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Avatrel™ Dielectric Polymers for Electronic Packaging

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Materials for packaging range from metals, to ceramics, to organic polymers. Recent industry trends have moved to an ever increasing adoption of polymer materials as the packaging material of choice for a varietyof applications ranging from interlayer dielectrics, to passivation layers, to die attach adhesives, to chip encapsulants (both molding and adhesive) and underfill materials to name a few. Most chips are packaged as single chips today. However to the extent that applications requiring advanced high-density chips are more in demand, multichip packages (or modules, MCMs) are becoming preferred since they decrease the wiring distance between chips by packaging the chips as close together as possible to reduce the propagation delay and increase the packaging interconnect wiring. Several MCM's designs have been developed: MCM-C (ceramic substrate), MCM-L (laminate substrate), MCM-Si (silicon substrate), and MCM-D (deposited dielectric substrate). For MCM's, according to Feger[1], polymers are becoming the dielectric materials of choice because:

1. The low dielectric constant of polymers allow higher packaging densities, faster transmission speeds, and lower power consumption.
2. Polymers are easy to process.
3. Polymeric properties can be tailored by changing their chemical compositions.

This is especially true for MCM-D/L (deposited dielectric over laminate) technology. These thin film multi-layered structures have the capability of closing the gap between the feature geometries of ICs (about sub-micron) and printed wiring boards (about 50-100 microns). This technology promises the ultimate in packaging, providing the highest density and speed in electronic devices.

BFGoodrich, along with our colleagues at Georgia Institute of Technology's Packaging Research Center, have been developing cyclic olefin-based Avatrel™ dielectric polymers that exhibit many of the key performance criteria required for these demanding applications. This polymer family, based principally on polynorbornene, is produced via new transition metal catalysts[2] which allow the polymerization of bulky, cyclic olefin monomers to form saturated polymers with high glass transition temperatures and the abilility to introduce specific functional functional groups to provide adhesion to various substrates.[3] Recently, we have been engaged in the parametric optimization of both the polymer and formulation to provide materials with the requisite balance of properties for these demanding application. These properties include:

- *Excellent, isotropic electrical properties.* A material with an isotropic dielectric constant of nominally 2.5. The material has an average permittivity of 2.477 ± 0.006 with an average loss tangent of 0.0017 ± 0.0007 (ASTM D 150) over a range of 1 MHz to 1.3 GHz, as shown below in Figure 1. Low dielectric constant is crucial as interconnect density increases. As space between conducting lines shrinks, inductance and cross-talk become problematic, but can be mitigated with lower dielectric constant materials. Polyimides, which are used extensively in the industry, exhibit anisotropic electrical properties; in-plane dielectric constant can be as high as 4 while out of plane dielectric constant is generally above 3.

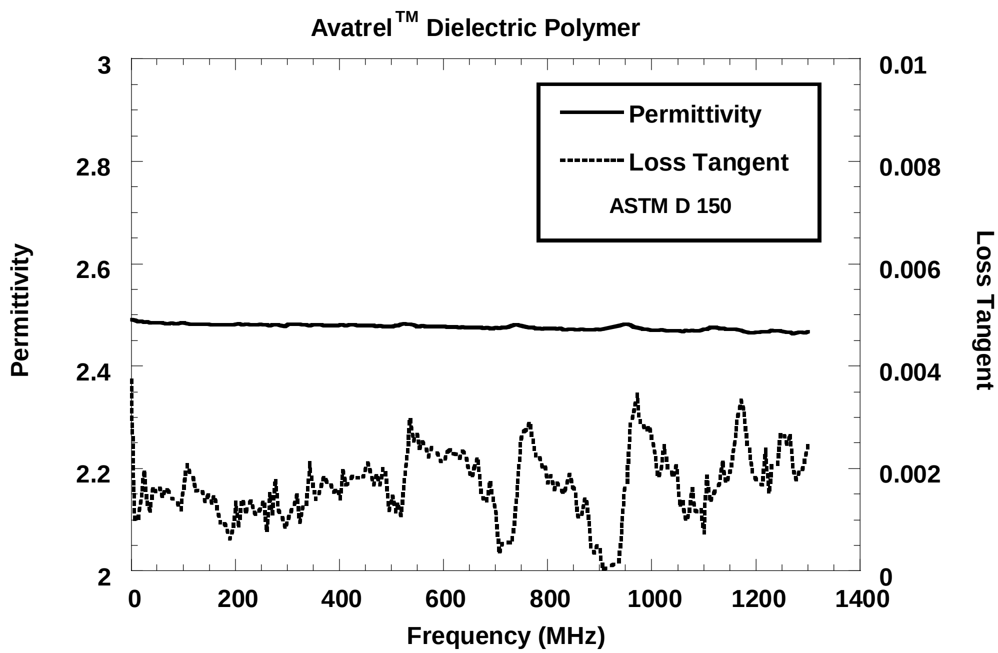

Figure 1: Permittivity and Loss Tangent for Avatrel™ Dielectric Polymer

- *Very low moisture absorption.* Avatrel™ dielectric polymers absorb approximately 0.1 weight percent water, while polyimides typically range from 2 to 3 wt%. Water uptake not only increases the dielectric constant of the medium but can introduce reliability issues by facilitating conductor corrosion.

