

DIELECTRIC FILM-FORMING COMPOSITION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Application Serial No.
5 63/531,581, filed on August 9, 2023, the contents of which are hereby incorporated by
reference in their entirety.

BACKGROUND TO THE DISCLOSURE

A dielectric material having low dielectric constant (Dk) and low dielectric loss
10 tangent (Df) can reduce the transmission loss for material used in high frequency
bands. It is an objective of this disclosure to provide dielectric material compositions
which are suitable to suppress the transmission loss of electrical signal in next-
generation high-frequency (10 GHz or greater) applications.

SUMMARY OF THE DISCLOSURE

In one aspect, this disclosure features a dielectric film-forming composition
containing: (a) at least one meth(acrylate)-containing polyphenylene ether resin;
(b) at least one second resin selected from a group consisting of i) at least one fully
imidized polyimide polymer; ii) at least one polyamic acid ester; iii) at least one cyclized
20 polydiene resin; and iv) a mixture of at least one cyclized polydiene resin and at least
one cyanate ester compound.

In some embodiments the dielectric film-forming compositions of this disclosure
are photosensitive compositions.

25 In another aspect, this disclosure features a process for preparing a dielectric
film, the process including: a) coating the dielectric film-forming composition described
herein on a substrate to form a film; and b) optionally baking the film at a temperature
from about 50°C to about 150°C for about 20 seconds to about 240 seconds.

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In another aspect, this disclosure features a process for preparing a dry film, the process includes: a) coating a carrier substrate with the dielectric film-forming composition described herein to form a coated composition; b) drying the coated composition to form a dry film; and c) optionally, applying a protective layer to the dry film.

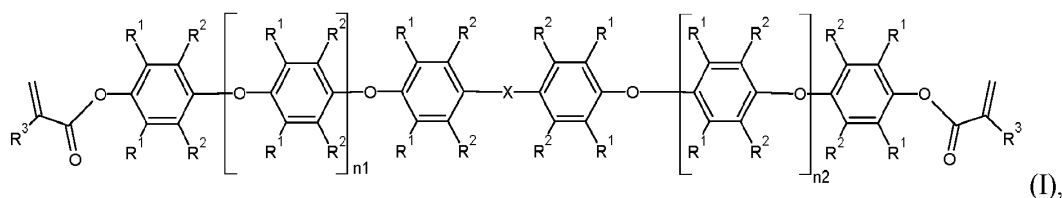
In still another aspect, this disclosure features a dielectric film containing (a) at least one meth(acrylate)-containing polyphenylene ether resin, (b) at least a second resin selected from the group consisting of: i) at least one fully imidized polyimide polymer; ii) at least one polyamic acid ester; iii) at least one cyclized polydiene resin; and iv) a mixture of at least one cyclized polydiene resin and at least one cyanate ester compound. In some embodiments the dielectric film of this invention is photosensitive.

DETAILED DESCRIPTION OF THE DISCLOSURE

In general, this disclosure relates to dielectric film-forming compositions, as well as related processes, dry films, and dielectric films.

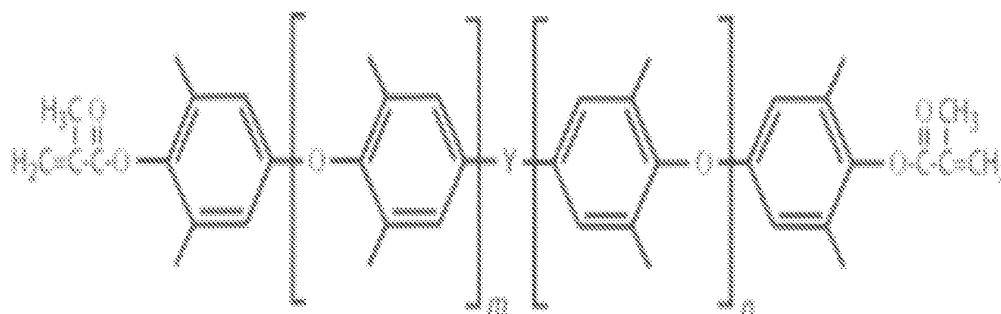
In some embodiments, the dielectric film-forming compositions described herein include at least one (e.g., two, three, or four) meth(acrylate)-containing polyphenylene ether resin. As mentioned herein, the meth(acrylate)-containing polyphenylene ether resin refers to a polyphenylene ether resin containing at least one (e.g., two) end group having an acrylate or methacrylate group that includes unsaturated double bond. As used herein, the term “(meth)acrylate” include both acrylates and methacrylates.

An example of the meth(acrylate)-containing polyphenylene ether resin described herein is a polymer of Structure (I):



in which each of n_1 and n_2 , independently, is an integer from 0 to 20; X is a $-C(O)-$, $-S(O)-$, $-S(O)_2-$, or $-C(RR')-$, in which each of R and R', independently, is H or C_1-C_6 alkyl; each R^1 , independently, is an aliphatic hydrocarbon group having 1 to 6 carbon atoms (e.g., C_1-C_6 alkyl); and each R^2 , independently is H, halo (e.g., F, Cl, Br, or I), or
 5 an aliphatic hydrocarbon group having 1 to 6 carbon atoms (e.g., C_1-C_6 alkyl).

An example of the polymer of Structure (I) is a polymer of Structure (II):



(II), in which each of m and n , independently, is an integer from 0 to 20, and Y is $-C(O)-$, $-S(O)-$, $-S(O)_2-$, or $-C(RR')-$, in which each of R and R', independently, is H or C_1-C_6 alkyl. A commercial example of a polymer of Structure (I) or (II) is SA9000 resin
 10 available from SABIC.

In some embodiments, the meth(acrylate)-containing polyphenylene ether resin
 15 can be in an amount of at least about 5 wt% (e.g., at least about 10 wt%, at least about 15 wt%, at least about 20 wt%, at least about 25 wt%, at least about 30 wt%, at least about 35 wt%, or at least about 40 wt%) to at most about 50 wt% (e.g., at most about 45 wt%, at most about 40 wt%, at most about 35 wt%, at most about 30 wt%, at most about 25 wt%, at most about 20 wt%, at most about 15 wt%, or at most about 10 wt%)
 20 of a dielectric film-forming composition described herein.

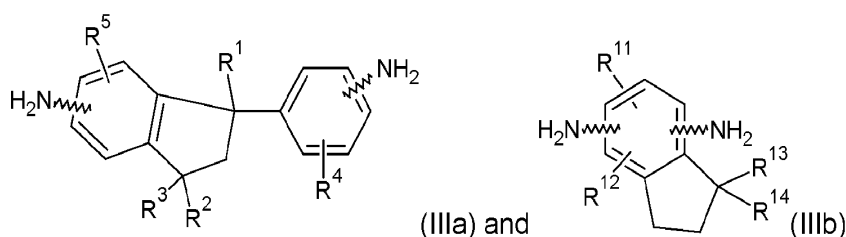
In some embodiments, the dielectric film-forming compositions described herein include at least one (e.g., two, three, or four) second resin (which differs from the meth(acrylate)-containing polyphenylene ether resin) selected from the group consisting
 25 of: i) at least one fully imidized polyimide polymer; ii) at least one polyamic acid ester; iii)

at least one cyclized polydiene resin; and iv) a mixture of a cyclized polydiene resin and a cyanate ester compound. In some embodiments, the dielectric film-forming compositions described herein can include any combination of polymers i-iv. As used herein, the term "fully imidized" means the polyimide polymers of this disclosure are at least about 90% (e.g., at least about 95%, at least about 98%, at least about 99%, or about 100%) imidized. Imidization to form a polyimide can be confirmed by observation of characteristic absorptions in the infrared spectrum from 1770 and 1700 cm^{-1} attributable to the imide ring structure.

