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[Continued on next page]

(54) Title: INTERFACIAL PROCESSES FOR PREPARING PHOTOACTIVE ADDITIVES

(57) Abstract: Different interfacial processes for producing photoactive additives are disclosed. Generally, the photoactive additives are formed from a photoactive moiety, a first linker moiety, and a diol chain extender. The resulting additives can be crosslinked with other polymers upon exposure to UV radiation.

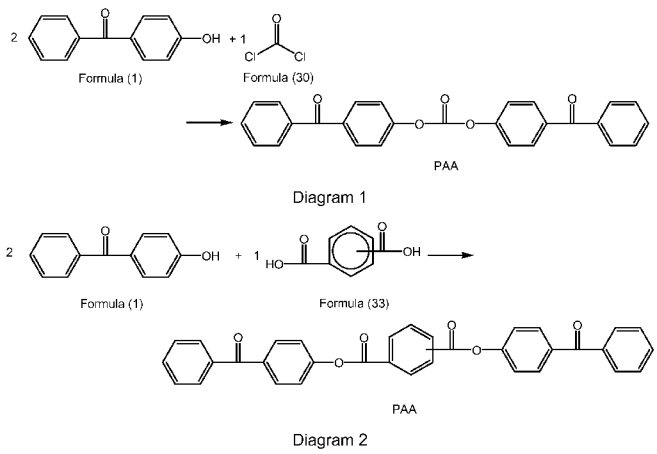


FIG. 1

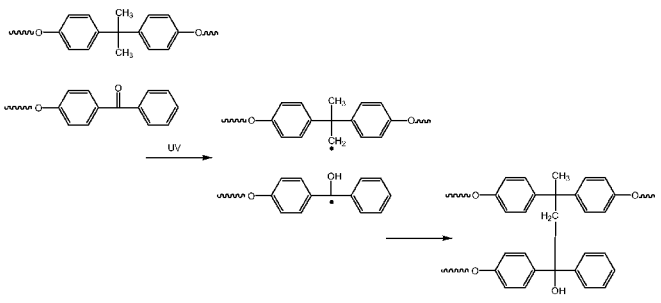


FIG. 6

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INTERFACIAL PROCESSES FOR PREPARING PHOTOACTIVE ADDITIVES

BACKGROUND

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 61/740,062, filed December 20, 2012, and to U.S. Provisional Patent Application Serial No. 61/791,886, filed March 15, 2013. The disclosure of each application is hereby fully incorporated by reference herein.

[0002] The present disclosure relates to processes for producing additives that can be used to crosslink polymers, such as polycarbonate polymers, for improved properties. Also included are compositions including such additives, as well as articles (e.g. sheets, films, etc.) formed from such compositions. More specifically, the present disclosure relates to interfacial processes for making such additives.

[0003] Polycarbonates (PC) are synthetic engineering thermoplastic resins, and are a useful class of polymers having many beneficial properties. They are useful for forming a wide variety of products, such as by molding, extrusion, and thermoforming processes. Polycarbonate resins are both strong and transparent, and are used for a number of different commercial applications, including electronic engineering (E&E) parts, mechanical parts, etc. Because of their broad use, particularly in electronic applications and auto part applications, the desired properties of polycarbonates include high impact strength and toughness, heat resistance, weather and ozone resistance, and good ductility.

[0004] Polycarbonate polymers/resins and blends containing polycarbonate polymers exhibit flame retardance properties. However, such polymers drip when exposed to a flame, and this behavior worsens as the wall thickness decreases. This behavior greatly diminishes their use in transparent and opaque thin wall applications where a V0 or 5VA flame retardance rating is required. These polymers also have relatively poor chemical resistance. It would be desirable to provide additives that can improve these properties.