- *Good thermo-mechanical properties.* Avatrel™ Dielectric Polymers have a glass transition temperatures of 330°C. Dynamic thermal stability is good up to 400°C (5% weight loss at 405°C in nitrogen) with good static stability up to 300°C (0.2 wt%/hr at 300°C in nitrogen). Stability at 250°C is excellent with static weight loss < 0.1 wt%/hr. Elongation to break is typically 20%. The tensile modulus for these materials is approximately 1 GPa.

- *Good adhesion to metals.* Avatrel™ Dielectric Polymers exhibit good adhesion (passes the cross-hatched tape test, ASTM D-3359-95a and IPC 650-TM) to metals such as Cu, Au, Al, Cr, Ti, and Si, as well as SiO_2. For example, in Figure 2, the adhesion of Avtrel™ Polymer to freshly prepared gold is compared with a typical polyimide. It is apparent that the Avatrel™ Dielectric polymer remains on the gold surface after a cross-hatched tape test whereas polyimide is easily removed from the gold surface following the same procedure. Additionally, Cu, Au, Al, Cr and Ti may be sputtered directly onto an Avatrel™ Dielectric Polymer surface with good adhesion. Polyimides on the other hand require tie layers and adhesion promoters, particularly for use with Cu or Au.

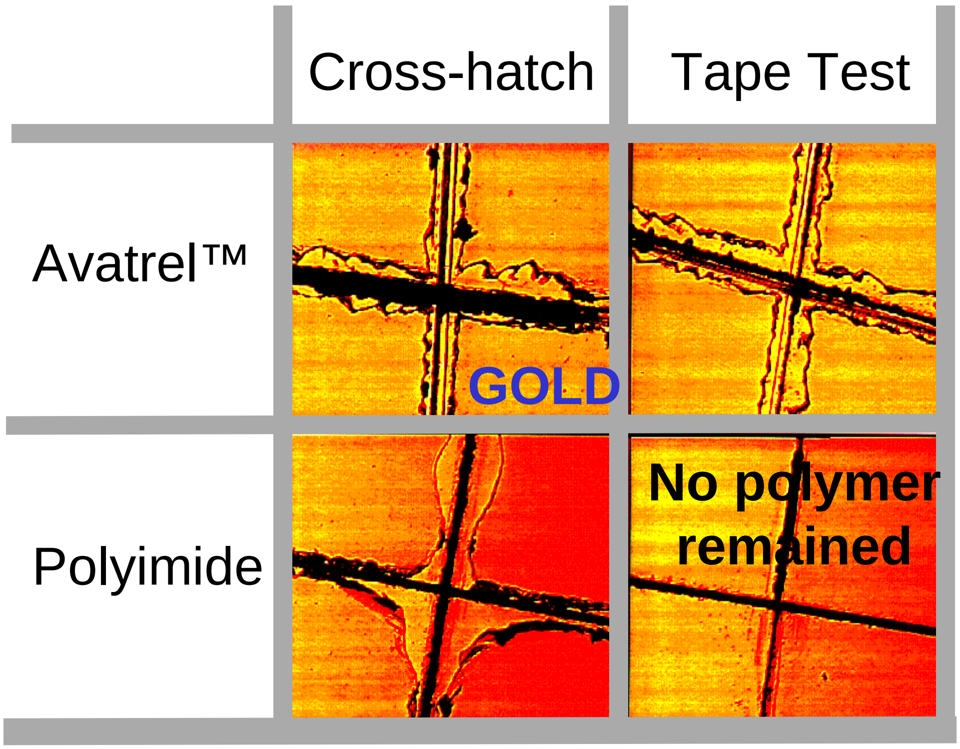

Figure 2: Adhesion of Avatrel™ Dielectric Polymer on a sputtered gold surface compared to a typical polyimide

- *Good Multilayering.* Avatrel™ Dielectric Polymers have been formulated to effect a light degree of crosslinking rendering the polymer insoluble and allowing multilayering. A typical cure would involve a thermal excursion between 200 and 300°C to effect the curing reaction.

- *Good Process Window, Low Shrinkage.* Avatrel™ Dielectric Polymers are fully polymerized having a typical weight average molecular weight of approximately 300,000. This means that most properties such as dielectric constant, moisture absorption and elongation to break are largely independent of processing since thermal excursions are not employed to promote backbone reactions . Contrast this with polyimides or BCB and epoxies which require thermal treatment to induce imidization or crosslinking, respectively.In the latter case, most of the polymer properties are developed during the cure cycle, and hence these properties are highly dependent on the exact cure schedule. A useful comparison in this regard is shrinkage upon cure. Avatrel™ Dielectric Polymers typically shrink on the order of 0.5% or less on cure, whereas shrinkage in other common polymer dielectrics can be as high as 50%.