In some embodiments, the at least one fully imidized polyimide described herein is prepared by reaction of at least one diamine as a monomer with at least one dianhydride (e.g., at least one tetracarboxylic acid dianhydride) as another monomer. Examples of diamines include, but are not limited to, p-phenylenediamine, m-phenylenediamine, o-phenylenediamine, 3-methyl-1,2-benzene-diamine, 1,2-diaminoethane, 1,3-diaminopropane, 1,4-diaminobutane, 1,5-diaminopentane, 1,6-diaminohexane, 1,7-diaminoheptane, 1,8-diaminooctane, 1,9-diaminononane, 1,10-diaminodecane, 1,2-diaminocyclohexane, 1,4-diaminocyclohexane, 1,3-cyclohexanebis(methylamine), 5-amino-1,3,3-trimethyl cyclohexanemethanamine, 2,5-diaminobenzotrifluoride, 3,5-diaminobenzotrifluoride, 1,3-diamino-2,4,5,6-tetrafluorobenzene, 4,4'-oxydianiline, 3,4'-oxydianiline, 3,3'-oxydianiline, 3,3'-diaminodiphenylsulfone, 4,4'-diaminodiphenylsulfones, 4,4'-isopropylidenedianiline, 4,4'-diaminodiphenylmethane, 2,2-bis(4-aminophenyl)propane, 4,4' diaminodiphenylpropane, 4,4'-diaminodiphenyl sulfide, 4,4'-diaminodiphenylsulfone, 4-aminophenyl-3-aminobenzoate, 2,2'-dimethyl-4,4'-diaminobiphenyl, 3,3'-dimethyl-4,4'-diaminobiphenyl, 2,2'-bis(trifluoromethyl) benzidine, 3,3'-bis(trifluoromethyl) benzidine, 2,2-bis[4-(4-aminophenoxy phenyl)] hexafluoropropane, 2,2-bis(3-amino-4-methylphenyl)-hexafluoropropane, 2,2-bis(3-aminophenyl)-1,1,1,3,3,3-hexafluoropropane, 1,3-bis-(4-aminophenoxy)benzene, 1,3-bis-(3-aminophenoxy)benzene, 1,4-bis-(4-aminophenoxy)benzene, 1,4-bis-(3-aminophenoxy)benzene, 1-(4-aminophenoxy)-3-(3-aminophenoxy)benzene, 2,2'-bis-(4-phenoxyaniline)isopropylidene, bis(p-beta-amino-t-butylphenyl)ether, p-bis-2-(2-methyl-4-aminopentyl)benzene, p-bis(1,1-dimethyl-5-

aminopentyl)benzene, 3,3'-dimethyl-4,4'-diaminobiphenyl, 4,4'-diaminobenzophenone, 3'-dichlorobenzidine, 2,2-bis [4-(4-aminophenoxy)phenyl] propane, 4,4'-[1,3-phenylenebis(1-Methyl-ethylidene)] bisaniline, 4,4'-[1,4-phenylenebis(1-methyl-ethylidene)]bis(aniline), 2,2-bis [4-(4-aminophenoxy) phenyl] sulfone, 2,2-bis [4-(3-aminophenoxy) benzene], 1,4-bis (4-aminophenoxy) benzene, 1,3-bis (4-aminophenoxy) benzene, (1,3'-bis (3-aminophenoxy) benzene, and 9H-fluorene-2,6-diamine.

In some embodiments, the at least one diamine includes a compound selected from the group consisting of a diamine of Structure (IIIa) and a diamine of Structure (IIIb):



in which each of R^1 , R^2 , R^3 , R^4 , R^5 , R^{11} , R^{12} , R^{13} , and R^{14} , independently, is H, a substituted or unsubstituted C_1 - C_6 linear or branched alkyl group, or C_5 - C_7 cycloalkyl group.

Examples of the substituted or unsubstituted C_1 - C_6 linear or branched alkyl groups in R^1 , R^2 , R^3 , R^4 , R^5 , R^{11} , R^{12} , R^{13} , and R^{14} include, but are not limited to, methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, amyl, hexyl, and 2-methylhexyl.

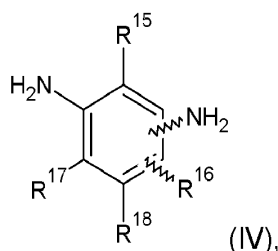
Examples of the C_5 - C_7 cycloalkyl group in R^1 , R^2 , R^3 , R^4 , R^5 , R^{11} , R^{12} , R^{13} , and R^{14} include, but are not limited to, cyclopentyl, cyclohexyl, and cycloheptyl.

Examples of diamines of Structure (IIIa) or (IIIb) include, but are not limited to, 1-(4-aminophenyl)-1,3,3-trimethylindan-5-amine (alternative names including 4,4'-[1,4-phenylene-bis(1-methylethylidene)] bisaniline, 1-(4-aminophenyl)-1,3,3-trimethyl-2H-inden-5-amine, 1-(4-aminophenyl)-1,3,3-trimethyl-indan-5-amine, [1-(4-aminophenyl)-1,3,3-trimethyl-indan-5-yl]amine, and 1-(4-aminophenyl)-2,3-dihydro-1,3,3-trimethyl-1H-

inden-5-amine), 5-amino-6-methyl-1-(3'-amino-4'-methylphenyl)-1,3,3-trimethylindan, 4-amino-6-methyl-1-(3'-amino-4'-methylphenyl)-1,3,3-trimethylindan, 5,7-diamino-1,1-dimethylindan, 4,7-diamino-1,1-dimethylindan, 5,7-diamino-1,1,4-trimethylindan, 5,7-diamino-1,1,6-trimethylindan, and 5,7-diamino-1,1-dimethyl-4-ethylindan.

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In some embodiments, the at least one diamine includes (a) a compound selected from the group consisting of a diamine of Structure (IIIa) and a diamine of Structure (IIIb), and (b) at least one diamine of Structure (IV),



- 10 in which each of R^{15} , R^{16} , R^{17} and R^{18} , independently, can be H, a substituted or unsubstituted C_1 - C_6 linear or branched alkyl group, or C_5 – C_7 cycloalkyl group, provided that at least two of R^{15} , R^{16} , R^{17} and R^{18} are not hydrogen.

- 15 Examples of the substituted or unsubstituted C_1 - C_6 linear or branched alkyl groups in R^{15} , R^{16} , R^{17} and R^{18} include, but are not limited to, methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, amyl, hexyl, and 2-methylhexyl. Examples of the C_5 – C_7 cycloalkyl group in R^{15} , R^{16} , R^{17} and R^{18} include, but are not limited to, cyclopentyl, cyclohexyl, and cycloheptyl.

- 20 Examples of diamines of Structure (IV) include, but are not limited to, 2,3,5,6-tetramethylphenylenediamine, 2,4-diamino-1,3,5-trimethylbenzene, 2,4-diamino-1,3,5-triethylbenzene, 2,4-diamino-3,5-dimethyl-1-ethylbenzene, 2,4-diamino-1,5-dimethyl-3-ethylbenzene, 2,4-diamino-1,3,5-triisopropylbenzene, 2,3,5,6-tetraisopropylphenylenediamine and 2,4-diamino-1,3,5,6-tetramethylbenzene.

