS test board