- *Low Stress.* Avatrel Dielectric Polymers typically exhibit low stress, for example 18 MPa for a 5 μm thick film on a silicon wafer. This is in part due to the low shrinkage of the material on cure. This result is particularly important given the CTE of this material (30 to 185°C) is 83 ppm/°C. The relatively high CTE is offset by the moderate Tensile Modulus for the material of nominally 1 GPa. It is important to note that the stress (σ) developed on a substrate is actually related to both the Tensile Modulus (E) and CTE (α) of the film by the following equation:

$$\sigma_{film} = \int_{T_{R.T.}}^{T_{\max}} \frac{E_{film}\left(\alpha_{film} - \alpha_{substrate}\right)}{1 - \nu_{film}} dT$$

Therefore, a material's CTE can be compensated for by adjusting the modulus of the material to result in a low stess system.

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- *Patterning.* Avatrel Dielectric Polymers can be patterned using Reactive Ion Etch (RIE) with a mixed gas plasma (40 sccm Ar, 15 sccm O_2 and 5 sccm CHF_3). With a 300 Watt Plasmatherm operating at 300 mTorr pressure an etch rate of nominally 0.8 μm/min has been observed. This etch rate is sufficiently fast to allow patterning using either a soft (photoresist) or a hard (SiO_2) mask – see Figure 3 for comparison of etch rates. Preliminary studies have also determined that laser ablation may also prove to be a viable patterning method (KrF laser at 248 nm)

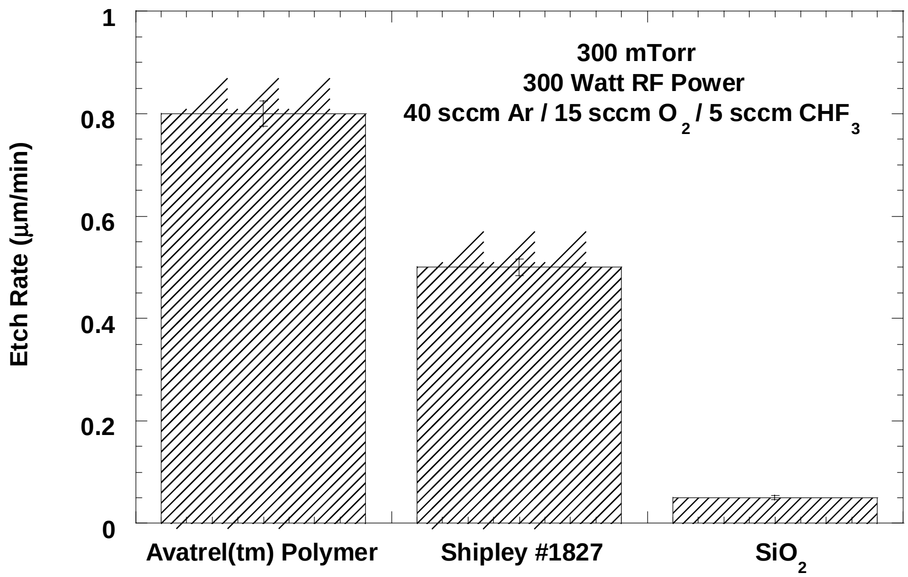

Figure 3: Etch Rate Comparison of Avatrel™ Polymer to Soft (photoresist) and Hard (SiO_2) Mask Etch Rates

In summary, Avatrel™ dielectric polymers have key performance properties that are not available in current dielectric materials. These superior features including a very low dielectric constant, low moisture absorption, and outstanding adhesion to many electronic metals. Avatrel™ polymers are readily deposited from solvent using simple deposition techniques with good planarization and very uniform films. For additional information on Avatrel™ dielectric polymers, please direct inquiries to: Sara A. Farling, BF Goodrich, 9911 Brecksville Road, Cleveland OH 44141-3247 Phone: (216) 447-5656; FAX: (216) 447 -5135; e-mail: farling@brk.bfg.com

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[1] C. Feger In *Multichip Module Technologies and Alternatives. The Basics*; Doane, D. A.; Franzon, P. D., Eds., Van Nostrand Reinhold: New York, 1993; p. 311.

[2] B. Goodall, G. Benedikt, L. McIntosh, D. Barnes, L. Rhodes, "*Addition Polymers Derived from Norbornene-Functional Monomers and Process Therefore*," WO 95/14048

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[3] L. McIntosh, B. Goodall, R. Shick and S. Jayaraman, "*Addition Polymers of Polycycloolefins Containing Silyl Functional Groups,*" WO 97/20871