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In some embodiments, the molar percentage of the diamines of Structures (IIIa) and (IIIb) in the total amount of diamines is at least about 10% (e.g., at least about 20%,

at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, or at least about 50%) to at most about 90% (e.g., at most about 85%, at most about 80%, at most about 75%, at most about 70%, at most about 65%, or at most about 60%).

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In some embodiments, the molar percentage of the diamines of Structure (IV) in the total amount of diamines (e.g., diamines of Structure (IIIa), (IIIb), and (IV)) is at least about 10% (e.g., at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, or at least about 50%) to at most about 90% (e.g., at most about 85%, at most about 80%, at most about 75%, at most about 70%, at most about 65%, or at most about 60%).

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In general, to form a polyimide polymer described herein, the diamines can be reacted with at least one dianhydride, such as at least one tetracarboxylic acid dianhydride.

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Examples of the tetracarboxylic acid anhydrides include, but are not limited to, 1-(3',4'-dicarboxyphenyl)-1,3,3-trimethylindan-5,6-dicarboxylic acid dianhydride, 1-(3',4'-dicarboxyphenyl)-1,3,3-trimethylindan-6,7-dicarboxylic acid dianhydride, 1-(3',4'-dicarboxyphenyl)-3-methylindan-5,6-dicarboxylic acid dianhydride, 1-(3',4'-dicarboxyphenyl)-3-methylindan-6,7-dicarboxylic acid anhydride, pyromellitic dianhydride, benzene-1,2,3,4-tetracarboxylic dianhydride, 2,3,5,6-naphthalenetetracarboxylic acid dianhydride, 2,3,6,7-naphthalenetetracarboxylic acid dianhydride, 1,4,5,8-naphthalenetetracarboxylic acid dianhydride, 2,6-dichloronaphthalene-1,4,5,8-tetracarboxylic dianhydride, 2,7-dichloronaphthalene-1,4,5,8-tetracarboxylic dianhydride, 2,3,6,7-tetrachloronaphthalene-1,4,5,8-tetracarboxylic dianhydride, phenanthrene-8,9,10-tetracarboxylic dianhydride, 3,4,9,10-perylenetetracarboxylic acid dianhydride, pyrazine-2,3,5,6-tetracarboxylic dianhydride, thiophene-2,3,4,5-tetracarboxylic dianhydride, 2,3,5,6-pyridinetetracarboxylic acid dianhydride, butane-1,2,3,4-tetracarboxylic acid dianhydride, 1,2,3,4-cyclopentanetetracarboxylic acid dianhydride, cyclobutane-

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1,2,3,4-tetracarboxylic acid dianhydride, cyclopentane-1,2,3,4-tetracarboxylic acid dianhydride, cyclohexane-1,2,4,5-tetracarboxylic acid dianhydride, norbornane-2,3,5,6-tetracarboxylic acid dianhydride, bicyclo[2.2.2]oct-7-ene-3,4,8,9-tetracarboxylic acid dianhydride, tetracyclo[4.4.1.0^{2,5}.0^{7,10}]undecane-1,2,3,4-tetracarboxylic acid dianhydride, 3,3',4,4'-benzophenone tetracarboxylic dianhydride, 2,2',3,3'-benzophenone tetracarboxylic dianhydride, 2,3,3',4'-benzophenone tetracarboxylic dianhydride, 3,3',4,4'-diphenylsulfone tetracarboxylic dianhydride, 2,2',3,3'-diphenylsulfone tetracarboxylic dianhydride, 2,3,3',4'-diphenylsulfone tetracarboxylic dianhydride, 3,3',4,4'-diphenyl ether tetracarboxylic dianhydride, 2,2',3,3'-diphenyl ether tetracarboxylic dianhydride, 2,3,3',4'-diphenyl ether tetracarboxylic dianhydride, 2,2-[bis(3, 4-dicarboxyphenyl)] hexafluoropropane dianhydride, ethyleneglycol bis(anhydrotrimellitate), and 5-(2,5-dioxotetrahydro)-3-methyl-3-cyclohexene-1,2-dicarboxylic dianhydride.

Other fully imidized polyimide polymers are described in, e.g., WO 2016/172089, U.S. Patent Nos. 10,036,952 and 10,563,014, and U.S. Application Publication No. 2015/0219990, the contents of which are incorporated herein by reference.

In some embodiments, the at least one polyamic acid ester described herein can be prepared by using the diamines and dianhydrides described herein as monomers. In some embodiments, one or more diamines are combined with one or more tetracarboxylic acid dianhydrides in at least one (e.g., two, three, or more) polymerization solvent to form a polyamic acid (PAA) polymer. In some embodiments, the PAA polymer thus formed can be esterified to form a polyamic acid ester, which can remain soluble in the polymerization solvents.

In some embodiments, the cyclized polydiene resin described herein (e.g., substituted or unsubstituted) can include homopolymers of conjugated dienes such as isoprene, butadiene, pentadiene, etc. In other embodiments, the cyclized polydiene resin include copolymers of such conjugated dienes with olefins (e.g., ethylene or propylene), styrene, or acrylates. Cyclization of polydiene occurs under influence of

heat, light, ultraviolet or nuclear radiation or in the presence of cation-donor catalysts (e.g., mineral acids, organic acids, or Lewis's acids). For example, two neighboring polymer structural units can participate in a cis olefin catalyzed cyclization, which can create a monocyclic structure by eliminating one double bond. When cyclization
5 continues, bi- or tri-cyclic structures can be created in later stages. Gradually, the unsaturation and elasticity of a polydiene is reduced as the result of successive cyclization of cis double bonds, and the toughness of the polydiene is increased. In some embodiments, the cyclization can be more efficient in polyisoprene than in polybutadiene. By controlling the temperature, catalyst concentration and/or reaction
10 time, a cyclization degree of from about 50% to about 95% can be achieved. Examples of such cyclization process have been described in, e.g., U.S. Patent Nos. 4,678,841 and 4,248,986, and European Patent No. 0063043, the contents of which are hereby incorporated by reference.

15 The cyclized polydiene resin can have any suitable weight average molecular weight (Mw) depending on the particular product application, solvent employed, and method of applying to the underlying substrate. For example, the cyclized polydiene resin can have a weight average molecular weight of at least about 5,000 Daltons (e.g., at least about 25,000 Daltons, at least about 50,000 Daltons, at least about 75,000
20 Dalton, at least about 100,000 Dalton, at least about 125,000 Daltons, or at least about

150,000 Daltons) and/or at most about 500,000 Daltons (e.g., at most about 400,000 Daltons, at most about 300,000 Daltons, or at most about 200,000 Daltons).

In some embodiments, the dielectric film-forming composition described herein
5 can include a mixture of cyclized polydiene resins. The mixture can include:

- a) at least one cyclized polydiene resin with a weight average molecular weight from about 5,000 Daltons to about 20,000 Daltons;
- b) at least one cyclized polydiene resin with a weight average molecular weight of from about 25,000 Daltons to about 60,000 Daltons; and
- 10 c) at least one cyclized polydiene resin with a weight average molecular weight of from about 70,000 Daltons to about 200,000 Daltons.

Without wishing to be bound by theory, it is believed that a dielectric film-forming composition containing a mixture of cyclized polydiene resins having different molecular
15 weights can result in a dielectric film having superior coating quality and film properties.

