



(51) International Patent Classification:

*C08G 65/40* (2006.01)      *C08G 59/50* (2006.01)  
*C08G 65/48* (2006.01)      *C08G 73/06* (2006.01)  
*C08G 59/22* (2006.01)

(21) International Application Number:

PCT/US2015/010221

(22) International Filing Date:

6 January 2015 (06.01.2015)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

14/168,323      30 January 2014 (30.01.2014)      US

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(81) Designated States (unless otherwise indicated, for every  
kind of national protection available): AE, AG, AL, AM,  
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,  
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SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,  
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every  
kind of regional protection available): ARIPO (BW, GH,  
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,  
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,  
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,  
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,  
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,  
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,  
GW, KM, ML, MR, NE, SN, TD, TG).

**Declarations under Rule 4.17:**

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

**Published:**

- with international search report (Art. 21(3))

(54) Title: COPOLYMER OF A BISPHENOL DIGLYCIDYL ETHER AND A PHENOLPHTHALENE AND/OR A PHENOLPHTHALIMIDINE, METHOD FOR THE PREPARATION THEREOF, ARTICLE COMPRISING THE COPOLYMER, AND COMPOSITIONS COMPRISING THE COPOLYMER

(57) Abstract: A copolymer exhibiting improved heat resistance relative to phenolic resins is formed by the reaction of a bisphenol diglycidyl ether and a phenolphthalein and/or a phenolphthalimidine in a molar ratio of 0.98:1 to 1.02:1 in the presence of a catalyst. The copolymer can be used to mold plastic parts. The copolymer is also useful as a flexibilizer in thermoset compositions, and useful as a compatibilizer in blends of polar and non-polar polymers, and blends of non-polar polymers and polar fillers.

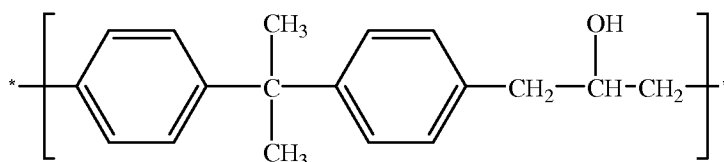


WO 2015/116349 A1

COPOLYMER OF A BISPHENOL DIGLYCIDYL ETHER AND A PHENOLPHTHALENE  
AND/OR A PHENOLPHTHALIMIDINE, METHOD FOR THE PREPARATION  
THEREOF, ARTICLE COMPRISING THE COPOLYMER, AND COMPOSITIONS  
COMPRISING THE COPOLYMER

BACKGROUND OF THE INVENTION

[0001] Poly(hydroxy ether)s, also known as phenoxy resins, are thermoplastics prepared by reaction of bisphenol A with epoxy resins to form a linear thermoplastic with repeat units having the structure

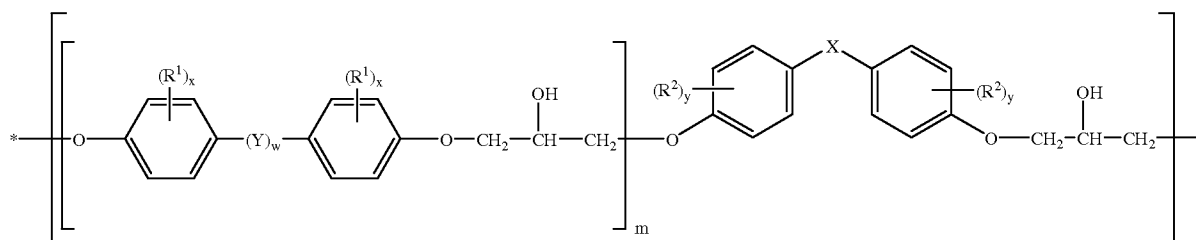


The backbone ether linkages and pendant hydroxyl groups promote wetting and bonding to polar substrates and fillers, and phenoxy resins are therefore used to enhance the properties of coatings, adhesives, inks, composites, fibers and plastics.

[0002] Although poly(hydroxy ether)s are good electrical insulators and have good impact resistance and excellent dimensional stability below 80°C, they have glass transition temperatures of about 90 °C. So, their properties begin to rapidly decline as the temperature approaches 90°C. For uses at or above 90°C, there is therefore a need for poly(hydroxy ether)s with higher glass transition temperatures.

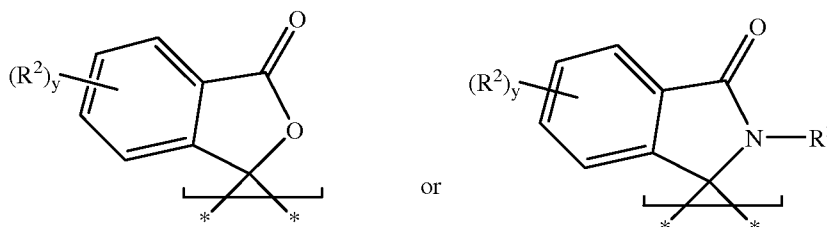
BRIEF SUMMARY OF EMBODIMENTS OF THE INVENTION

[0003] One embodiment is a copolymer comprising repeat units having the structure

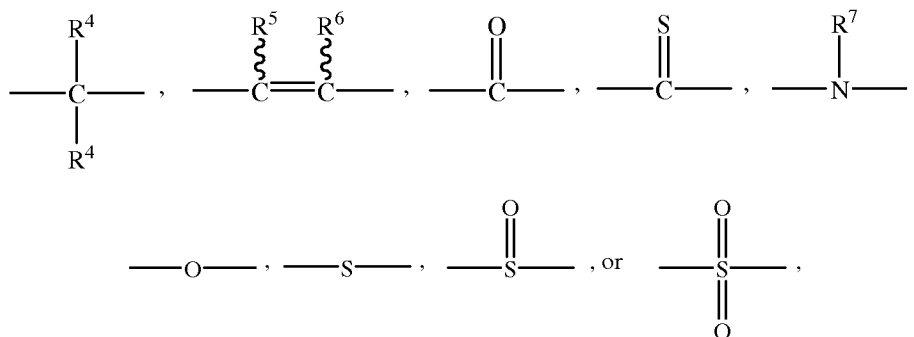


wherein the average value of m is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the

halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

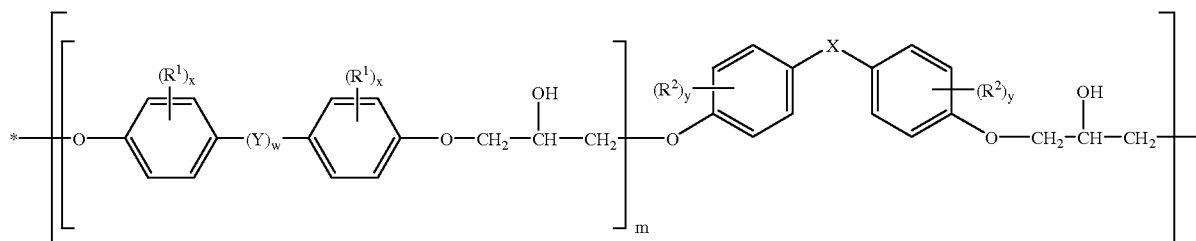
[0004] Another embodiment is a method of forming a copolymer, the method comprising: reacting an oligomeric bisphenol diglycidyl ether and a phenolphthalein or phenolphthalimidine in a molar ratio of 0.98:1 to 1.02:1 in the presence of a tertiary amine catalyst to form a copolymer.

[0005] Another embodiment is an article comprising the copolymer.

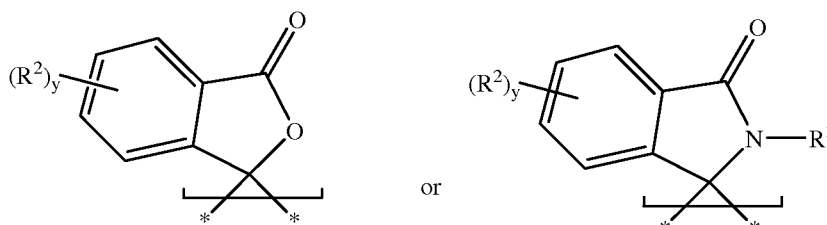
[0006] These and other embodiments are described in detail below.

DETAILED DESCRIPTION OF THE INVENTION

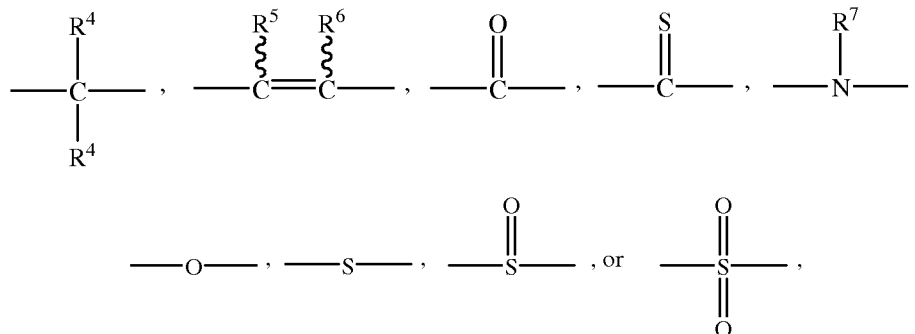
[0007] The present inventor has determined that the need for a poly(hydroxy ether) with a glass transition temperatures above 90°C is fulfilled by a copolymer of an oligomeric bisphenol diglycidyl ether and a phenolphthalein or phenolphthalimidine. Thus, one embodiment is a copolymer comprising repeat units having the structure



wherein the average value of m (that is, the average of all occurrences of m) is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



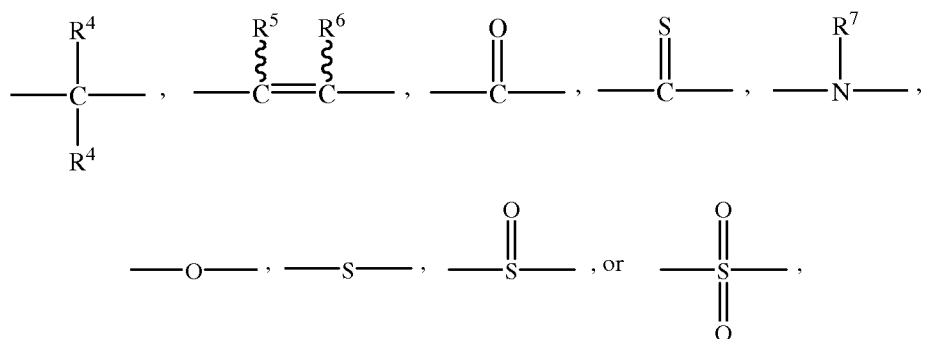
wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

[0008] As used herein, the term “hydrocarbyl”, whether used by itself, or as a prefix, suffix, or fragment of another term, refers to a residue that contains only carbon and hydrogen unless it is specifically identified as “substituted hydrocarbyl”. The hydrocarbyl residue can be aliphatic or aromatic, straight-chain, cyclic, bicyclic, branched, saturated, or unsaturated. It can also contain combinations of aliphatic, aromatic, straight chain, cyclic, bicyclic, branched, saturated, and unsaturated hydrocarbon moieties. When the hydrocarbyl residue is described as substituted, it can contain heteroatoms in addition to carbon and hydrogen.

[0009] In the structure of the copolymer repeat unit above, the oligomeric nature of

the bisphenol diglycidyl ether is reflected in the average value of  $m$  for the copolymer (that is, the average of all occurrences of  $m$  for the copolymer), which is 1.2 to 10. Within this range, the average value of  $m$  can be 1.3 to 8, specifically 1.5 to 7.