BRIEF DESCRIPTION

[0005] The present disclosure relates to processes for producing additives which can be used to crosslink resins (e.g. polycarbonates) and improve their flame resistance and chemical resistance. The additives are formed by the reaction of at

least a first photoactive moiety with a first linker moiety. Generally, carbonate or ester linkages are found in the additives. Also included are the photoactive additives produced by these processes and/or crosslinked polymers and articles formed thereby. In particular embodiments, the photoactive additives are polycarbonate polymers containing a monohydroxybenzophenone endcap group that can crosslink when exposed to ultraviolet (UV) radiation.

[0006] Disclosed herein in different embodiments are processes for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising: combining the monohydroxybenzophenone, dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent to form a reaction mixture; and adding the carbonate precursor to the reaction mixture to obtain the photoactive additive.

[0007] In particular embodiments, the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

[0008] A second end-capping agent can be present in the reaction mixture in addition to the monohydroxybenzophenone. The second end-capping agent can be selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol. Sometimes, the reaction mixture further comprises a phase transfer catalyst, such as methyltributylammonium chloride.

[0009] The pH of the reaction mixture can be maintained from about 8.5 to about 10 while the carbonate precursor is added to the reaction mixture. The carbonate precursor can be added to the reaction mixture over a time period of about 30 minutes to about 40 minutes.

[0010] The resulting photoactive additive may contain less than 1900 ppm of diarylcarbonates, including about 100 ppm or less of diarylcarbonates. The resulting photoactive additive does not contain residual pyridine.

[0011] The resulting photoactive additive may have a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards. The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector is 1.8 or less, when using a GPC method and polycarbonate molecular weight standards, including 1.5 or less. The resulting photoactive additive

may have a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg, or a MVR of 8 to 12 cc/10 min, or a MVR of 8 to 10 cc/10 min.

[0012] Also described herein are various processes for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising: combining the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent to form a reaction mixture; adding the carbonate precursor to the reaction mixture over a first time period; and adding the monohydroxybenzophenone to the reaction mixture during the first time period to obtain the photoactive additive.

[0013] In particular embodiments, the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

[0014] The monohydroxybenzophenone may be dissolved in a solvent prior to being added to the reaction mixture, the solvent being either the water-immiscible organic solvent or water containing a base. In more specific embodiments, the monohydroxybenzophenone is dissolved in a dilute aqueous sodium hydroxide solution. In particular embodiments, the solution includes about 1.2 moles of NaOH per mole of the monohydroxybenzophenone, and contains about 10 wt% of the monohydroxybenzophenone (remainder water).

[0015] The monohydroxybenzophenone may be added to the reaction mixture over a portion of the first time period corresponding to from 10% to about 40% of the total charge of the carbonate precursor.

[0016] A second end-capping agent can be present in the reaction mixture in addition to the monohydroxybenzophenone. The second end-capping agent can be selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol.

[0017] The resulting photoactive additive may contain less than 700 ppm of diarylcarbonates, including about 100 ppm or less of diarylcarbonates. The resulting photoactive additive does not contain residual pyridine.

[0018] The resulting photoactive additive may have a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards. The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using

an RI detector is 1.5 or less, when using a GPC method and polycarbonate molecular weight standards. The resulting photoactive additive may have a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg, or a MVR of 8 to 12 cc/10 min, or a MVR of 8 to 10 cc/10 min.

[0019] Also disclosed are various processes for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising: combining the dihydroxy compound, water, and water-immiscible solvent to form a reaction mixture; adding the carbonate precursor to the reaction mixture to convert the dihydroxy compound into a bischloroformate; adding the monohydroxybenzophenone and the tertiary amine catalyst to the reaction mixture; and reacting the reaction mixture to obtain the photoactive additive.

[0020] In particular embodiments, the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

[0021] A second end-capping agent can be present in the reaction mixture in addition to the monohydroxybenzophenone. The second end-capping agent can be selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol. Sometimes, the reaction mixture further comprises a phase transfer catalyst, such as methyltributylammonium chloride.

[0022] The resulting photoactive additive may contain about 100 ppm or less of diarylcarbonates. The resulting photoactive additive does not contain residual pyridine.