In some embodiments, the double bond content in an uncyclized polyisoprene is 14.7 mmols unsaturation per 1 gram of polyisoprene, i.e., the inverse of the molecular weight of an isoprene unit (i.e., 68 g/mol). In general, the double bond content in a
20 cyclized polyisoprene decreases as the degree of cyclization increases. In some embodiments, the amount of double bond or unsaturation of a cyclized polydiene resin (e.g., in xylene) can range from at least about 1 mmol (e.g., at least about 2 mmols, at least about 3 mmols, at least about 4 mmols, or at least about 5 mmols) to at most about 12 mmols (e.g., at most about 11 mmols, at least about 10 mmols, at least about
25 9 mmols, or at least about 8 mmols) per 1 gram of polyisoprene after cyclization.

In general, an increase of bicyclic and tricyclic structures in a cyclized polydiene resin increases the glass transition temperature (T_g) of the polydiene resin. In some
30 embodiments, the T_g of the cyclized polydiene resin disclosed herein can be at least about 0°C (e.g., at least about 5°C, at least about 10°C, at least about 15°C, at least about 20°C, or at least about 25°C) and/or at most about 100°C (e.g., at most about

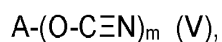
90°C, at most about 80°C, at most about 70°C, at most about 60°C, or at most about 50°C). In some embodiments, two or more cyclized polydiene resins having different properties (e.g., different unsaturation or Tg) can be used together in the dielectric film-forming composition described herein.

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In some embodiments, the cyclized polydiene resin described herein can include one or more substituted or unsubstituted alkenyl group. As used herein, possible substituents on a substituted group (e.g., a substituted alkyl, alkenyl, alkylene, cycloalkyl, cycloalkylene, aryl, arylalkyl, or heteroaryl group) or a substituted compound include C₁-C₁₀ alkyl (e.g., methyl, ethyl, or propyl), halogen (F, Cl, Br, or I), cyano, and phenyl.

In some embodiments, the cyclized polydiene resin described herein can be in an amount of from at least about 2 weight % (e.g., at least about 3 weight %, at least about 4 weight %, at least about 5 weight %, at least about 8 weight %, or at least 10 weight %) to at most about 40 weight % (e.g., at most about 35 weight %, at most about 30 weight %, at most about 25 weight %, at most about 20 weight %, or at most about 15 weight %) of the dielectric film-forming composition described herein.

In embodiments where the dielectric film-forming compositions described herein include a cyclized polydiene resin, the compositions can further include at least one cyanate ester compound as a part of the second resin. In some embodiments, the cyanate ester compound can have Structure (V):



wherein m is an integer of at least 2 (i.e., $m \geq 2$) and A is a divalent organic group containing a substituted or unsubstituted aromatic group (e.g., the cyanate ester groups -O-C≡N are directly bonded to the substituted or unsubstituted aromatic organic group). In some embodiments, the aromatic group can include aryl and heteroaryl groups. The term “aryl” used herein refers to a hydrocarbon moiety having one or more aromatic rings. Examples of aryl moieties include phenyl (Ph), phenylene, naphthyl, naphthylene, pyrenyl, anthryl, and phenanthryl. The term “heteroaryl” used herein

refers to a moiety having one or more aromatic rings that contain at least one heteroatom (e.g., N, O, or S). Examples of heteroaryl moieties include furyl, furylene, fluorenyl, pyrrolyl, thienyl, oxazolyl, imidazolyl, thiazolyl, pyridinyl, pyrimidinyl, quinazolinyl, quinolyl, isoquinolyl and indolyl.

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Specific examples of suitable cyanate ester compounds include 2-bis(4-cyanatophenyl)propane, hexafluorobisphenol A dicyanate, bis(4-cyanate-3,5-dimethylphenyl)methane, 1,3-bis(4-cyanatephenyl-1-(methylethylidene))benzene, bis(4-cyanatephenyl)thioether, and bis(4-cyanatephenyl)ether; a polyfunctional cyanate ester
10 derived from a phenol novolac, cresol novolac, or dicyclopentadiene structure-containing phenol resin, or the like. Other examples of cyanate ester compounds have been described in, e.g., U.S. Patent Nos. 3,595,900; 4,894,414, and 4,785, 034, the contents of which are hereby incorporated by reference. In some embodiments, two or more cyanate ester compounds can be used in the dielectric film-forming composition
15 described herein.

In some embodiments, the cyanate curing catalyst can be selected from the group consisting of metal carboxylate salts and metal acetylacetonate salts. The metal in the metal carboxylate salts and metal acetylacetonate salts can be selected from the
20 group consisting of zinc, copper, manganese, cobalt, iron, nickel, aluminum, titanium, zirconium, and mixtures thereof. Examples of cyanate curing catalysts include metal salts such as zirconyl dimethacrylate, zinc octanoate, zinc naphthenate, cobalt naphthenate, copper naphthenate, and acetylacetone iron; phenol compounds such as octylphenol and nonylphenol; alcohols such as 1-butanol and 2-ethylhexanol; imidazole
25 compounds such as 2-methylimidazole, 2-ethyl-4-methylimidazole, 2-phenylimidazole, 1-cyanoethyl-2-phenylimidazole, 1-cyanoethyl-2-ethyl-4-methylimidazole, 2-phenyl-4,5-dihydroxymethylimidazole, and 2-phenyl-4-methyl-5-hydroxymethylimidazole; amine compounds such as dicyandiamide, benzyldimethylamine, and 4-methyl-N,N-dimethylbenzylamine; phosphorus compounds such as phosphine compounds and
30 phosphonium compounds; epoxy-imidazole adduct compounds; and peroxides such as benzoyl peroxide, p-chlorobenzoyl peroxide, di-t-butyl peroxide, diisopropyl

peroxycarbonate, and di-2-ethylhexyl peroxycarbonate. These catalysts are commercially available. Examples of the commercially available catalysts include Amicure PN-23 (trade name, manufactured by Ajinomoto Fine-Techno Co., Inc.), Novacure HX-3721 (trade name, manufactured by Asahi Kasei Corporation.), and
5 Fujicure FX-1000 (trade name, manufactured by Fuji Kasei Kogyo Co., Ltd.). One or a combination of two or more of these catalysts can be used in the composition described herein. Other examples of such catalysts have been described in, e.g., U.S. Patent Application number 2018/0105488 and U.S. Patent number 9,822,226, the contents of which are hereby incorporated by reference.

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In some embodiments, the cyanate ester compound described herein can be in an amount of from at least about 1 weight % (e.g., at least about 2 weight %, at least about 3 weight %, at least about 4 weight %, or at least about 5 weight%) to at most about 25 weight % (e.g., at most about 20 weight %, at most about 15 weight %, at
15 most about 10 weight %, or at most about 8 weight %) of the dielectric film-forming composition described herein.

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In some embodiments, the second resin can be in an amount of at least about 50 wt% (e.g., at least about 55 wt%, at least about 60 wt%, at least about 65 wt%, at least about 70 wt%, at least about 75 wt%, at least about 80 wt%, or at least about 85 wt%) to at most about 90wt% (e.g., at most about 90 wt%, at most about 85 wt%, at most about 80 wt%, at most about 75 wt%, at most about 70 wt%, at most about 65 wt%, or at most about 60 wt%) of a dielectric film-forming composition described herein.