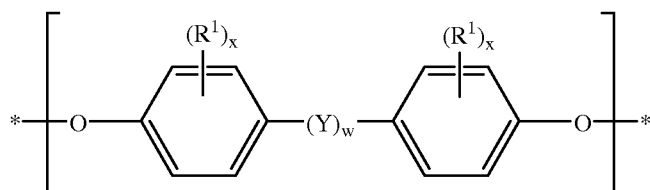
[0010] In the structure of the copolymer repeat unit above, the structural variable “ $w$ ” signifies the presence ( $w=1$ ) or absence ( $w=0$ ) of a divalent linking group between the two phenoxy ether moieties derived from the oligomeric bisphenol diglycidyl ether. Thus, each occurrence of  $w$  is independently 0 or 1. In some embodiments,  $w$  is 0. In some embodiments,  $w$  is 1. When  $w$  is 1, the divalent linking group  $Y$  is present, and each occurrence of  $Y$  is independently



wherein each occurrence of  $\text{R}^4$ ,  $\text{R}^5$ ,  $\text{R}^6$ , and  $\text{R}^7$  is independently hydrogen or an unsubstituted or substituted  $\text{C}_1$ - $\text{C}_{12}$  hydrocarbyl. In some embodiments, each occurrence of  $\text{R}^4$ ,  $\text{R}^5$ ,  $\text{R}^6$ , and  $\text{R}^7$  is independently hydrogen or an unsubstituted  $\text{C}_1$ - $\text{C}_{12}$  hydrocarbyl.

[0011] In the structure of the copolymer repeat unit above, each occurrence of  $x$  is the number of substituents on the respective phenylene group of the phenoxy ether moieties derived from the oligomeric bisphenol diglycidyl ether. Each occurrence of  $x$  can have a value of 0, 1, 2, 3, or 4. In some embodiments, each occurrence of  $x$  is 0, in which case, a hydrogen atom occupies each unsubstituted position on the 1,2-phenylene ring. When  $x$  is 1, 2, 3, or 4, the respective phenylene group has a number of substituents of  $\text{R}^1$  equal to the value of  $x$ . Each occurrence of  $\text{R}^1$  is independently halogen,  $\text{C}_1$ - $\text{C}_{12}$  hydrocarbylthio,  $\text{C}_1$ - $\text{C}_{12}$  hydrocarbyloxy,  $\text{C}_2$ - $\text{C}_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $\text{C}_1$ - $\text{C}_{12}$  hydrocarbyl.

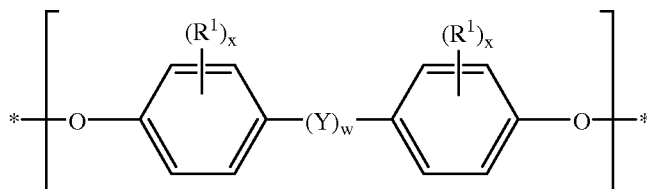
[0012] In some embodiments,  $w$  is 0, and



is the residue of a dihydroxybiphenyl compound such as 4,4'-dihydroxybiphenyl,

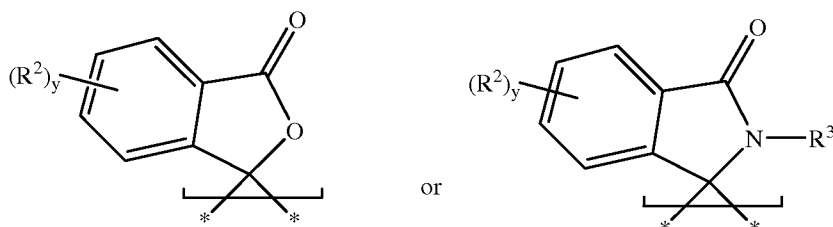
3,4'-dihydroxybiphenyl, 3,3'-dihydroxybiphenyl, 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl, or 2,2',3,3',5,5'-hexamethyl-4,4'-dihydroxybiphenyl.

[0013] In some embodiments, w is 1, and



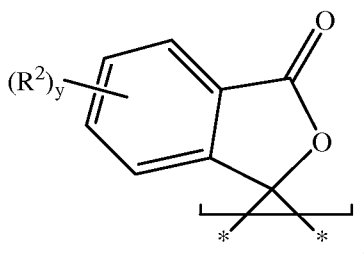
is the residue of a bisphenol such as bis(4-hydroxyphenyl)methane, bis(4-hydroxyphenyl)diphenylmethane, bis(4-hydroxyphenyl)-1-naphthylmethane, 1,2-bis(4-hydroxyphenyl)ethane, 1,1-bis(4-hydroxyphenyl)-1-phenylethane, 2-(4-hydroxyphenyl)-2-(3-hydroxyphenyl)propane, bis(4-hydroxyphenyl)phenylmethane, 2,2-bis(4-hydroxy-3-bromophenyl)propane, 1,1-bis(hydroxyphenyl)cyclopentane, 1,1-bis(4-hydroxyphenyl)cyclohexane, 1,1-bis(4-hydroxyphenyl)isobutene, 1,1-bis(4-hydroxyphenyl)cyclododecane, trans-2,3-bis(4-hydroxyphenyl)-2-butene, 2,2-bis(4-hydroxyphenyl)adamantane, alpha,alpha'-bis(4-hydroxyphenyl)toluene, bis(4-hydroxyphenyl)acetonitrile, 2,2-bis(3-methyl-4-hydroxyphenyl)propane, 2,2-bis(3-ethyl-4-hydroxyphenyl)propane, 2,2-bis(3-n-propyl-4-hydroxyphenyl)propane, 2,2-bis(3-isopropyl-4-hydroxyphenyl)propane, 2,2-bis(3-sec-butyl-4-hydroxyphenyl)propane, 2,2-bis(3-t-butyl-4-hydroxyphenyl)propane, 2,2-bis(3-cyclohexyl-4-hydroxyphenyl)propane, 2,2-bis(3-allyl-4-hydroxyphenyl)propane, 2,2-bis(3-methoxy-4-hydroxyphenyl)propane, 2,2-bis(4-hydroxyphenyl)hexafluoropropane, 1,1-dichloro-2,2-bis(4-hydroxyphenyl)ethylene, 1,1-dibromo-2,2-bis(4-hydroxyphenyl)ethylene, 1,1-dichloro-2,2-bis(5-phenoxy-4-hydroxyphenyl)ethylene, 4,4'-dihydroxybenzophenone, 3,3-bis(4-hydroxyphenyl)-2-butanone, 1,6-bis(4-hydroxyphenyl)-1,6-hexanedione, ethylene glycol bis(4-hydroxyphenyl)ether, bis(4-hydroxyphenyl)ether, bis(4-hydroxyphenyl)sulfide, bis(4-hydroxyphenyl)sulfoxide, bis(4-hydroxyphenyl)sulfone, 9,9-bis(4-hydroxyphenyl)fluorene, 6,6'-dihydroxy-3,3,3',3'-tetramethylspiro(bis)indane ("spirobiindane bisphenol"), 3,3-bis(4-hydroxyphenyl)phthalimide, 2,7-dihydroxyphenoxathin, 3,6-dihydroxydibenzofuran, 3,6-dihydroxydibenzothiophene, or 2,7-dihydroxycarbazole.

[0014] In the structure of the copolymer repeat unit above, each occurrence of X is independently



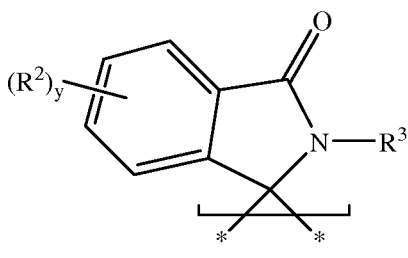
wherein each occurrence of  $y$  is independently 0, 1, 2, 3, or 4; each occurrence of  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and each occurrence of  $R^3$  is independently hydrogen, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl. In some embodiments, each occurrence of  $y$  is 0.

[0015] In some embodiments, at least one occurrence of X is

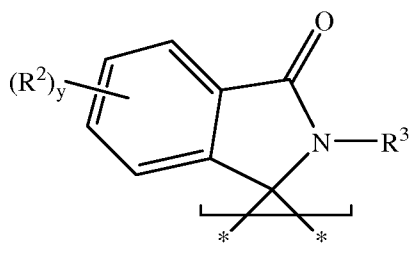


wherein each occurrence of  $y$  is independently 0, 1, 2, 3, or 4; and each occurrence of  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl. In some embodiments, each occurrence of  $y$  is 0.

[0016] In some embodiments, at least one occurrence of X is



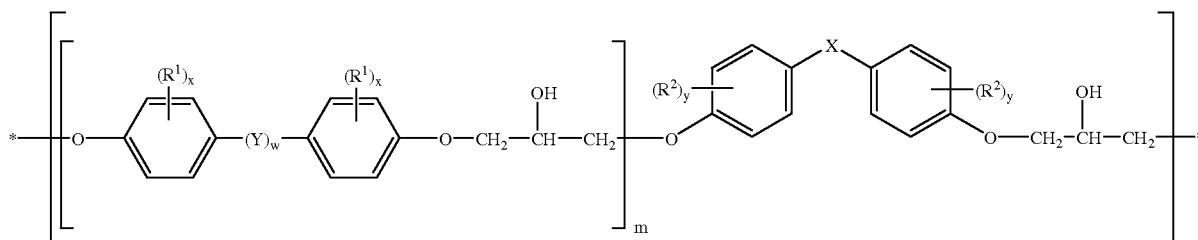
wherein each occurrence of  $y$  is independently 0, 1, 2, 3, or 4; each occurrence of  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and each occurrence of  $R^3$  is independently  $C_1$ - $C_{12}$  alkyl, or unsubstituted or substituted phenyl. In some embodiments,  $R^3$  is phenyl. In some embodiments, each occurrence of X is



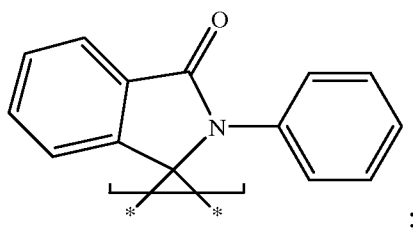
each occurrence of  $y$  is 0, and each occurrence of  $R^3$  is phenyl.

[0017] In some embodiments, the copolymer has a weight average molecular weight of 10,000 to 100,000 atomic mass units. Within this range, the weight average molecular weight can be 15,000 to 70,000 atomic mass units, specifically 20,000 to 40,000 atomic mass units. Weight average molecular weight can be determined by gel permeation chromatography using polystyrene standards.

