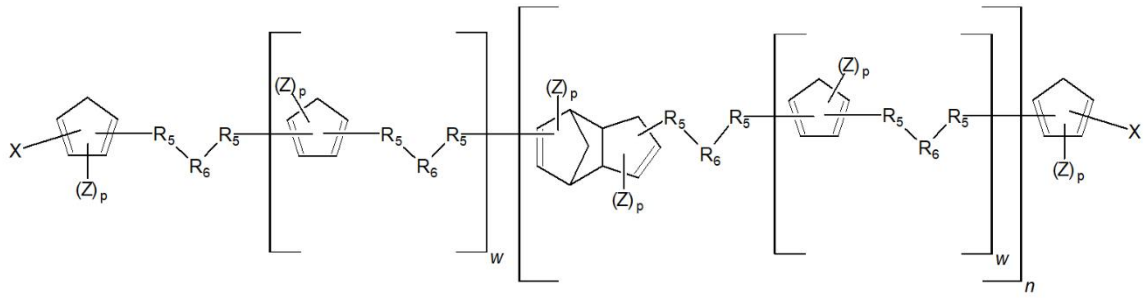
failed to teach the effect of multiple reactive species on the dicyclopentadiene formed during dimerization and oligomerization of the bis(cyclopentadienyl) compounds.

## SUMMARY ~~OF THE INVENTION~~

It has now been found that bis(substituted(aryl/alkyl)-cyclopentadiene) compounds and their dimers/oligomers have increased stability over their previously described pure alkyl-, or aryl- counterparts. Advantageously, these bis(substituted(aryl/alkyl)-cyclopentadiene) compounds can achieve high glass transition temperatures and have low dielectric properties suitable for high frequency printed circuit boards, antennas, radomes, and other electronic devices.

In one ~~aspect~~example, the present ~~invention~~ disclosure provides compounds having a structure defined by Formula (I):



(I)

wherein:

(a) each $R_5$ is independently a methylene group ($CH_2$), or a methylene group substituted with one or more -H, -$CH_3$, or halogen functionalities;

(b) each $R_6$ is independently a bond or a straight-chain or branched, linear or cyclic, saturated or unsaturated, substituted or unsubstituted, aliphatic or aromatic group having between 1 and 20 carbon atoms;

(c) each X is independently a functionality possessing at least one non-aromatic alkene, alkyne, $CH_3$-$(CH_2)_n$- (where n = 0 to 12), or an aromatic moiety;

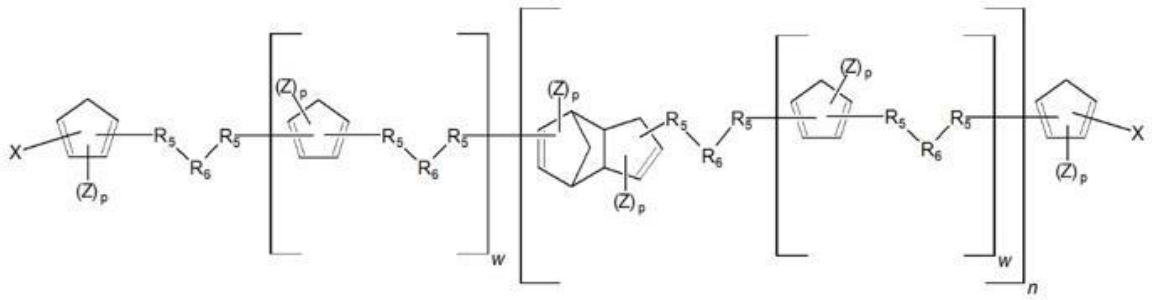
(d) each Z is independently either H or X and each p is independently an integer from 1-4;

(e) each w is independently 0, or an integer greater than or equal to 1; and

(i) when w is 0, the bracket region represents a bond and n is 0, or an integer greater than or equal to 1; and

(ii) when n is 0, the bracket region represents a bond.

In an aspect, there is provided a polymer, copolymer or oligomer derived from a resin having a structure defined by Formula (I)



(I)

wherein:

(a) each R5 is independently a methylene group ($CH_2$), or a methylene group substituted with one or more -H, -$CH_3$, or halogen functionalities;

(b) each R6 is independently a bond or a straight-chain or branched, linear or cyclic, saturated or unsaturated, substituted or unsubstituted, aliphatic or aromatic group having between 1 and 20 carbon atoms;

(c) each X is independently a functionality possessing at least one non-

aromatic alkene, alkyne, CH3-(CH2)n- (where n = 0 to 12), or an aromatic moiety;