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In some embodiments, the dielectric film-forming compositions described herein can optionally include at least one (e.g., two, three, or four) cross-linker. In some embodiments, the cross-linker described herein can include at least two (e.g., three or four) functional groups capable of reacting with a substituted or unsubstituted alkenyl group on the cyclized polydiene resin to form a cross-linked dielectric film. An example

of a cross-linker is a compound containing at least two (meth)acrylate groups, at least two olefin groups, at least two cycloolefin groups, or at least two alkynyl groups.

Examples of compounds containing at least two cycloolefin groups include, but are not limited to, dicyclopentadiene, norbornadiene and the like. Examples of compounds containing two olefin groups include divinyl benzene, ethylene norbornene and the like. In some embodiments, compounds containing at least two (meth)acrylate groups include di(meth)acrylate of unsubstituted or substituted linear, branch or cyclic C₁-C₁₀ alkyl groups, and di(meth)acrylate of unsubstituted or substituted aromatic groups. Examples of such compounds include, but are not limited to, 1,3-butylene glycol di(meth)acrylate, 1,4-butanediol di(meth)acrylate, 1,5-pentanediol di(meth)acrylate, 1,6-hexanediol di(meth)acrylate, 1,9-nonanediol di(meth)acrylate, 1,10-decanediol di(meth)acrylate, 1,12-dodecanediol di(meth)acrylate, tetraethyleneglycol di(meth)acrylate, cyclohexane dimethanol di(meth)acrylate, tricyclodecanedimethanol diacrylate, 1,4-phenylene di(meth)acrylate, 2,2-bis[4-(2-hydroxy-3-methacryloxypropoxy)phenyl]propane, tricyclodecane dimethanol di(meth)acrylate, and trimethylol propane ethoxylate tri(meth)acrylate. Other examples of cross-linkers have been described in, e.g., U.S. Patent Nos. 10,036,952; 10,563,014, and U.S. Application Publication No. 2015219990, the contents of which are hereby incorporated by reference. In some embodiments, two or more cross-linkers can be used together in a dielectric film-forming compositions described herein.

In some embodiments, the at least one cross-linker can be in an amount of from at least about 1 weight % (e.g., at least about 2 weight %, at least about 3 weight %, at least about 4 weight %, or at least 5 weight %) to at most about 25 weight % (e.g., at most about 20 weight %, at most about 15 weight %, at most about 10 weight %, or at most about 8 weight %) of the total weight of a dielectric film-forming composition described herein. Without wishing to be bound by theory, it is believed that the cross-linker can result in crosslinking in the dielectric film (e.g., upon exposure to radiation or heat), which facilitates forming a solubility contrast before and after exposure. In addition, without wishing to be bound by theory, it is believed that a dielectric film-

forming composition containing a relative large amount of a cross-linker can result in a dielectric film having a relatively high T_g.

In some embodiments, the dielectric film-forming compositions described herein
5 can optionally include at least one (e.g., two, three, or four) catalyst (e.g., an initiator). The catalyst is capable of inducing crosslinking or polymerization reaction when exposed to heat (thermal initiator) and/or a source of radiation (photoinitiator). Specific examples of thermal initiators include, but are not limited to, benzoyl peroxide, dicumyl peroxide, 2,2-azobis(2-methylbutyronitrile) and the like. Other examples of thermal
10 initiators have been described in, e.g., U.S. Patent No. 10,563,014, the contents of which are hereby incorporated by reference. Specific examples of photoinitiators include, but are not limited to, 2-(benzoyloxyimino)-1-[4-(phenylthio)phenyl]-1-octanone (Irgacure OXE-01 from BASF), 1-[9-ethyl-6-(2-methylbenzoyl)-9H-carbazol-3-yl]ethanone 1-(O-acetyloxime) (Irgacure OXE-2 from BASF), ethoxy(2,4,6-
15 trimethylbenzoyl)phenyl phosphine oxide (Lucerin TPO-L from BASF), NCI-831 (ADEKA Corp.), NCI-930 (ADEKA Corp.), N-1919 (ADEKA Corp.), and the like. Other examples of photoinitiators have been described in, e.g., U.S. Patent Nos. 10,036,952 and 10,563,014, and U.S. Patent Application Nos. 2015/0219990 and 2019/0018321, the contents of which are hereby incorporated by reference.

20

In some embodiments, the amount of the catalyst is at least about 0.2 weight % (e.g., at least about 0.5 weight %, at least about 0.8 weight %, at least about 1.0 weight %, or at least about 1.5 weight %) and/or at most about 3.0 weight % (e.g., at most about 2.8 weight %, at most about 2.6 weight %, at most about 2.4 weight %, or at most
25 about 2.0 weight%) of the total weight of a dielectric film-forming composition described herein.

In some embodiments, the dielectric film-forming compositions described herein can optionally include at least one (e.g., two, three, or four) solvent (e.g., an organic solvent).

5

Examples of suitable organic solvents include, but are not limited to, alkylene carbonates such as ethylene carbonate, propylene carbonate, butylene carbonate, and glycerin carbonate; lactones such as gamma-butyrolactone, ϵ -caprolactone, γ -caprolactone and δ -valerolactone; cycloketones such as cyclopentanone and
10 cyclohexanone; linear ketones such as methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK); esters such as n-butyl acetate; ester alcohol such as ethyl lactate; ether alcohols such as tetrahydrofurfuryl alcohol; glycol esters such as propylene glycol methyl ether acetate; glycol ethers such as propylene glycol methyl ether (PGME); cyclic ethers such as tetrahydrofuran (THF); aromatic hydrocarbons such as toluene,
15 xylenes, mesitylene, tetralin; and pyrrolidones such as N-methyl-2-pyrrolidone.

In some embodiments, the amount of the solvent is at least about 40 weight % (e.g., at least about 45 weight %, at least about 50 weight %, at least about 55 weight %, at least about 60 weight %, or at least about 65 weight %) and/or at most about 98
20 weight % (e.g., at most about 95 weight %, at most about 90 weight %, at most about 85 weight %, at most about 80 weight %, or at most about 75 weight %) of the total weight of a dielectric film-forming composition described herein.

In some embodiments, the dielectric film-forming compositions described herein
25 can optionally further include at least one (e.g., two, three, or four) adhesion promoter (e.g., a silane containing alkoxy groups). Suitable adhesion promoters are described in "Silane Coupling Agent" Edwin P. Plueddemann, 1982 Plenum Press, New York; and U.S. Patent No. 9,519,216, the contents of which are hereby incorporated by reference.

30 In some embodiments, the amount of the optional adhesion promoter is at least about 0.5 weight % (e.g., at least about 0.8 weight %, at least about 1 weight %, or at

least about 1.5 weight %) and/or at most about 4 weight % (e.g., at most about 3.5 weight %, at most about 3 weight %, at most about 2.5 weight %, or at most about 2 weight%) of the total weight of a dielectric film-forming composition described herein.

5 In some embodiments, the present disclosure describes a photosensitive composition including:

- a. at least one meth(acrylate)-containing polyphenylene ether resin,
- b. at least one fully imidized polyimide polymer;
- c. at least one second resin described herein;
- 10 d. at least one crosslinker;
- e. at least one catalyst;
- f. optionally at least one adhesion promoter; and
- g. optionally at least one solvent.

15 In some embodiments, the present disclosure features a dielectric film (e.g., a cross-linked dielectric film) that includes (a) at least one meth(acrylate)-containing polyphenylene ether resin, and (b) at least one second resin selected from the group consisting of: i) at least one fully imidized polyimide polymer; ii) at least one polyamic acid ester; iii) at least one cyclized polydiene resin; and iv) a mixture of at least one
20 cyclized polydiene resin and at least one cyanate ester compound.