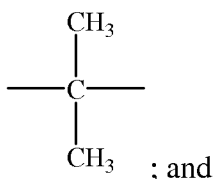
[0018] In a very specific embodiment of the copolymer comprising repeat units having the structure



the average value of  $m$  is 1.5 to 7; each occurrence of  $w$  is 1; each occurrence of  $x$  and  $y$  is 0; each occurrence of  $X$  is



each occurrence of  $Y$  is



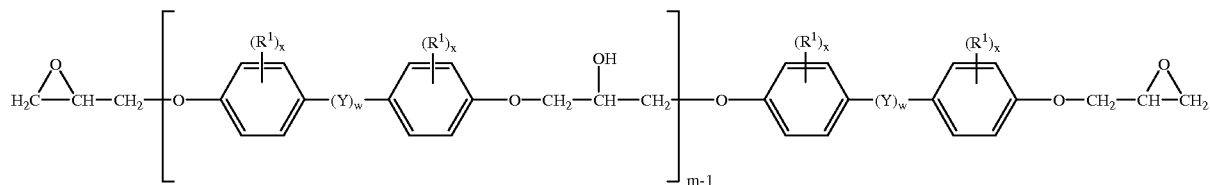
the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

[0019] The copolymer can be formed by the reaction of an oligomeric bisphenol diglycidyl ether and a phenolphthalein or phenolphthalimidine. Specifically, one method of forming a copolymer comprises: reacting (a) an oligomeric bisphenol diglycidyl ether and (b) a phenolphthalein, a phenolphthalimidine, or a combination thereof in the presence of a

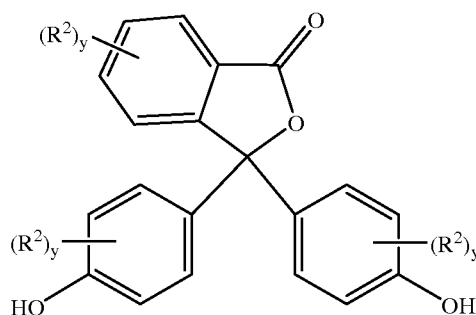


tertiary amine catalyst to form a copolymer; wherein the molar ratio of (a) an oligomeric bisphenol diglycidyl ether to (b) a phenolphthalein, a phenolphthalimidine, or a combination thereof is 0.98:1 to 1.02:1. Within the range of 0.98:1 to 1.02:1, the molar ratio of the oligomeric bisphenol diglycidyl ether to the phenolphthalein and/or phenolphthalimidine can be 0.99:1 to 1.01:1.

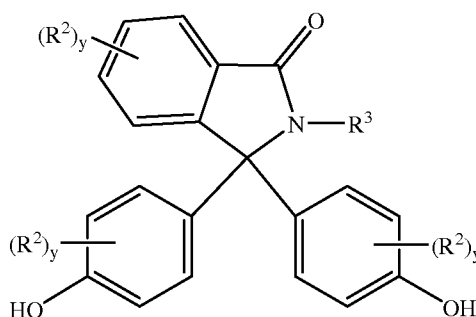
[0020] In some embodiments, the oligomeric bisphenol diglycidyl ether has the structure



wherein  $m$  is, on average, 1.2 to 10; the phenolphthalein has the structure



wherein each occurrence of  $y$  is independently 0, 1, 2, 3, or 4; and each occurrence of  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and the phenolphthalimidine has the structure



wherein  $y$  and  $R^2$  are as defined above, and  $R^3$  is independently hydrogen, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl.

[0021] Suitable tertiary amine catalysts include, for example, triethylamine, tri-*n*-propylamine, tri-*n*-butylamine, dimethylaniline, diethylaniline, alpha-methylbenzyl dimethylamine, *N,N*-dimethylaminoethanol, *N,N*-dimethylaminopyridine,

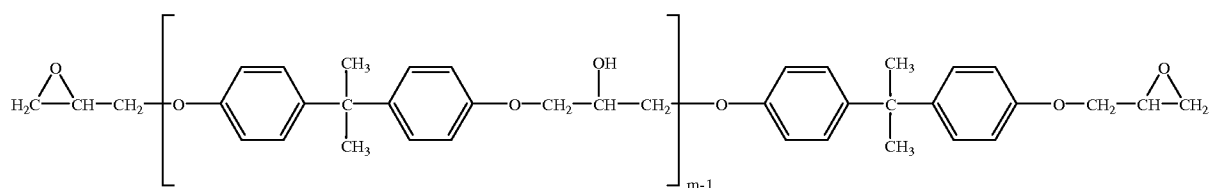
alkylimidazoles, and combinations thereof. In some embodiments, the catalyst comprises *N,N*-dimethylaminopyridine.

[0022] The reaction can be conducted in the presence of a solvent. Suitable solvents include aromatic hydrocarbons, chlorinated hydrocarbons, and polar aprotic solvents. Suitable polar aprotic solvents are ketones, esters, ethers, amides, nitriles, sulfoxides, sulfones, and combinations thereof. In some embodiments, the solvent comprises cyclohexanone.

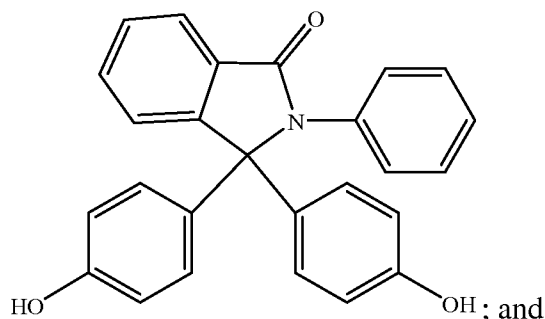
[0023] The method is capable of producing a high molecular weight copolymer. In some embodiments, the copolymer has a weight average molecular weight of 10,000 to 100,000 atomic mass units. Within this range, the weight average molecular weight can be 15,000 to 70,000, specifically 20,000 to 40,000.

[0024] In some embodiments, the oligomeric bisphenol diglycidyl ether is added to the phenolphthalein, phenolphthalimidine, or combination thereof so that there is always an excess of phenolic groups over epoxy groups in the reaction mixture. The oligomeric bisphenol diglycidyl ether can be added in portions over about 15 to about 300 minutes, specifically about 30 to about 270 minutes, more specifically about 45 to about 240 minutes, still more specifically about 60 to about 210 minutes, and even more specifically about 90 to about 180 minutes. After addition of the oligomeric bisphenol diglycidyl ether to the phenolphthalein, phenolphthalimidine, or combination thereof is complete, the mixture can be stirred for about 1 to about 12 hours at the reaction temperature. The reaction can be conducted at a temperature of about 100 to about 200 °C, specifically, about 120 to about 180 °C, more specifically, about 130 to about 170 °C, and still more specifically, about 140 to about 160 °C.

[0025] In a very specific embodiment of the method of producing the copolymer, the oligomeric bisphenol diglycidyl ether and the phenolphthalimidine are in a molar ratio of 0.99:1 to 1.01:1; the oligomeric bisphenol diglycidyl ether has the structure



wherein *m* is, on average, 1.5 to 7; the phenolphthalimidine has the structure



the copolymer has a weight average molecular weight of 20,000-40,000 atomic mass units.

[0026] The copolymer can be used to form articles, including toys, display casings, and housings for consumer electronic or office equipment.

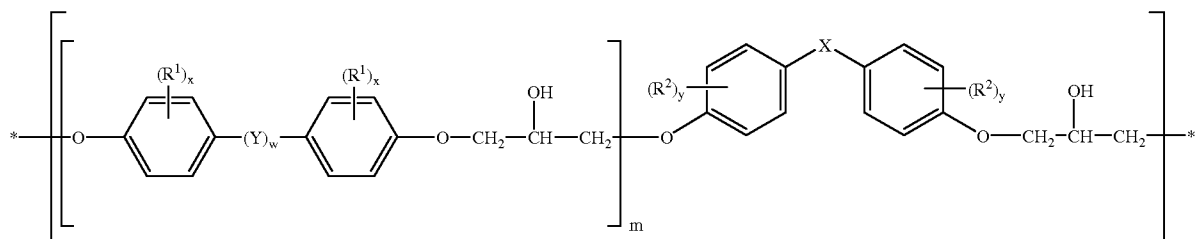
[0027] The copolymer can also be used as a flexibilizer for crosslinked phenolic and epoxy resins in adhesives, coating, and composites. Thus, one embodiment is a composition comprising 80 to 99 weight percent of a thermoset resin comprising aromatic groups, and 1 to 20 weight percent of the copolymer. All of the variations of the copolymer described above apply as well to the copolymer as a flexibilizer. Another embodiment is an article comprising the composition comprising 80 to 99 weight percent of a thermoset resin comprising aromatic groups, and 1 to 20 weight percent of the copolymer. Uses of the composition in such articles include, for example, wire coatings, printed circuit board coatings, coatings for flexible packaging, coatings for rigid packaging, can coatings, coil coatings, pipe coatings, tie layers, wood coatings, plastic coatings, and glass coatings,

[0028] The copolymer can also be used as a compatibilizer in blends of polar and non-polar polymers. Thus, one embodiment is a composition comprising, based on the total weight of the composition, 2 to 20 weight percent of the copolymer, 5 to 68 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof, and 30 to 93 weight percent of a polar polymer selected from the group consisting of cellulose esters, poly(alkyl (meth)acrylate)s, polyamides, polycarbonates, polyesters, polyetherimides, polysulfones, polyethersulfones, poly(ethylene-ethyl acrylate)s, poly(ethylene-vinyl acetate)s, polyurethanes, poly(vinyl acetate)s, poly(vinyl alcohol)s, poly(styrene-acrylonitrile)s, poly(styrene-maleic anhydride)s, poly(vinyl butyral)s, and combinations thereof. All of the variations of the copolymer described above apply as well to the copolymer as a compatibilizer.

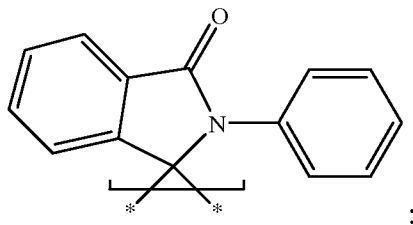
[0029] The copolymer can also be used as a compatibilizer in blends of polar fillers

and non-polar polymers. Thus, one embodiment is a composition comprising, based on the total weight of the composition, 2 to 20 weight percent of the copolymer; 30 to 93 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof; and 5 to 50 weight percent of polar filler selected from the group consisting of glass fibers, glass flakes, glass beads, clays, talcs, micas, silicas, aluminas, titanium dioxides, wollastonites, calcium carbonates, calcium sulfates, barium sulfates, dolomites, processed mineral fibers, metal oxides, metal hydroxides, ceramic fibers, and combinations thereof.

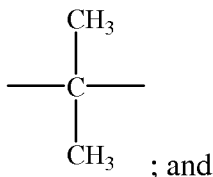
[0030] In a very specific embodiment of the article, in the copolymer comprising repeat units having the structure



the average value of m is 1.5 to 7; each occurrence of w is 1; each occurrence of x and y is 0; each occurrence of X is



each occurrence of Y is

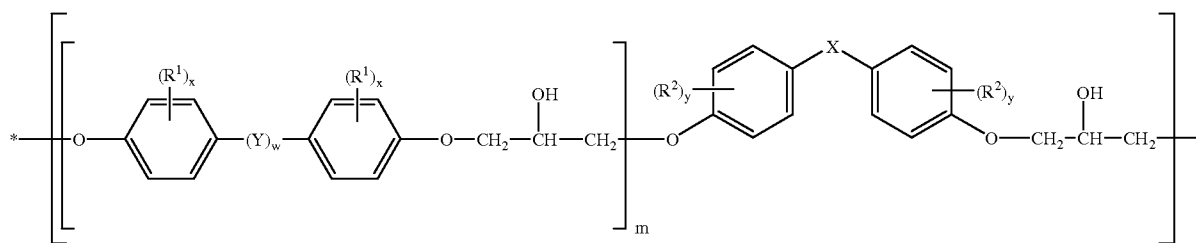


the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

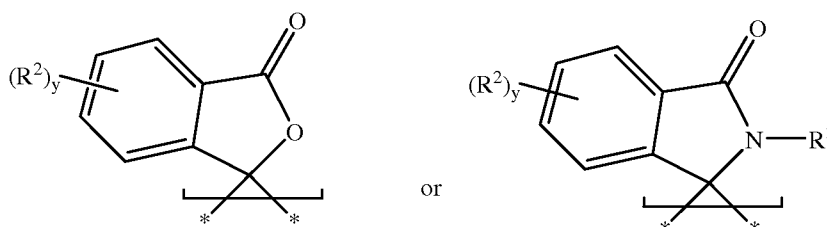
[0031] All ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. Each range disclosed herein constitutes a disclosure of any point or sub-range lying within the disclosed range.