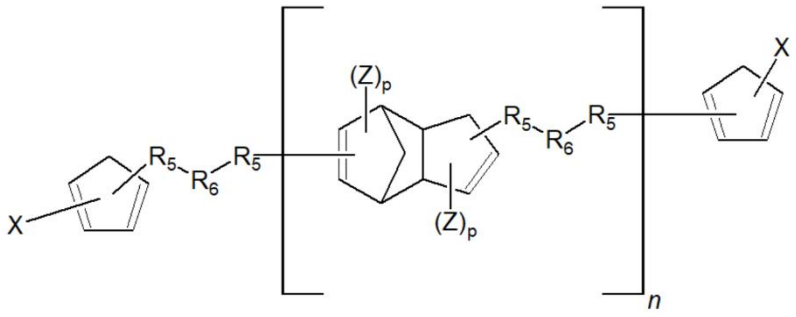
(d) each Z is independently either H or X, and each p is independently an integer from 1-4;

(e) each w is independently 0, or an integer greater than or equal to 1, and

(i) when w is 0, the bracket region represents a bond and n is an integer greater than or equal to 1;

and wherein the polymer, copolymer or oligomer comprises a dissipation (Df) value ranging from between about 0.0001 to about 0.004.

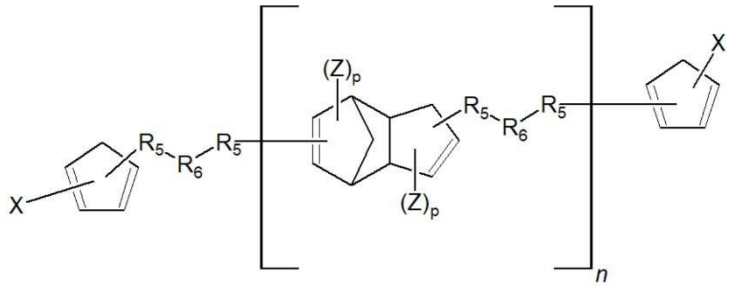
In some ~~embodiments~~ examples of Formula (I), the value of w is equal to zero, representing a bond between the $R_5$ group and the cyclopentadiene or dicyclopentadiene. These compounds of Formula (I) may be defined by Formula (II):




(II)

In another aspect, there is provided a polymer, copolymer or oligomer derived from one or more resins having a structure defined by Formula (II)

3b




(II)

wherein:

(a) each R5 is a methylene group (CH2);

(b) each R6 is independently a bond, a phenyl group, or an aliphatic carbon chain of the form –(CH2)y-, wherein y = 1 – 12.

(c) each X is independently an allyl, propargyl, butenyl, benzyl, or styrenyl group;

(d) each Z is independently either H or X, and each p is independently an integer from 1- 4;

(e) n is an integer greater than or equal to 1.

Polymers, copolymers and oligomers derived from resins having a structure defined by Formula (I) may be thermoset polymers with high glass transition temperature and other properties suitable for use in advanced material applications. The properties of these polymers may be tuned by using resins and resin blends containing more than one X moiety and/or more than one $R_6$ moiety.

Without being bound by example, a resin of Formula (I) where $R_6$ is an alkyl group may generate a polymer with a desirable polymerization rate but a low glass transition temperature,

whereas a resin of Formula (I) where $R_6$ is an aryl group may generate a polymer with high glass transition temperature but undesirable polymerization rate. Combining resins with alkyl $R_6$ groups and resins with aryl $R_6$ groups may generate a polymer with improved overall properties compared to the polymer derived from any single resin of Formula (I).

In another aspect,, there is provided a composition comprising (i) a polymer, copolymer or oligomer as defined above; and (ii) a second component selected from the group consisting of polyethylenes, polypropylenes, polybutylenes, low vinyl polybutadienes, high vinyl polybutadienes, polystyrenes, butadiene-styrene copolymers, styrene-maleic anhydride (SMA) polymers, acrylonitrile-butadiene-styrene (ABS) polymers, polydicyclopentadienes, epoxies, polyurethanes, cyanate esters, poly(phenylene oxide), ethylene-propylene-diene monomer (EPDM) polymers, cyclic olefin copolymers (COC), polyimides, bismaleimides, phosphazenes, olefin-modified phosphazenes, acrylates, vinyl esters, polylactones, polycarbonates, polysulfones, polythioethers, polyetheretherketones (PEEK), polydimethylsiloxanes (PDMS), polyethylene terephthalates (PET), and polybutylene terephthalates (PBT), styrene, divinylbenzene, 1,2-bis(vinylphenyl)ethane, vinylbenzyl ether compounds, vinyl ether compounds, allyl ether compounds, vinylphenyl monomers, vinyl monomers, and allyl monomers.