 In some embodiments, a dielectric film can be prepared by a method that includes: a) coating a dielectric film-forming composition described herein on a substrate (e.g. a semiconductor substrate such as a wafer) to form a film (e.g., a
25 dielectric film); b) optionally baking the film at an elevated temperature (e.g., from about 50°C to about 150°C) for a period of time (e.g., from about 20 seconds to about 240 seconds); and c) optionally exposing (e.g., flood exposing without using a mask such as a patterned mask) the film to radiation, heat or a combination of both radiation and heat. In some embodiments, the dielectric film prepared by the above process (which can use

a broad exposure without a mask) can be crosslinked but does not include a pattern or a relief image.

Coating methods for preparation of the dielectric film include, but are not limited to, spin coating, spray coating, roll coating, rod coating, rotation coating, slit coating, compression coating, curtain coating, die coating, wire bar coating, knife coating and lamination of dry film. Semiconductor substrates could have circular shape such as wafers or could be panels. In some embodiments, semiconductor substrates could be a silicon substrate, a copper substrate, an aluminum substrate, a silicon oxide substrate, a silicon nitride substrate, a glass substrate, an organic substrate, a copper cladded laminate or a dielectric material substrate.

Film thickness of the dielectric film of this disclosure is not particularly limited. In some embodiments, the dielectric film has a film thickness of at least about 1 micron (e.g., at least about 2 microns, at least about 3 microns, at least about 4 microns, at least about 5 microns, at least about 7 microns, at least about 10 microns, at least about 15 microns, at least about 20 microns, at least about 25 microns, at least 50 microns or at least 100 microns) and/or at most about 5000 microns (5 mm) (e.g., at most about 4000 microns, at most about 3000 microns most about 2000 microns, at most about 1000 microns, at most about 500 microns, at most about 400 microns, at most about 300 microns, or at least 200 microns).

In some embodiments, the dielectric film-forming compositions of this disclosure are photopatternable. In such embodiments, the process to prepare a patterned dielectric film includes converting the dielectric film prepared from a dielectric film-forming composition into a patterned dielectric film by a lithographic process. In such cases, the conversion can include exposing the dielectric film to high energy radiation (such as electron beams, ultraviolet light, and X-ray) using a patterned mask.

After the exposure, the dielectric film can optionally be heat treated to at a temperature of at least about 50°C (e.g., at least about 55°C, at least about 60°C, or at

least about 65°C) to at most about 100°C (e.g., at most about 95°C, or at most about 90°C, at most about 85°C, at most about 80°C, at most about 75°C, or at most about 70°C) for at least about 60 seconds (e.g., at least about 80 seconds, or at least about 100 seconds) to at most about 240 seconds (e.g., at most about 180 seconds, at most
5 about 120 seconds or at most about 90 seconds). The heat treatment is usually accomplished by use of a hot plate or oven.

After the exposure and/or heat treatment, the dielectric film can be developed to remove unexposed portions by using a developer to form openings or a relief image on
10 the substrate. Development can be carried out by, for example, an immersion method or a spraying method. Microholes and fine lines can be generated in the dielectric film on the laminated substrate after development.

In some embodiments, the dielectric film can be developed by using an organic
15 developer. Examples of such developers include, but are not limited to, cyclohexanone, xylene, toluene, tetralin, gamma-butyrolactone (GBL), dimethyl sulfoxide (DMSO), N,N-diethylacetamide, methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), 2-heptanone, cyclopentanone (CP), cyclohexanone, n-butyl acetate (nBA), propylene glycol methyl ether acetate (PGMEA), propylene glycol methyl ether (PGME), ethyl
20 lactate (EL), propyl lactate, 3-methyl-3-methoxybutanol, tetralin, isophorone, ethylene glycol monobutyl ether, diethylene glycol monoethyl ether, diethylene glycol monoethyl ether acetate, diethylene glycol dimethyl ether, diethylene glycol methylethyl ether, triethylene glycol monoethyl ether, dipropylene glycol monomethyl ether, methyl 3-methoxypropionate, ethyl 3-ethoxypropionate, diethyl malonate, ethylene glycol, 1,4:3,6-
25 dianhydrosorbitol, isosorbide dimethyl ether, 1,4:3,6-dianhydrosorbitol 2,5-diethyl ether (2,5-diethylisosorbide) and mixtures thereof. Preferred developers are cyclohexanone, xylene, toluene and tetralin. These developers can be used individually or in combination of two or more to optimize the image quality for the particular composition and lithographic process.

30

In some embodiments, a dielectric film described herein is not photopatternable. In such cases, patterning can be accomplished by mechanical laser drilling or by a bilayer process. Laser drilling generally involves a stationary laser beam that uses its high power density to melt or vaporize materials from the target substrate or workpiece.

5 In principle, laser drilling is governed by an energy balance between the irradiating energy from the laser beam and the conduction heat into the substrate, the energy losses to the environment, and the energy required for a phase change in the workpiece. Examples of mechanical laser drilling described in, e.g., U.S. Patent No. 6,353, 999; the contents of which are hereby incorporated by reference.

10

In some embodiments, a dielectric film described herein can have a relatively low dissipation factor (Df). For example, a dielectric film described herein can have a Df of at most about 0.01 (e.g., at most about 0.008, at most about 0.006, at most about 0.005, at most about 0.004, at most about 0.002, or at most about 0.001) and at

15 least about 0.0001 when measured at 5-50 GHz after curing. The dielectric constant (Dk) and dissipation factor (Df) are measured at variable frequency from 1 GHz to 75 GHz using a split cylinder resonator following IPC TM-650 2.5.5.13 method, well known to those skilled in the art.

20

In some embodiments, the present disclosure features a method for preparing a dry film. In some embodiments, the method includes a) coating a carrier substrate with a dielectric film-forming composition described herein to form a coated composition; b) drying the coated composition to form a dielectric film; and c) optionally, applying a protective layer to the dielectric film. In some embodiments, the dry film can include a carrier substrate, a dielectric film, and optionally a protective layer.

25

In some embodiments, the carrier substrate is a single or multiple layer plastic film, which can include one or more polymers (e.g., polyethylene terephthalate). In some embodiments, the carrier substrate has excellent optical transparency and it is substantially transparent to actinic irradiation used to form a relief pattern in the polymer

30 layer. The thickness of the carrier substrate is preferably in the range of at least about 10 microns (e.g., at least about 15 microns, at least about 20 microns, at least about 30

microns, at least about 40 microns, at least about 50 microns or at least about 60 microns) to at most about 150 microns (e.g., at most about 140 microns, at most about 120 microns, at most about 100 microns, at most about 90 microns, at most about 80 microns, or at most about 70 microns).

5

In some embodiments, the protective layer is a single or multiple layer film, which can include one or more polymers (e.g., polyethylene or polypropylene). Examples of carrier substrates and protective layers have been described in, e.g., U.S. Application Publication No. 2016/0313642, the contents of which are hereby incorporated by
10 reference.

In some embodiments, the dielectric film of the dry film can be delaminated from carrier layer as a self-standing dry film. A self-standing dry film is a film that can maintain its physical integrity without using any support layer such as a carrier layer. In
15 some embodiments, a self-standing dielectric dry film is not crosslinked or cured and can include the components of the dielectric film-forming composition described herein except for the solvent.