[0032] The invention includes at least the following embodiments.

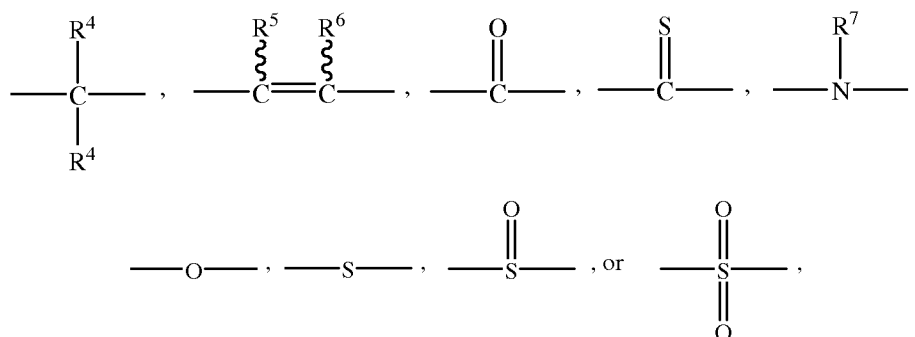
[0033] Embodiment 1: A copolymer comprising repeat units having the structure



wherein the average value of m is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



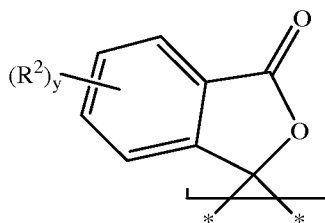
wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

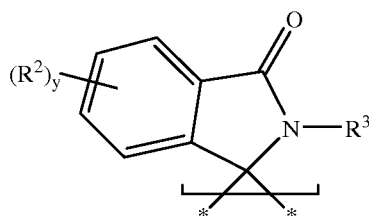
[0034] Embodiment 2: The copolymer of embodiment 1, wherein the average value of m is 1.5 to 7 for the copolymer.

[0035] Embodiment 3: The copolymer of embodiment 1 or 2, wherein each occurrence of X is



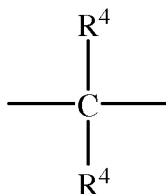
wherein  $y$  and  $R^2$  are as defined in embodiment 1.

[0036] Embodiment 4: The copolymer of embodiment 1 or 2, wherein each occurrence of X is



wherein  $y$ ,  $R^2$ , and  $R^3$  are as defined in embodiment 1.

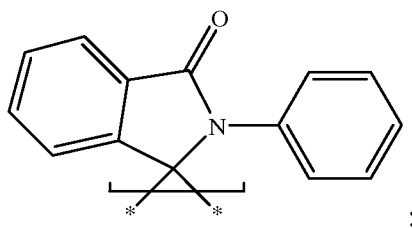
[0037] Embodiment 5: The copolymer of any of embodiments 1-4, wherein each occurrence of  $w$  is 1, and each occurrence of Y is



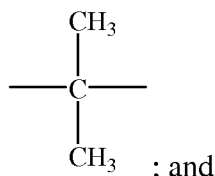
wherein  $R^4$  is as defined in embodiment 1.

[0038] Embodiment 6: The copolymer of any of embodiments 1-5, having a weight average molecular weight of 10,000 to 100,000 atomic mass units.

[0039] Embodiment 7: The copolymer of embodiment 1, wherein the average value of  $m$  is 1.5 to 7; each occurrence of  $w$  is 1; each occurrence of  $x$  and  $y$  is 0; each occurrence of X is



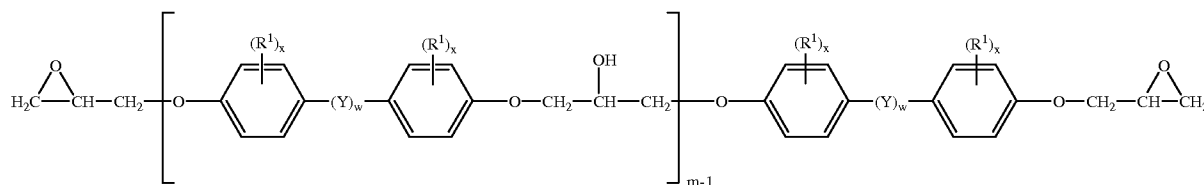
each occurrence of Y is



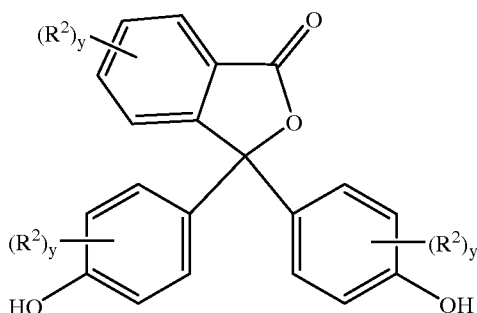
the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

[0040] Embodiment 8: A method of forming a copolymer, the method comprising: reacting an oligomeric bisphenol diglycidyl ether and a phenolphthalein, a phenolphthalimidine, or a combination thereof in a molar ratio of 0.98:1 to 1.02:1 in the presence of a tertiary amine catalyst to form a copolymer.

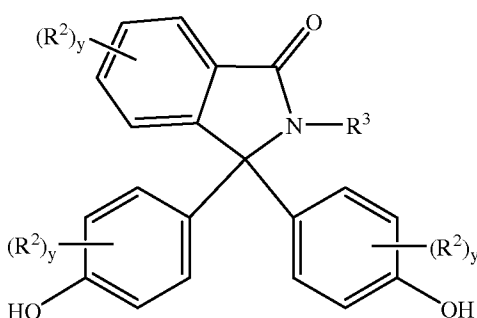
[0041] Embodiment 9: The method of embodiment 8, wherein the oligomeric bisphenol diglycidyl ether has the structure



wherein  $m$  is, on average, 1.2 to 10; the phenolphthalein has the structure



wherein each occurrence of  $y$  is independently 0, 1, 2, 3, or 4; and each occurrence of  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and the phenolphthalimidine has the structure



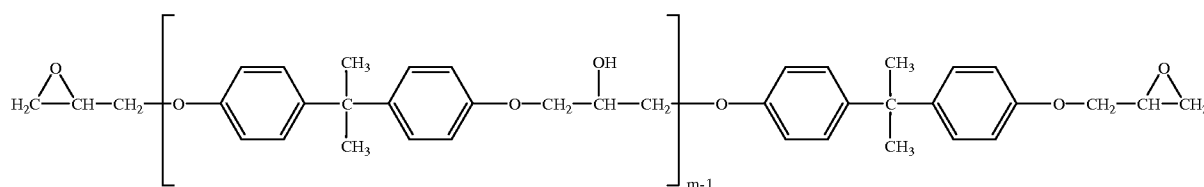
wherein  $y$  and  $R^2$  are as defined above, and  $R^3$  is independently hydrogen, or unsubstituted or

substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

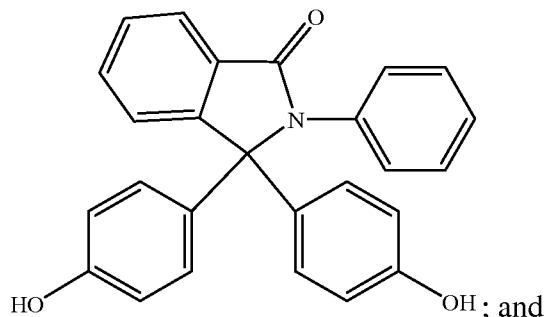
[0042] Embodiment 10: The method of embodiment 8 or 9, wherein the tertiary amine catalyst comprises triethylamine, tri-*n*-propylamine, tri-*n*-butylamine, dimethylaniline, diethylaniline, alpha-methylbenzyltrimethylammonium, *N,N*-dimethylaminoethanol, *N,N*-dimethylaminopyridine, alkylimidazoles, or a combination thereof.

[0043] Embodiment 11: The method of any of embodiments 8-10, having a weight average molecular weight of 10,000 to 100,000 atomic mass units.

[0044] Embodiment 12: The method of embodiment 8, wherein said reacting comprises reacting the oligomeric bisphenol diglycidyl ether and the phenolphthalimidine in a molar ratio of 0.99:1 to 1.01:1; wherein the oligomeric bisphenol diglycidyl ether has the structure

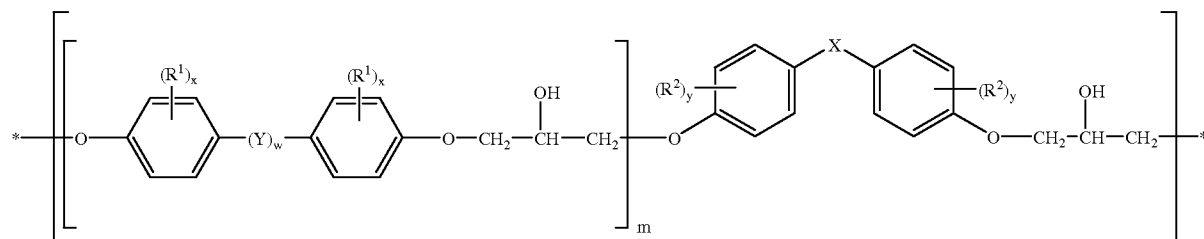


wherein *m* is, on average, 1.5 to 7; wherein the phenolphthalimidine has the structure



wherein the copolymer has a weight average molecular weight of 20,000-40,000 atomic mass units.

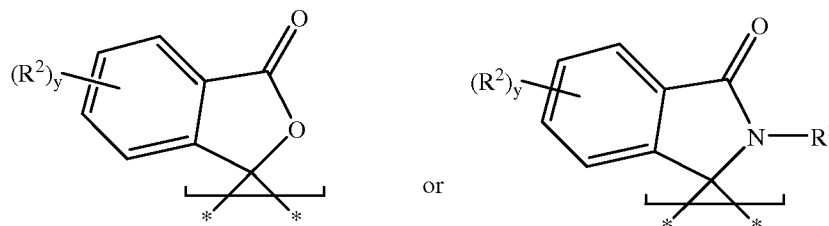
[0045] Embodiment 13: An article, comprising a copolymer comprising repeat units having the structure



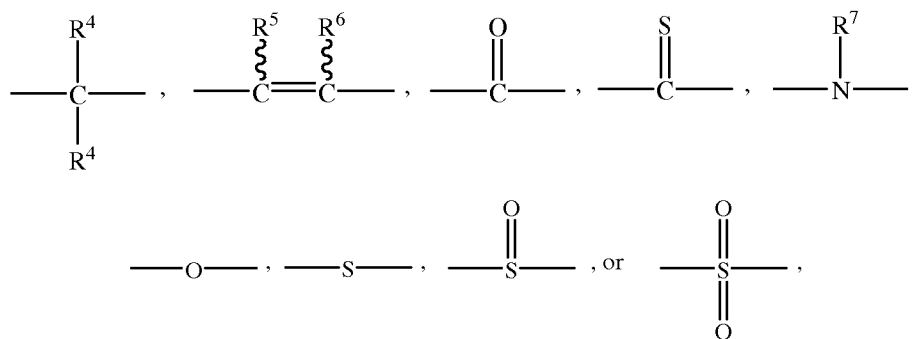
wherein the average value of *m* is 1.2 to 10 for the copolymer; each occurrence of *w* is independently 0 or 1; each occurrence of *x* and *y* is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub>



hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



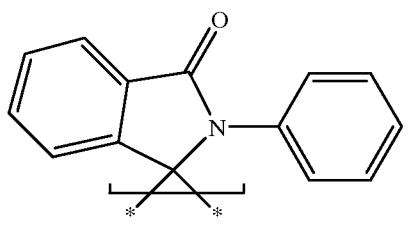
wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



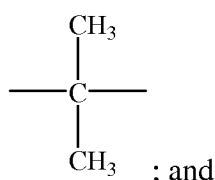
wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

[0046] Embodiment 14: The article of embodiment 13, wherein the article is a toy, a display casing, or a housing for consumer electronic or office equipment.

