High Performance Cyclic Olefins for Wireless Applications

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As wireless approaches become more prevalent, they will increasingly challenge the performance limitations of currently available materials. Therefore, there is a growing need for high performance dielectric materials.

Cyclic olefins have been tailored to provide for the high performance dielectric needs of the rapidly growing wireless industry. Avatrel™ dielectric polymers, a novel cyclic olefin produced by BFGoodrich, possess the necessary electrical and physical properties to meet the stringent demands of this growing area.

The hydrocarbon nature of cyclic olefins provides for inherently good electrical properties. The polymers are very hydrophobic with a moisture absorption of 0.1%. The electrical properties of Avatrel™ Dielectric Polymers have been measured at high frequency. At 5 GHz, the loss tangent was 0.0009 with a dielectric constant of 2.7. Avatrel™ Dielectric Polymers also exhibit isotropic electrical behavior. Mechanical properties have been tailored by the addition of alkyl side chains and triethoxysilyl side groups to increase the elongation and to provide adhesion, respectively.

I. Introduction

The rapid innovations and growth in wireless technology demand higher performance dielectric materials. A material's electrical properties such as loss tangent and dielectric constant have a direct implication on the final performance of a wireless device. Superior electrical properties must be accompanied by the proper mechanical properties, in order for a device to properly function. Moisture uptake, residual stress, and elongation are important mechanical properties. All of these material properties are irrelevant if the processing conditions are not compatible with substrate materials and efficient manufacturing practices.

II. Developments

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.[1] This novel catalysts system allows the polymerization of bulky, cyclic olefin monomers to form saturated polymers with high glass transition temperatures and the ability to introduce specific functional groups to provide adhesion to various substrates and to improve mechanical properties.[2] 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 applications.

A. Electrical Properties

1) Excellent, isotropic dielectric properties

Avatrel™ Dielectric Polymer has a loss tangent of <0.001 at 5 GHz with a dielectric constant of 2.7.[3] A 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. A low loss tangent is especially important in wireless applications where signal strength must be maximized. Electrical loss in a dielectric material translates immediately into signal degradation. Therefore, device performance can be severely limited by a high loss material.

Avatrel™ Dielectric Polymers also have the advantage of exhibiting isotropic electrical properties.[4]

On the other hand, polyimides, which are used extensively in the industry, exhibit anisotropic electrical properties. The in-plane dielectric constant can be as high as 4 while out of plane dielectric constant is generally above 3.

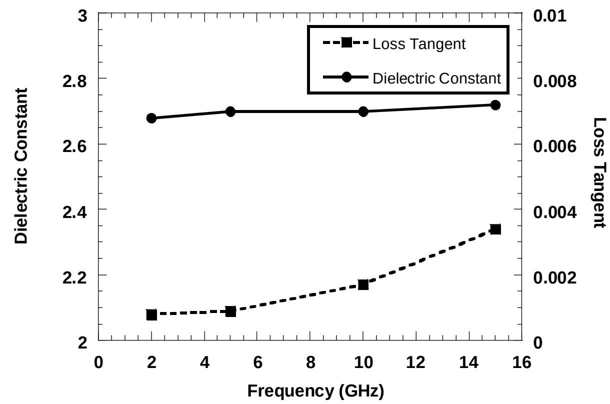

Figure #1. Dielectric Constant and Loss Tangent of Avatrel™ Dielectric Polymer[3]

B. Physical Properties

1) Extremely low moisture uptake

Avatrel™ dielectric polymers absorb only 0.1 weight percent water, while polyimides typically range from 2 to 3 weight percent. Water uptake not only increases the dielectric constant and the dielectric loss of the medium but can introduce reliability issues by facilitating conductor corrosion and copper ion migration.

2) Good, thermo-mechanical properties.

Avatrel™ Dielectric Polymers have a glass transition temperature of 330°C. Dynamic thermal stability is good up to 350°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.

3) Great Adhesion

Avatrel™ Dielectric Polymers exhibit good adhesion (passes the crosshatched tape test, ASTM D-3359-

95a and IPC 650-TM) to materials such as BT/Laminate, Cu, Au, Al, Cr, Ti, and Si, as well as SiO_2. 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 spin-on adhesion promoters, particularly for use with Cu or Au.

4) 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 that the CTE of this material (30 to 185°C) is 83 ppm/°C. The moderate Tensile Modulus for the material of nominally 1 GPa offsets the relatively high CTE. 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:

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

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

C. Thermal Processing

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, BCB, or 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%.

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 to 250^{o}C for 1 hour to effect the curing reaction.

D. Patterning

1) Reactive Ion Etch

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).

Using a Plasmatherm operating at 300 mTorr pressure and 300 watts, 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.

2) Laser Ablation

With the help of Electro Scientific Industries, it has been demonstrated that Avatrel™ dielectric polymers can be patterned using a frequency tripled YAG (355 nm). At 355 nm, laser processing conditions have been outlined that are appropriate to wireless fabrication.

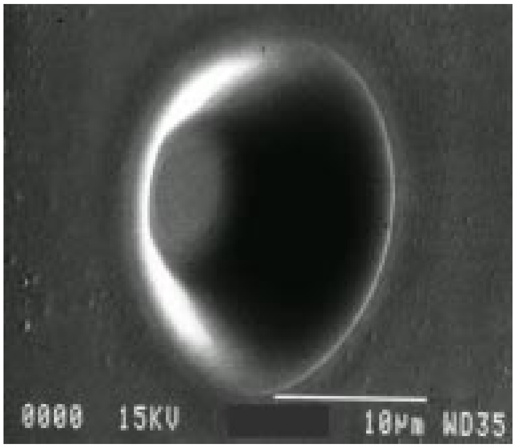

Figure #2: Via fabricated in Avatrel™ Dielectric Polymer using a 355 nm YAG laser, courtesy ESI.

III. Summary

Avatrel™ dielectric polymers have key performance properties that are not available in current dielectric materials. These superior features including a low loss tangent, low dielectric constant, low moisture absorption, and outstanding adhesion to many electronic metals make Avatrel™ Dielectric Polymers uniquely suited to applications in the wireless revolution.

For additional information on Avatrel™ dielectric polymers, please direct inquiries to: Sara A. Farling, BFGoodrich, 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] B. Goodall, G. Benedikt, L. McIntosh, D. Barnes, L. Rhodes, "*Addition Polymers Derived from Norbornene-Functional Monomers and Process Therefore*," WO 95/14048

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

[3] Measured by Trace Labs-East per ASTM-D-150, 1998.

[4] K. S. Patel, P. A. Kohl, S. A. Bidstrup-Allen, "*Novel Technique for Measuring Through-Plane Modulus in Thin Polymer Films*," Presentation during 4th International Symposium and Exhibition on Advanced Packaging Materials.