In some embodiments, the dielectric film prepared from a dielectric film-forming
20 composition described herein can have a relatively low dielectric loss tangent. For example, the dielectric loss tangent of the dielectric film (e.g., a crosslinked or uncrosslinked dielectric film) prepared from a dielectric film-forming composition of this disclosure measured at 10 GHz can be in the range of from at least about 0.001 (e.g., at least about 0.005, at least about 0.01, or at least about 0.05) to at most about 0.1 (e.g.,
25 at most about 0.08, at most about 0.06, at most about 0.05, at most about 0.04, or at most about 0.020).

In some embodiments, this disclosure features three dimensional objects, that include at least one layer of conducting metal and a dielectric film (e.g., a crosslinked,
30 patterned dielectric film) formed by using the dielectric film-forming composition of this

disclosure. In some embodiments, the three dimensional object can include dielectric films in at least two stacks (e.g., at least three stacks).

The following examples are provided to illustrate the principles and practice of the present disclosure more clearly. It should be understood that the present disclosure is not limited to the examples described.

EXAMPLES

Example 1: Preparation and application of dielectric film-forming composition 1

Dielectric film-forming composition 1 is prepared by mixing a cyclized polyisoprene (SC Rubber supplied by Fujifilm Electronic Materials U.S.A., 57.90 g, of a solution of 28.5% in xylene), SA9000 (available from Sabic, 6.6 g), 2,2-bis(4-cyanatophenyl)propane (8.25 g), dicumyl peroxide (0.50 g), and xylene (1.75 g) to obtain a homogeneous solution. The solution is filtered by using a 5.0 micron PTFE filter.

In this Example, SC rubber is used as a cyclized polydiene; 2,2-bis(4-cyanatophenyl)propane is used as a cyanate ester compound; SA9000 is used as low Df methacrylate-containing polyphenylene ether resin, dicumyl peroxide is used as a thermal initiator, and xylene is used as a solvent.

The dielectric film-forming composition 1 prepared above is applied on a 35-micron thick PET using an applicator to form a dielectric film. The film is baked at 95°C for 10 minutes using a hot plate to remove the majority of the solvent. The film is baked at 150°C for 1 hour under nitrogen to achieve a stable dielectric film with a thickness of 120 microns. After the dielectric film is lifted from the PET film, it is placed on a 25-micron KAPTON film and then baked at 200°C for an additional hour under nitrogen.

After cooling to room temperature, the dielectric film is removed from the KAPTON film and slitted to form 3 mm width films, which are analyzed by thermomechanical analysis ("TMA") for thermomechanical properties using TMA 450 (available from TA Instruments, USA). The CTE (coefficient of linear thermal expansion) is 100ppm/K measured at the temperature range from 25°C to 120°C.

Example 2: Preparation and application of dielectric film-forming composition 2

Dielectric film-forming composition 2 is prepared by mixing a cyclized polyisoprene (SC Rubber supplied by Fujifilm Electronic Materials U.S.A., 57.90 g of 28.5% solution of in xylene), SA9000 (available from Sabic, 6.6 g), tricyclodecanedimethanol diacrylate (6.60 g), 2,2-bis(4-cyanatophenyl)propane (8.25 g), silica (12.0 g, Silica nanoparticles SUPSIL™ PREMIUM, monodisperse, charge-stabilized supplied by Superior Silica), dicumyl peroxide (0.50 g), and xylene (1.75 g) to obtain a homogeneous solution. The solution is filtered by using a 5.0 micron PTFE filter.

In this Example, SC rubber is used as a cyclized polydiene, silica is used as an inorganic particle filler, SA9000 is used as low Df methacrylate-containing polyphenylene ether resin, tricyclodecanedimethanol diacrylate is used as a crosslinker, 2,2-bis(4-cyanatophenyl)propane is used as a cyanate ester compound, dicumyl peroxide is used as a thermal initiator, and xylene is used as a solvent.

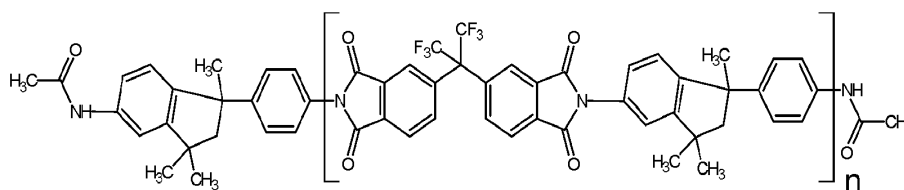
The dielectric film-forming composition 2 is applied on a 35-micron thick PET film using an applicator to form a dielectric film. The film is baked at 105°C for 7 minutes using a hot plate to remove the majority of the solvent. The film is then baked at 160°C for 185 minutes under nitrogen to achieve a stable dielectric film with a thickness of 90 microns. After the dielectric film is lifted from the PET film, it is placed on a 25-micron KAPTON film and then baked at 210°C for an additional hour under nitrogen.

After cooling to room temperature, the dielectric film is removed from the KAPTON film and slitted to form 3 mm width films, which are analyzed by TMA for

thermomechanical properties. The CTE (coefficient of linear thermal expansion) is 60ppm/K measured at the temperature range from 25°C to 120°C

Synthesis Example 1 (P-1)

Preparation of 6FDA/DAPI polyimide



Polymer (Poly-1)

- 10 Solid 2,2'-bis(3,4-dicarboxyphenyl)hexafluoropropane dianhydride (6FDA) (3.34 Kg, 7.52 mole) was charged to a solution of 4,4'-[1,4-phenylene-bis(1-methylethylidene)] bisaniline (DAPI) (2.18 Kg, 8.19 mole) in NMP (22.06 Kg) at room temperature. Additional NMP (8.16 Kg) was used to rinse the dianhydride into solution. The reaction temperature was increased to 60°C and the mixture was allowed to react for 3.5 hours.
- 15 Next, acetic anhydride (1.257 Kg) and pyridine (495 g) were added, the reaction temperature was increased to 100°C, and the mixture was allowed to react for 12 hours.

- The reaction mixture was cooled to room temperature and transferred to a larger vessel equipped with a mechanical stirrer. The reaction solution was diluted using ethyl acetate as a purification solvent and washed with water for one hour. Stirring was
- 20 stopped and the mixture was allowed to stand undisturbed. Once phase separation had occurred, the aqueous phase was removed. The organic phase was diluted using a combination of cyclopentanone and toluene as purification solvents and washed three more times with water. The amounts of purification solvents (i.e., cyclopentanone and
- 25 toluene) and water used in all of the washes are shown in Table 1.

TABLE 1

	Wash 1	Wash 2	Wash 3
Cyclopentanone (Kg)	39.76	5.66	5.29
Toluene (Kg)	25.52	---	---
Water (Kg)	38.18	46.62	46.62

The washed organic phase was concentrated by vacuum distillation. cyclopentanone (7.1 Kg) was added as an isolation solvent and vacuum distillation was continued to form a polymer solution (P-1). The molecular weight of polymer Poly-1
5 was 53,500 Daltons and the solid% in the solution (P-1) was 31.85%. The molar ratio of dianhydride to diamine in this Example was 0.92.