[0047] Embodiment 15: The article of embodiment 13 or 14, wherein the average value of m is 1.5 to 7; each occurrence of w is 1; each occurrence of x and y is 0; each occurrence of X is

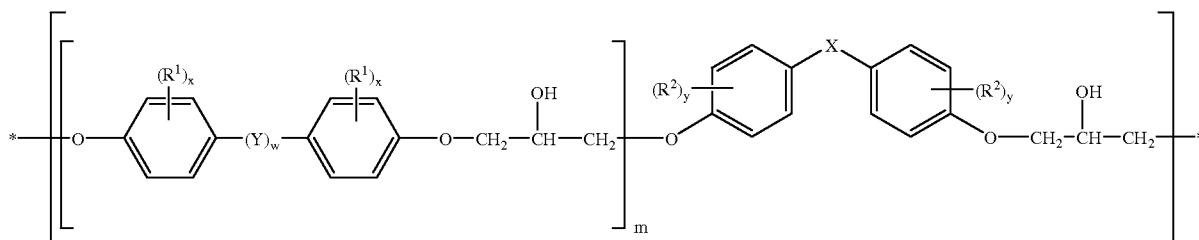


R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of Y is

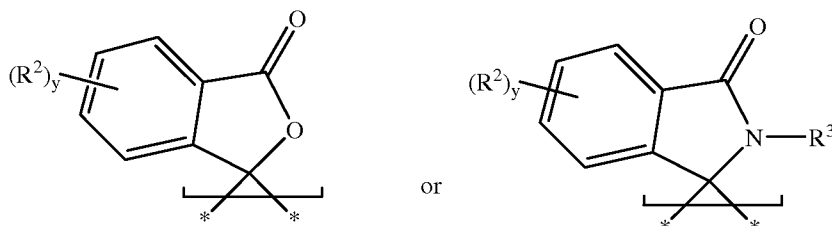


the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

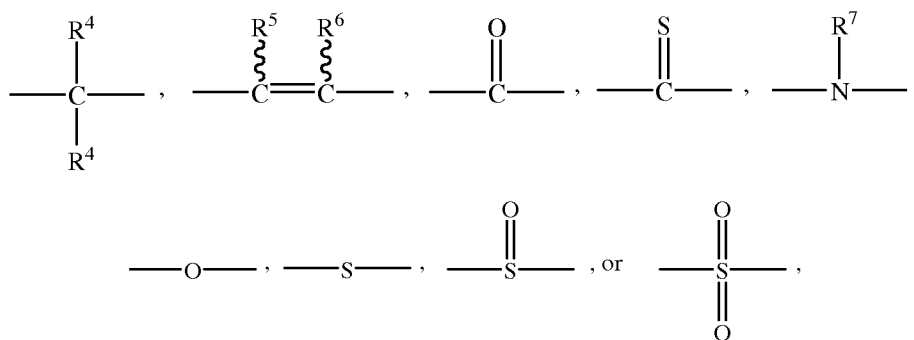
[0048] Embodiment 16: A composition comprising, based on the total weight of the composition: 80 to 99 weight percent of a thermoset resin comprising aromatic groups; and 1 to 20 weight percent of a copolymer comprising repeat units having the structure



wherein the average value of m is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



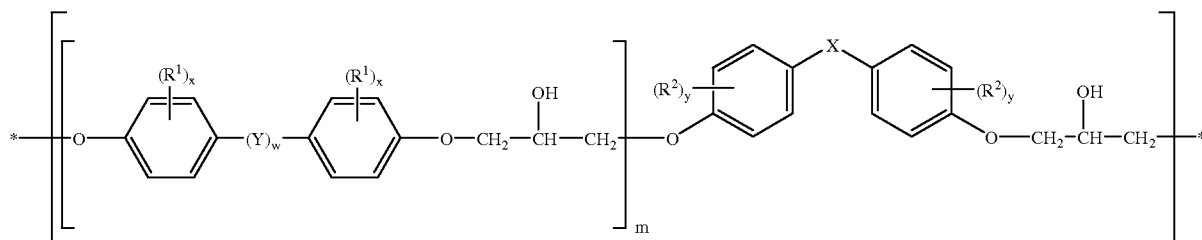
wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



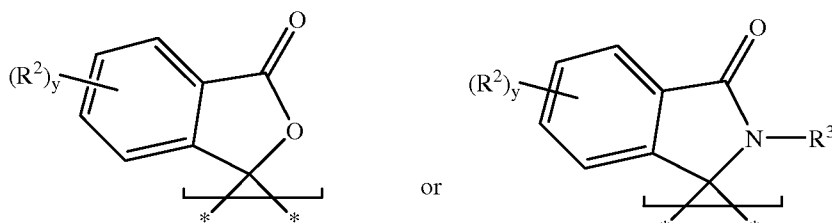
wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

[0049] Embodiment 17: A composition comprising, based on the total weight of the composition: 5 to 68 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and

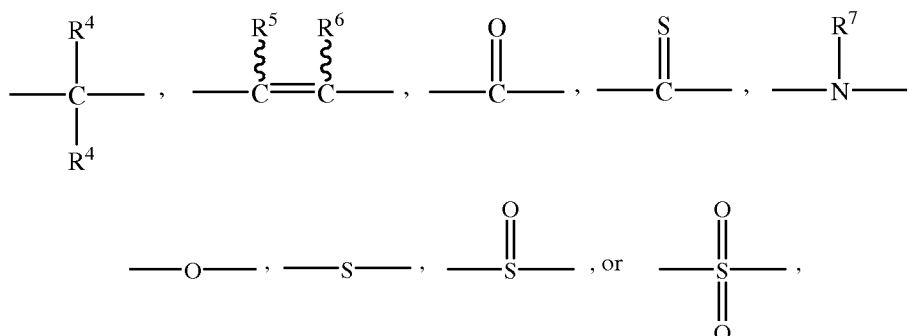
conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof; 30 to 93 weight percent of a polar polymer selected from the group consisting of cellulose esters, poly(alkyl (meth)acrylate)s, polyamides, polycarbonates, polyesters, polyetherimides, polysulfones, polyethersulfones, poly(ethylene-ethyl acrylate)s, poly(ethylene-vinyl acetate)s, polyurethanes, poly(vinyl acetate)s, poly(vinyl alcohol)s, poly(styrene-acrylonitrile)s, poly(styrene-maleic anhydride)s, poly(vinyl butyral)s, and combinations thereof; and 2 to 20 weight percent of a copolymer comprising repeat units having the structure



wherein the average value of m is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently

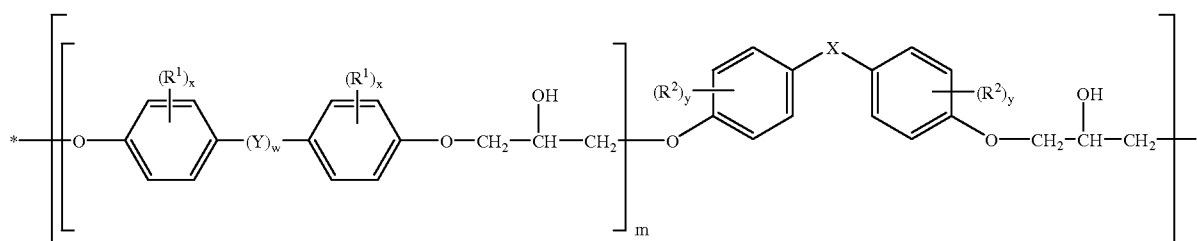


wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently

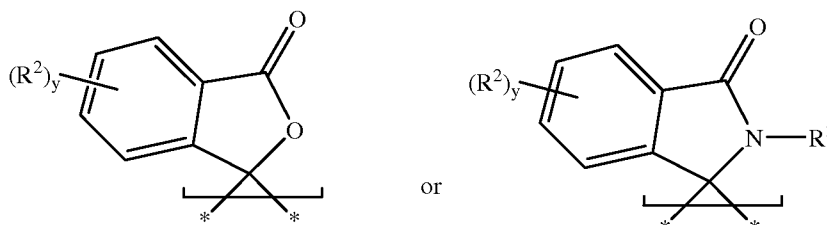


wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

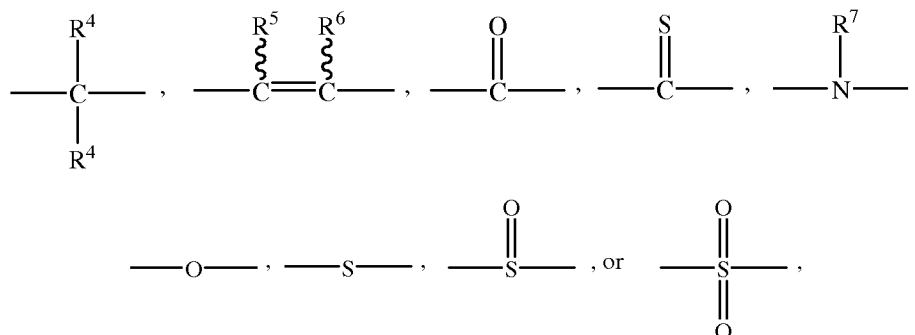
[0050] Embodiment 18: A composition comprising, based on the total weight of the composition: 30 to 93 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof; 5 to 50 weight percent of polar filler selected from the group consisting of glass fibers, glass flakes, glass beads, clays, talcs, micas, silicas, aluminas, titanium dioxides, wollastonites, calcium carbonates, calcium sulfates, barium sulfates, dolomites, processed mineral fibers, metal oxides, metal hydroxides, ceramic fibers, and combinations thereof; and 2 to 20 weight percent of a copolymer comprising repeat units having the structure



wherein the average value of m is 1.2 to 10 for the copolymer; each occurrence of w is independently 0 or 1; each occurrence of x and y is independently 0, 1, 2, 3, or 4; each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; each occurrence of X is independently



wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

[0051] The invention is further illustrated by the following non-limiting examples.

#### EXAMPLE 1

[0052] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 11.6 weight percent PPPBP hydroxy ether repeat units. N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine having a purity of 99.909% as determined by HPLC was obtained from Shirdi Chemical PVT. Ltd. and used as received. The diglycidyl ether of bisphenol A was obtained as DER<sup>TM</sup> 667E from Dow. The monomer characteristics and amounts are summarized in Table 1, where "HEW" stands for hydroxyl equivalent weight in units of grams per equivalent, "EEW" stands for epoxy equivalent weight in units of grams per equivalent.