In another aspect, there is provided a copolymer derived from polymerization of the polymer, copolymer, or oligomer as defined above, and a comonomer, wherein the comonomer is selected from the group consisting of styrene, divinyl benzene, vinyl toluene, methyl styrene, tert-butyl styrene, alpha-methyl styrene, alpha-methyl styrene dimer, vinyl cyclohexene, ethylidene norbornene, vinyl norbornene, alpha- pinene, beta-pinene, limonene, other terpenes, polybutadienes, modified polybutadienes, polystyrenes (homopolymer and block-

copolymers), modified polystyrenes, polyterpenes, other vinyl-reactive monomers, and reactive dimers/oligomers/polymers/copolymers thereof.

In another aspect, there is provided a printed circuit board, prepreg, or laminate comprising a material comprised of the polymer, copolymer or oligomer as defined above.

In another aspect, there is provided a radome or satellite structure comprising a material comprised of the polymer, copolymer or oligomer as defined above.

In another aspect, there is provided a base station, circuit board, server, or router comprising a material comprised of the polymer, copolymer or oligomer as defined above.

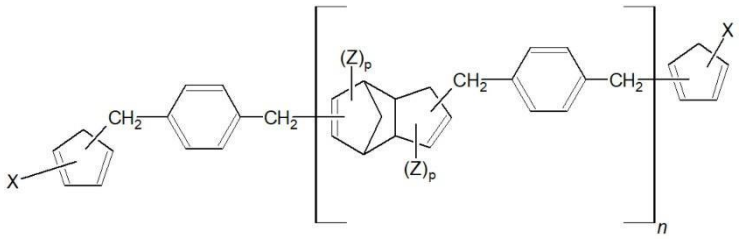
In another aspect, there is provided a material for use in any one of: (i) a copper-clad laminate (CCL), (ii) a high-density interconnect (HDI) substrate, (iii) an integrated circuit (IC) substrate in printed circuit boards at high temperature and low Df applications; (iv) a molding compound in power device application; and (v) a radio frequency (RF) heating in oil and gas applications, wherein the material comprises the polymer, copolymer, or oligomer as defined above.

In another aspect, there is provided a 3D printing resin composition comprised of the polymer, copolymer or oligomer as defined above suitable for digital light printing (DLP), continuous liquid interface printing (CLIP), Stereo-lithography (SL).

In another aspect, there is provided a polymer, copolymer, or oligomer derived from at least two resins wherein

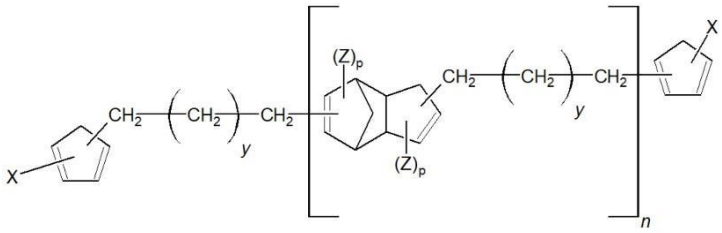
(a) a first resin comprises a structure:

4b



and isomers thereof, and;

(b) a second resin comprises a structure:



and isomers thereof;

wherein

(i) each X is independently an allyl, benzyl, or styrenyl group, and;
(ii) each Z is independently either H or X, and each p is independently an integer from 1-4;

(iii) n is an integer greater than or equal to 1, and;

(iv) y = 1 – 12, and;

(iv) the polymer, copolymer, or oligomer comprises a dissipation value (Df) value ranging from about 0.0001 to about 0.004.

## DETAILED DESCRIPTION OF THE INVENTION

The invention provides a thermosetting resin with a high glass transition temperature, which has excellent dielectric properties and low water absorption. Embodiments of this

invention include thermosetting resins which are suitable for applications that require ultra-low loss dielectric properties and ultra-low moisture absorption properties. Polymers, copolymers, or oligomers derived from these thermosetting resins have a dissipation (Df) value ranging from between about 0.0001 to about 0.004; a dielectric (Dk) value ranging from between about 1.5 to about 3 at 1 – 50 GHz; a Tg greater than 150°C; and a molecular weight ranging from about 200 to about 1,000,000 Da.

It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited. It should also be understood that where a variable (e.g., "w") is used more than once in any formula or chemical structure, that each use of the variable in the Formula or chemical structure is independent of any other use unless explicitly noted otherwise. For example, if the variable "w" is used twice within the same Formula, each "w′" may be the same or different, i.e., if "w" is defined as 0 or an integer ranging from 1 to 150, each "w" may independently be selected from 0 or an integer ranging from 1 to 150. Likewise, and again by way of example, if the moiety "$R_5$"