Example 3: Preparation and application of Photosensitive Dielectric Film Forming Composition

10

Photosensitive dielectric film forming composition 3 is prepared by using 89.7 g of polymer solution (P-1) prepared above, 8.00 g cyclopentanone, 2.04 g of a 0.5 wt% solution of PolyFox 6320 (available from OMNOVA Solutions) in cyclopentanone, 1.92 g of methacryloxypropyl trimethoxysilane, 1.92 g of 1-(O-acetyloxime)-1-[9-ethyl-6-(2-
15 methylbenzoyl)-9H-carbazol-3-yl]ethanone (OXE-02 from BASF), 0.077 g *para*-benzoquinone, 15.840 g of tetra-ethyleneglycol diacrylate, and 5.280 g of SA 9000. After being stirred mechanically for 24 hours, the solution is filtered by using a 0.2 micron PTFE filter to form a photosensitive dielectric film forming composition 3.

20

In this Example, polyimide solution (P-1) is used as a fully cyclized polyimide, SA9000 is used as low Df methacrylate-containing polyphenylene ether resin, tetra-ethyleneglycol diacrylate is used as a crosslinker, 1-(O-acetyloxime)-1-[9-ethyl-6-(2-methylbenzoyl)-9H-carbazol-3-yl]ethanone is used as a photoinitiator, methacryloxypropyl trimethoxysilane is used as an adhesion promoter, and
25 cyclopentanone is used as a solvent.

The photosensitive dielectric film-forming composition 3 is applied on a 35-micron thick PET film using an applicator to form a dielectric film. The film is baked at 95°C for 7 minutes using a hot plate to remove the majority of the solvent. The film is then baked at 160°C for 185 minutes under nitrogen to achieve a stable dielectric film with a thickness of 70 microns. After the dielectric film is lifted from the PET film, it is placed on a 25-micron KAPTON film and then baked at 200°C for an additional hour under nitrogen.

After cooling to room temperature, the dielectric film is removed from the KAPTON film and slitted to form 3 mm width films, which are analyzed by TMA for thermomechanical properties. The CTE (coefficient of linear thermal expansion) is 65ppm/K measured at the temperature range from 25°C to 120°C.

Table 2 summarizes the dielectric constant (Dk) and dissipation factor (Df) for Composition of Example 3.

Table 2.

Sample ID	Frequency 15 GHz		Frequency 35 GHz	
	Dk	Df	Dk	Df
Example 3	2.85	0.0075	2.90	0.0048

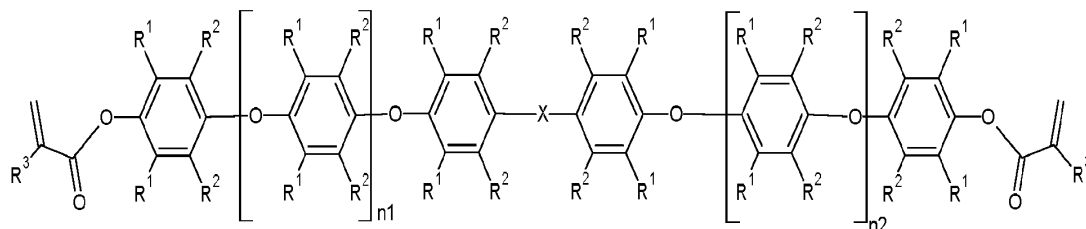
Other aspects, embodiments, and features are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A dielectric film-forming composition, comprising:
 - (a) at least one meth(acrylate)-containing polyphenylene ether resin, and
 - (b) at least one second resin selected from the group consisting of:
 - i) at least one fully imidized polyimide polymer;
 - ii) at least one polyamic acid ester;
 - iii) at least one cyclized polydiene resin; and
 - iv) a mixture of at least one cyclized polydiene resin and at least one cyanate ester compound.

2. The composition of claim 1, wherein the at least one meth(acrylate)-containing polyphenylene ether resin comprises a polyphenylene ether resin having at least one meth(acrylate) group as an end group.

3. The composition of claim 2, wherein the at least one meth(acrylate)-containing polyphenylene ether resin comprises a polymer of Structure (I):



(I),

in which

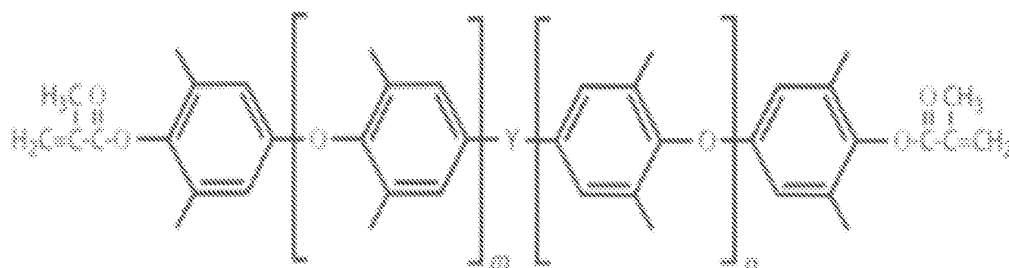
each of n_1 and n_2 , independently, is an integer from 0 to 20;

X is a $-C(O)-$, $-S(O)-$, $-S(O)_2-$, or $-C(RR')$, in which each of R and R' , independently, is H or C_1-C_6 alkyl;

each R^1 , independently, is an aliphatic hydrocarbon group having 1 to 6 carbon atoms; and

each R^2 , independently, is H, halo, or an aliphatic hydrocarbon group having 1 to 6 carbon atoms.

4. The composition of claim 2, wherein the at least one meth(acrylate)-containing polyphenylene ether resin comprises a polymer of Structure (II):



(II),

in which each of m and n, independently, is an integer from 0 to 20, and Y is -C(O)-, -S(O)-, -S(O)₂-, or -C(RR')-, in which each of R and R', independently, is H or C1-C6 alkyl.

5. The composition of any one of claims 1-4, wherein the at least one meth(acrylate)-containing polyphenylene ether resin is from about 5 wt% to about 50 wt% of the composition.

6. The composition of any one of claims 1-5, wherein the at least one second resin is from about 50 wt% to about 90 wt% of the composition.

7. The composition of any one of claims 1-6, further comprising at least one cross-linker, at least one catalyst, at least one adhesion promoter, at least one solvent.

8. A process for preparing a dielectric film, comprising:
- a) coating the dielectric film-forming composition of any one of claims 1-7 on a substrate to form a film; and
 - b) optionally baking the film at a temperature from about 50°C to about 150°C for about 20 seconds to about 240 seconds.
9. The process of claim 8, further comprising exposing the film to radiation, heat, or a combination thereof without a mask.
10. A process for preparing a dry film, comprising:
- a) coating a carrier substrate with the dielectric film-forming composition of any one of claims 1-7 to form a coated composition;
 - b) drying the coated composition to form a dielectric film; and
 - c) optionally, applying a protective layer to the dielectric film.
11. The dielectric film of claim 1-10, wherein the dielectric film has a dissipation factor (Df) at 5 GHz of at most about 0.01 after curing by exposing the film to radiation, heat, or a combination thereof without a mask.
12. A photosensitive dielectric film forming composition, comprising:
- (a) at least one meth(acrylate)-containing polyphenylene ether resin, and
 - (b) at least one second resin selected from the group consisting of:
 - i) at least one fully imidized polyimide polymer;
 - ii) at least one polyamic acid ester;
 - iii) at least one cyclized polydiene resin; and
 - iv) a mixture of at least one cyclized polydiene resin and at least one cyanate ester compound.
 - (c) at least one cross-linker,
 - (d) at least one catalyst, and
 - (e) at least one solvent.