Table 1

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalents
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	25.32	0.1289
Diglycidyl ether of bisphenol A	DER <sup>TM</sup> 667E	--	1774	224.68	0.1288

[0053] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 2.

Table 2

Time (min)	PPPBP (wt%)
0	48.96
30	20.03
60	13.35
90	8.90

120	7.12
150	1.64

[0054] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 235 grams (94% yield).

#### EXAMPLE 2

[0055] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 21.4 weight percent PPPBP hydroxy ether repeat units. The diglycidyl ether of bisphenol A was obtained as EPON™ 1004F from Momentive. The monomer characteristics and amounts are summarized in Table 3.

Table 3

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalent
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	46.81	0.23822
Diglycidyl ether of bisphenol A	EPON™ 1004F	--	853	203.19	0.23821

[0056] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 4.

Table 4

Time (min)	PPPBP (wt%)
0	54.14
30	19.69
60	12.30
90	7.38

120	4.92
150	1.57

[0057] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 239 grams (95.6% yield).

#### EXAMPLE 3

[0058] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 31.0 weight percent PPPBP hydroxy ether repeat units. The diglycidyl ether of bisphenol A was obtained as EPON™ 1001F from Momentive. The monomer identities and amounts are summarized in Table 5.

Table 5

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalent
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	67.81	0.34509
Diglycidyl ether of bisphenol A	EPON™ 1001F	--	528	182.19	0.34506

[0059] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 4.

Table 6

Time (min)	PPPBP (wt%)
0	54.89
30	21.95
60	13.72
90	7.14

120	1.65
150	0.65

[0060] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 229 grams (91.6% yield).

#### EXAMPLE 4

[0061] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 14.4 weight percent PPPBP hydroxy ether repeat units. The diglycidyl ether of bisphenol A was obtained as DER<sup>TM</sup> 6155 from Dow. The monomer identities and amounts are summarized in Table 7.

Table 7

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalent
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	31.47	0.16015
Diglycidyl ether of bisphenol A	DER <sup>TM</sup> 6155	--	1365	218.53	0.16010

[0062] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 8.

Table 8

Time (min)	PPPBP (wt%)
0	50.33
30	25.17
60	11.44
90	7.78



120	4.58
150	0.70

[0063] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 234 grams (93.6% yield).

#### EXAMPLE 5

[0064] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 21.4 weight percent PPPBP hydroxy ether repeat units. The diglycidyl ether of bisphenol A was obtained as EPON™ 1004F from Momentive. The monomer identities and amounts are summarized in Table 9. Example 5 is similar to Example 2, except that Example 5 uses different monomer amounts and addition times.

Table 9

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalents
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	46.93	0.23883
Diglycidyl ether of bisphenol A	EPON™ 1004F	--	853	203.69	0.23879

[0065] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 10.

Table 10

Time (min)	PPPBP (wt%)
0	54.13
30	22.15
60	12.30

90	7.38
120	3.45
150	0.59

[0066] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 227 grams (90.6% yield).

#### EXAMPLE 6

[0067] This example illustrates the synthesis of a poly(hydroxy ether) copolymer with 21.4 weight percent PPPBP hydroxy ether repeat units. The diglycidyl ether of bisphenol A was obtained as EPON™ 1004F from Momentive. The monomer identities and amounts are summarized in Table 11. Example 6 is similar to Example 3, except that Example 6 uses different monomer amounts and addition times.

Table 11

Monomer	Designation	HEW (g/eq.)	EEW (g/eq.)	Grams	Equivalents
N-Phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine	PPPBP	196.5	--	67.94	0.34575
Diglycidyl ether of bisphenol A	EPON™ 1001F	--	528	182.52	0.34568

[0068] To a one liter, three-necked, roundbottom flask equipped with a mechanical stirrer, thermocouple probe, powder funnel, and heating mantel was added 250 milliliters cyclohexanone, which was heated to 150°C. The PPPBP was added and dissolved. Then 2.5 grams (0.0205 moles) of N,N-dimethylaminopyridine (DMAP) was added and dissolved. The epoxy resin was added in portions over 150 minutes, approximately following the guidelines in Table 12.

Table 12

Time (min)	PPPBP (wt%)
0	54.34
30	22.50

60	13.17
90	7.68
120	1.66
150	0.65

[0069] The solution was stirred for 7 hours at 150°C. The reaction mixture was cooled below 80°C and diluted with 200 milliliters 2-butanone. The reaction product was isolated by precipitation in methanol, filtered, washed with methanol, and dried in a vacuum oven at 100°C. The weight of the material was 238 grams (95% yield).

#### CHARACTERIZATION OF POLYHYDROXYETHERS

[0070] Comparative Example 1 was a copolymer of bisphenol A and bisphenol A diglycidyl ether, obtained as InChemRez™ PKHC Phenoxy Resin. Characterization of the Examples 1-5 and Comparative Example 1 is summarized in Table 13, where PPPBP PHE (wt%) is the weight percent of PPPBP poly(hydroxy ether) repeat units based on the total weight of the copolymer; “T<sub>g</sub> (°C)” is the glass transition temperature in degrees centigrade; “M<sub>w</sub> (AMU)” is the weight average molecular weight in atomic mass units; “M<sub>n</sub> (AMU)” is the number average molecular weight in atomic mass units; and “M<sub>w</sub>/M<sub>n</sub>” is the polydispersity. All copolymers exhibited single glass transition temperatures by Differential Scanning Calorimetry (DSC). The glass transition temperatures increase with increased content of PPPBP. Glass transition temperature (T<sub>g</sub>) was measured by differential scanning calorimetry (DSC) according to ASTM D3418-08. Number average molecular weight (M<sub>n</sub>), weight average molecular weight (M<sub>w</sub>), and polydispersity (M<sub>w</sub>/M<sub>n</sub>) were determined by gel permeation chromatography (GPC) using polystyrene standards on an Agilent 1100 Series HPLC System with two Phenomenex PHENOGEL™ 5μ Linear columns and a UV detector. Chloroform with 50 parts per million by weight dibutylamine was the eluent. The injection volume was 50 microliters.

[0071] The higher glass transition temperatures for phthalimidine bisphenol poly(hydroxy ether) copolymers relative to bisphenol A poly(hydroxy ether) copolymers will allow them to be used at substantially higher temperatures in applications including molded articles, adhesives, coatings, and thermosets.

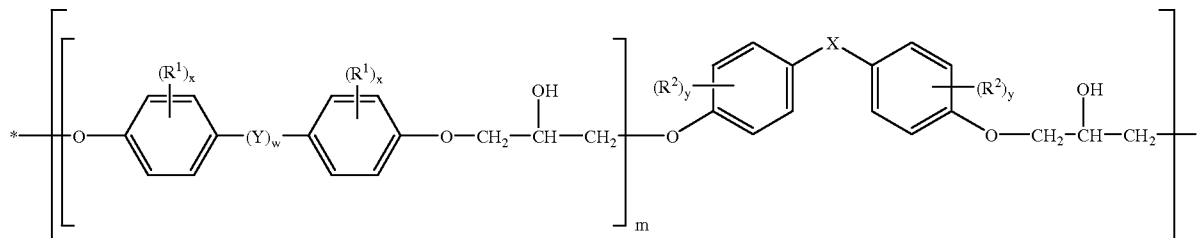
Table 13

	PPPBP PHE (wt%)	T <sub>g</sub> (°C)	M <sub>w</sub> (AMU)	M <sub>n</sub> (AMU)	M <sub>w</sub> /M <sub>n</sub>
C. Ex. 1	0	90	52000	10200	5.10

Ex. 1	11.6	117	26700	7200	3.71
Ex. 2	21.4	128	28300	7530	3.76
Ex. 3	31.0	137	30450	7870	3.87
Ex. 4	14.4	124	30990	8330	3.72
Ex. 5	21.4	131	32800	8620	3.81
Ex. 6	31.0	140	35990	9100	3.96

## CLAIMS

1. A copolymer comprising repeat units having the structure



wherein

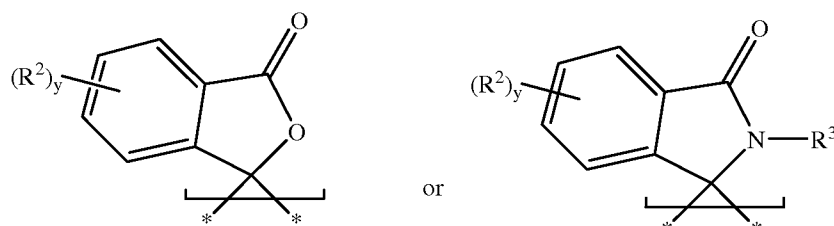
the average value of  $m$  is 1.2 to 10 for the copolymer;

each occurrence of  $w$  is independently 0 or 1;

each occurrence of  $x$  and  $y$  is independently 0, 1, 2, 3, or 4;

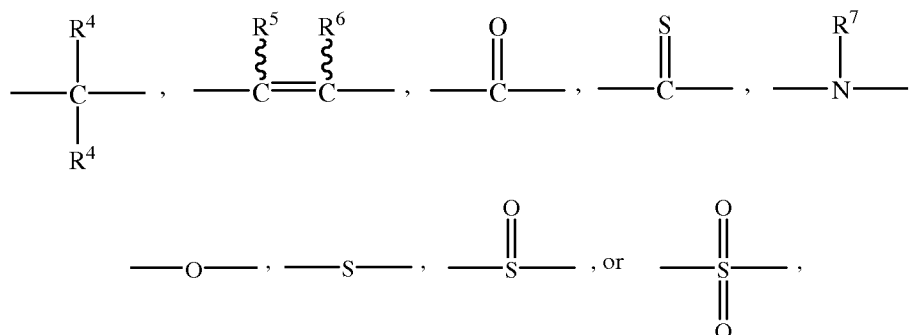
each occurrence of  $R^1$  and  $R^2$  is independently halogen,  $C_1$ - $C_{12}$  hydrocarbylthio,  $C_1$ - $C_{12}$  hydrocarbyloxy,  $C_2$ - $C_{12}$  halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl;

each occurrence of  $X$  is independently



wherein  $y$  and  $R^2$  are defined above, and each occurrence of  $R^3$  is independently hydrogen, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and

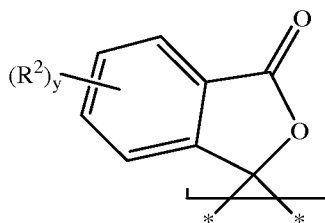
each occurrence of  $Y$  is independently



wherein each occurrence of  $R^4$ ,  $R^5$ ,  $R^6$ , and  $R^7$  is independently hydrogen or an unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl.

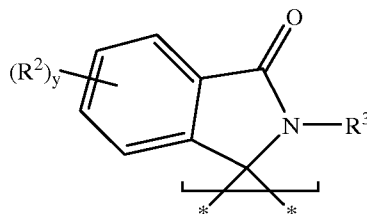
2. The copolymer of claim 1, wherein the average value of  $m$  is 1.5 to 7 for the copolymer.

3. The copolymer of claim 1, wherein each occurrence of  $X$  is



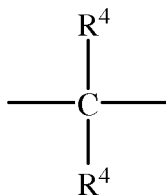
wherein  $y$  and  $R^2$  are as defined in claim 1.

4. The copolymer of claim 1, wherein each occurrence of X is



wherein  $y$ ,  $R^2$ , and  $R^3$  are as defined in claim 1.

5. The copolymer of claim 1, wherein each occurrence of  $w$  is 1, and each occurrence of Y is



wherein  $R^4$  is as defined in claim 1.

6. The copolymer of any of claims 1-5, having a weight average molecular weight of 10,000 to 100,000 atomic mass units.

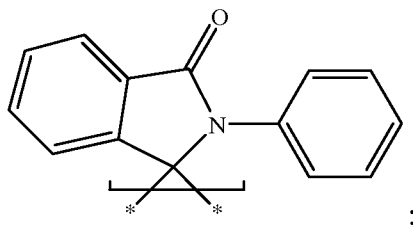
7. The copolymer of claim 1, wherein

the average value of  $m$  is 1.5 to 7;

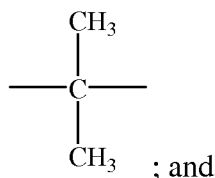
each occurrence of  $w$  is 1;

each occurrence of  $x$  and  $y$  is 0;

each occurrence of X is



each occurrence of Y is



the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

8. A method of forming a copolymer, the method comprising:

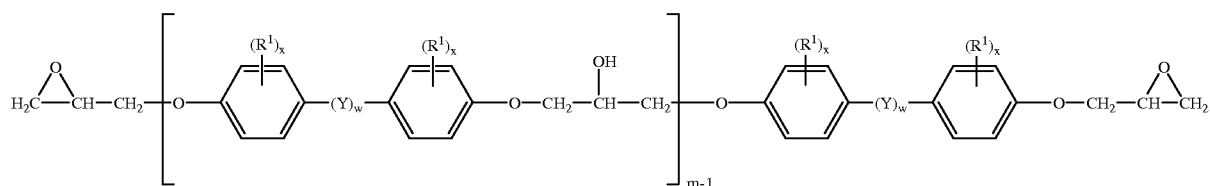
reacting

an oligomeric bisphenol diglycidyl ether and

a phenolphthalein, a phenolphthalimidine, or a combination thereof

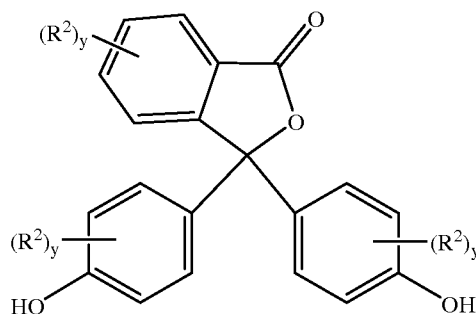
in a molar ratio of 0.98:1 to 1.02:1 in the presence of a tertiary amine catalyst to form a copolymer.

9. The method of claim 8, wherein the oligomeric bisphenol diglycidyl ether has the structure



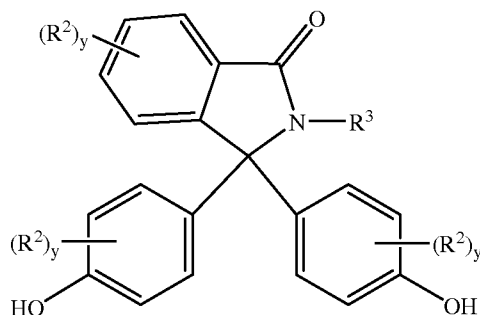
wherein m is, on average, 1.2 to 10;

the phenolphthalein has the structure



wherein each occurrence of y is independently 0, 1, 2, 3, or 4; and each occurrence of R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and

the phenolphthalimidine has the structure



wherein  $y$  and  $R^2$  are as defined above, and  $R^3$  is independently hydrogen, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl.

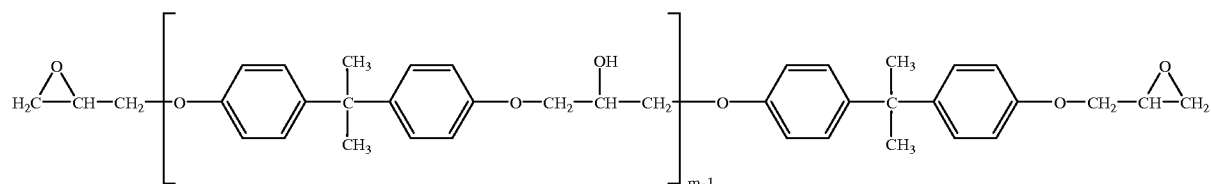
10. The method of claim 8, wherein the tertiary amine catalyst comprises triethylamine, tri-*n*-propylamine, tri-*n*-butylamine, dimethylaniline, diethylaniline, alpha-methylbenzylidimethylamine, *N,N*-dimethylaminoethanol, *N,N*-dimethylaminopyridine, alkyimidazoles, or a combination thereof.

11. The method of any of claims 8-10, having a weight average molecular weight of 10,000 to 100,000 atomic mass units.

12. The method of claim 8,

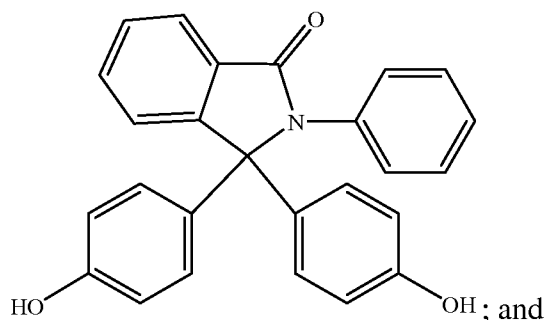
wherein said reacting comprises reacting the oligomeric bisphenol diglycidyl ether and the phenolphthalimidine in a molar ratio of 0.99:1 to 1.01:1;

wherein the oligomeric bisphenol diglycidyl ether has the structure



wherein  $m$  is, on average, 1.5 to 7;

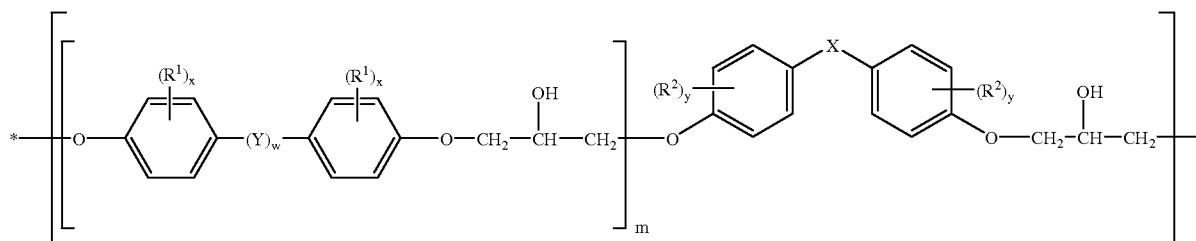
wherein the phenolphthalimidine has the structure



wherein the copolymer has a weight average molecular weight of 20,000-40,000 atomic mass units.

13. An article, comprising a copolymer comprising repeat units having the structure





wherein

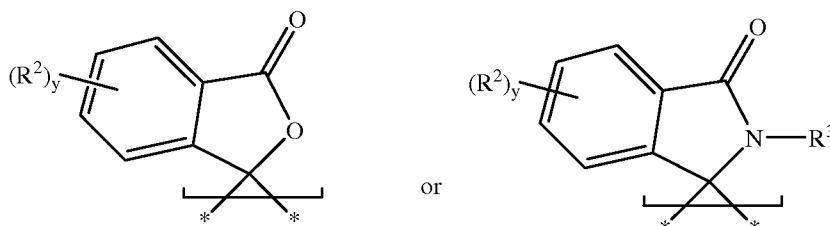
the average value of m is 1.2 to 10 for the copolymer;

each occurrence of w is independently 0 or 1;

each occurrence of x and y is independently 0, 1, 2, 3, or 4;

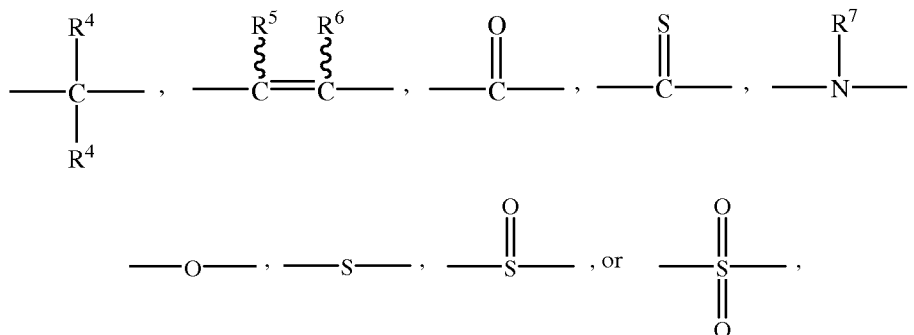
each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl;

each occurrence of X is independently



wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and

each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

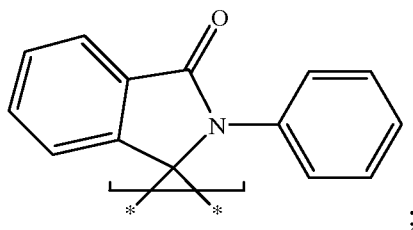
14. The article of claim 13, wherein the article is a toy, a display casing, or a housing for consumer electronic or office equipment.

15. The article of claim 13 or 14,

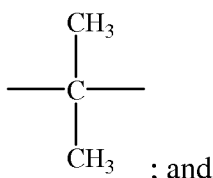
wherein

the average value of m is 1.5 to 7;

each occurrence of w is 1;  
 each occurrence of x and y is 0;  
 each occurrence of X is

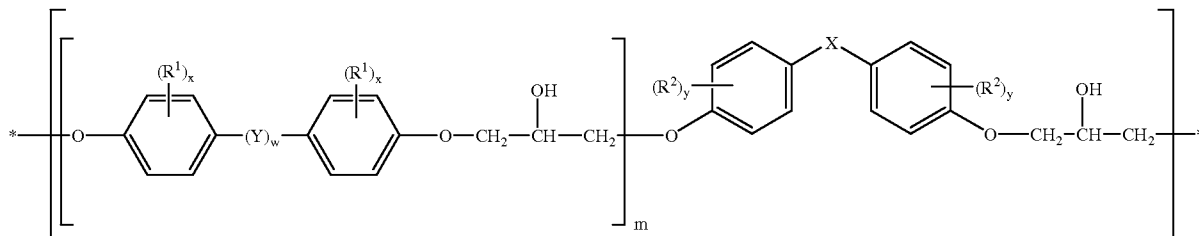


R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl;  
 each occurrence of Y is



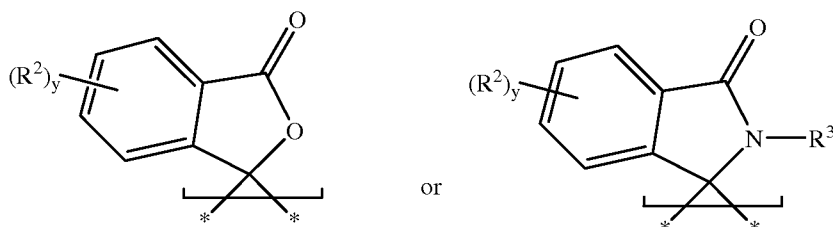
the copolymer has a weight average molecular weight of 20,000 to 40,000 atomic mass units.

16. A composition comprising, based on the total weight of the composition:  
 80 to 99 weight percent of a thermoset resin comprising aromatic groups; and  
 1 to 20 weight percent of a copolymer comprising repeat units having the structure



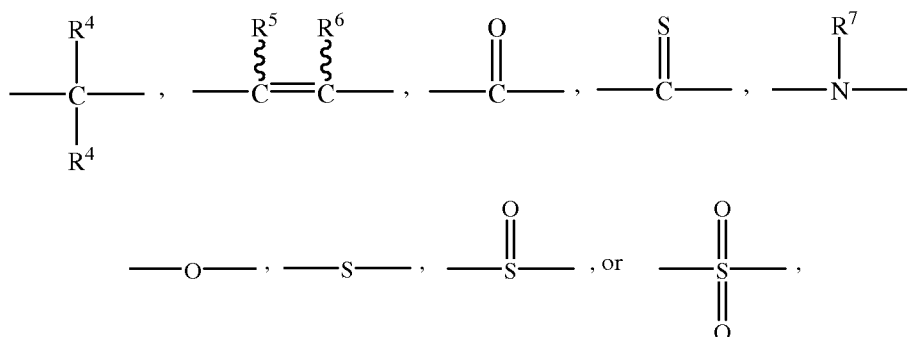
wherein

the average value of m is 1.2 to 10 for the copolymer;  
 each occurrence of w is independently 0 or 1;  
 each occurrence of x and y is independently 0, 1, 2, 3, or 4;  
 each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl;  
 each occurrence of X is independently



wherein  $y$  and  $R^2$  are defined above, and each occurrence of  $R^3$  is independently hydrogen, or unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl; and

each occurrence of  $Y$  is independently



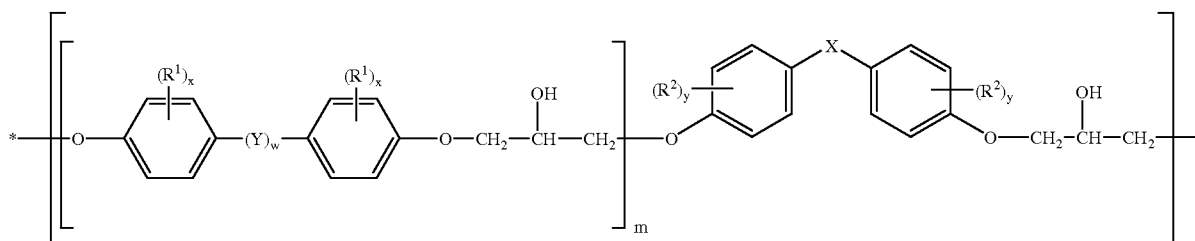
wherein each occurrence of  $R^4$ ,  $R^5$ ,  $R^6$ , and  $R^7$  is independently hydrogen or an unsubstituted or substituted  $C_1$ - $C_{12}$  hydrocarbyl.

17. A composition comprising, based on the total weight of the composition:

5 to 68 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof;

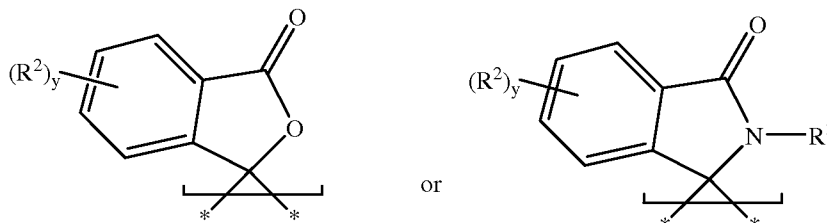
30 to 93 weight percent of a polar polymer selected from the group consisting of cellulose esters, poly(alkyl (meth)acrylate)s, polyamides, polycarbonates, polyesters, polyetherimides, polysulfones, polyethersulfones, poly(ethylene-ethyl acrylate)s, poly(ethylene-vinyl acetate)s, polyurethanes, poly(vinyl acetate)s, poly(vinyl alcohol)s, poly(styrene-acrylonitrile)s, poly(styrene-maleic anhydride)s, poly(vinyl butyral)s, and combinations thereof; and

2 to 20 weight percent of a copolymer comprising repeat units having the structure

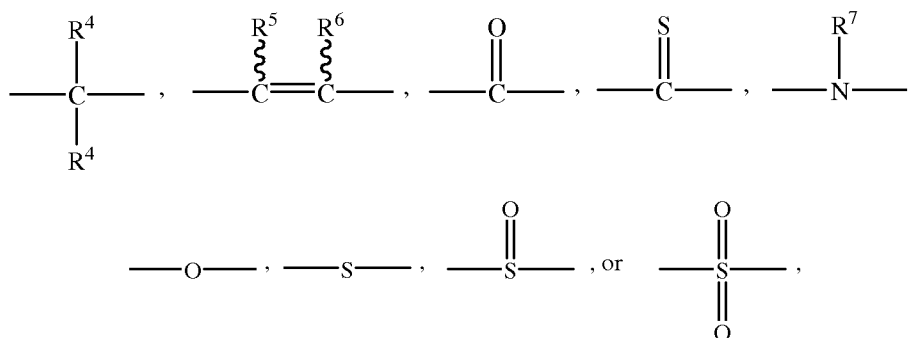


wherein

the average value of m is 1.2 to 10 for the copolymer;  
 each occurrence of w is independently 0 or 1;  
 each occurrence of x and y is independently 0, 1, 2, 3, or 4;  
 each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halohydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl;  
 each occurrence of X is independently

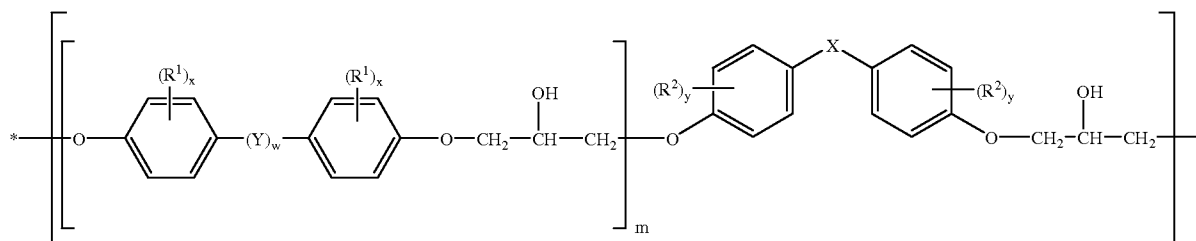


wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and  
 each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

18. A composition comprising, based on the total weight of the composition:
  - 30 to 93 weight percent of a non-polar polymer selected from the group consisting of unhydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, hydrogenated block copolymers of alkenyl aromatic compounds and conjugated dienes, poly(alkenyl aromatic)s, poly(phenylene ether)s, and combinations thereof;
  - 5 to 50 weight percent of polar filler selected from the group consisting of glass fibers, glass flakes, glass beads, clays, talcs, micas, silicas, aluminas, titanium dioxides, wollastonites, calcium carbonates, calcium sulfates, barium sulfates, dolomites, processed mineral fibers, metal oxides, metal hydroxides, ceramic fibers, and combinations thereof; and
  - 2 to 20 weight percent of a copolymer comprising repeat units having the structure



wherein

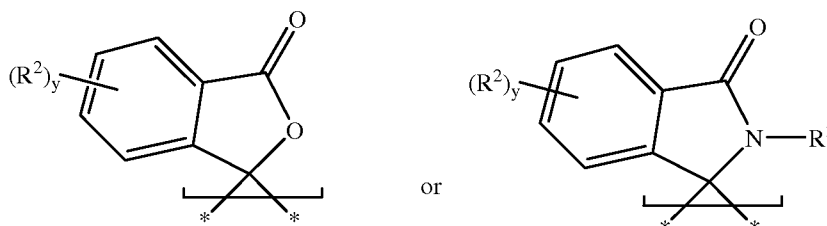
the average value of m is 1.2 to 10 for the copolymer;

each occurrence of w is independently 0 or 1;

each occurrence of x and y is independently 0, 1, 2, 3, or 4;

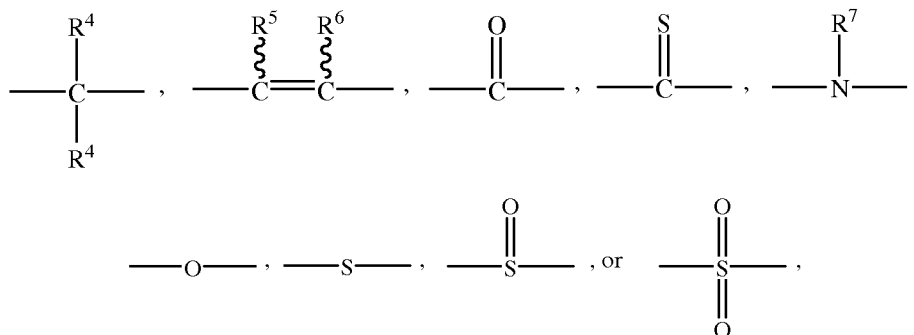
each occurrence of R<sup>1</sup> and R<sup>2</sup> is independently halogen, C<sub>1</sub>-C<sub>12</sub> hydrocarbylthio, C<sub>1</sub>-C<sub>12</sub> hydrocarbyloxy, C<sub>2</sub>-C<sub>12</sub> halo-hydrocarbyloxy wherein at least two carbon atoms separate the halogen and oxygen atoms, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl;

each occurrence of X is independently



wherein y and R<sup>2</sup> are defined above, and each occurrence of R<sup>3</sup> is independently hydrogen, or unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl; and

each occurrence of Y is independently



wherein each occurrence of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, and R<sup>7</sup> is independently hydrogen or an unsubstituted or substituted C<sub>1</sub>-C<sub>12</sub> hydrocarbyl.

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2015/010221****A. CLASSIFICATION OF SUBJECT MATTER****C08G 65/40(2006.01)i, C08G 65/48(2006.01)i, C08G 59/22(2006.01)i, C08G 59/50(2006.01)i, C08G 73/06(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

C08G 65/40; C08G 64/00; C08L 69/00; C08L 71/10; C08K 7/14; B65B 55/00; C08G 65/48; C08G 59/22; C08G 59/50; C08G 73/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords: copolymer, phenolphthalein, phenolphthalimidine, oligomeric, bisphenol diglycidyl ether, glass transition temperature

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5814373 A (WHITE, JERRY E. et al.) 29 September 1998 See abstract; column 1, lines 54-56, column 5, line 16 - column 6, line 35, column 10, lines 1-5; claims 1-3; and table I.	1-16
Y		17, 18
Y	US 2012-0329939 A1 (PETERS, EDWARD NORMAN) 27 December 2012 See abstract; paragraphs [0002]-[0006], [0040], [0044] and [0052]-[0061]; and claims 1-34.	17, 18
A		1-16
A	SHIH, WEG-CHANG et al. 'Synthesis and characterization of phenoxy resins prepared from diglycidyl ether of bisphenol A and various aromatic dihydroxyl monomers.' Journal of Applied Polymer Science, 1999, Vol. 73, No. 12, pp. 2369-2376 See abstract; page 2370; and tables I and II.	1-18
A	US 2007-0123686 A1 (MAHOOD, JAMES A. et al.) 31 May 2007 See abstract; paragraphs [0002], [0014]-[0016], [0034] and [0047]-[0067]; and claims 1-21.	1-18

 Further documents are listed in the continuation of Box C. See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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Date of the actual completion of the international search

27 March 2015 (27.03.2015)

Date of mailing of the international search report

**27 March 2015 (27.03.2015)**

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**INTERNATIONAL SEARCH REPORT**

International application No.

**PCT/US2015/010221**

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