[0023] The resulting photoactive additive may have a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards. The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector is 1.2 or less, when using a GPC method and polycarbonate molecular weight standards. The resulting photoactive additive may have a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg, or a MVR of 8 to 12 cc/10 min, or a MVR of 8 to 10 cc/10 min.

[0024] Also disclosed herein are various processes for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent,

comprising: pre-reacting the monohydroxybenzophenone with the carbonate precursor in a tubular reactor to convert the monohydroxybenzophenone into a monochloroformate; combining the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent in a reaction mixture; adding the carbonate precursor to the reaction mixture over a first time period; and adding the monochloroformate compound to the reaction mixture throughout the first time period to obtain the photoactive additive.

[0025] In particular embodiments, the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

[0026] A second end-capping agent can be present in the reaction mixture in addition to the monohydroxybenzophenone. The second end-capping agent can be selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol. Sometimes, the reaction mixture further comprises a phase transfer catalyst, such as methyltributylammonium chloride.

[0027] The resulting photoactive additive may have a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards. The resulting photoactive additive may have a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg, or a MVR of 8 to 12 cc/10 min, or a MVR of 8 to 10 cc/10 min.

[0028] These and other non-limiting characteristics are more particularly described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The following is a brief description of the drawings, which are presented for the purposes of illustrating the exemplary embodiments disclosed herein and not for the purposes of limiting the same.

[0030] **FIG. 1** illustrates the formation of a photoactive additive (compound) from a monofunctional photoactive moiety and a first linker moiety.

[0031] **FIG. 2** illustrates the formation of a photoactive additive (oligomer/polymer) from a monofunctional photoactive moiety, a first linker moiety, a diol chain extender, and an endcapping agent.

[0032] **FIG. 3** illustrates the formation of a photoactive additive (oligomer/polymer) from a first photoactive moiety, a first linker moiety, and a diol chain extender.

[0033] **FIG. 4** illustrates the formation of a photoactive additive (compound) from a first photoactive moiety, a first linker moiety, and a secondary linker moiety.

[0034] **FIG. 5** illustrates the formation of a photoactive additive from a first photoactive moiety, a second photoactive moiety, a first linker moiety, and a secondary linker moiety.

[0035] **FIG. 6** illustrates the crosslinking mechanism of the photoactive additive.

[0036] **FIG. 7** illustrates a first process for forming the photoactive additive ("upfront" or "solution addition").

[0037] **FIG. 8** illustrates another process for forming the photoactive additive through an intermediate bischloroformate.

[0038] **FIG. 9** illustrates another process for forming the photoactive additive using a tubular reactor and pre-reaction of some reactants.

[0039] **FIG. 10** depicts polycarbonate composition molecular weight as a function of UV-exposure.

[0040] **FIG. 11** depicts the molecular weight build (%) as a function of 4-hydroxybenzophenone endcap content in polycarbonate compositions treated with UV-radiation.

[0041] **FIG. 12** depicts overlayed NMR spectra demonstrating peak intensity increase at 3.48 ppm showing progression of polycarbonate cross-linking.

[0042] **FIG. 13** depicts NMR peak intensity at 3.48 ppm as a function of UV-treatment of 4-hydroxybenzophenone endcapped polycarbonates.

[0043] **FIG. 14** depicts polycarbonate composition molecular weight as a function of sun exposure time.

[0044] **FIG. 15** depicts small amplitude oscillatory rheology [parallel-plate] of a low-flow BPA-polycarbonate resin.

[0045] **FIG. 16** depicts small amplitude oscillatory rheology [parallel-plate] of a low-flow benzophenone endcapped BPA-polycarbonate copolymer resin.

DETAILED DESCRIPTION

[0046] The present disclosure may be understood more readily by reference to the following detailed description of desired embodiments and the examples included therein. In the following specification and the claims which follow, reference will be made to a number of terms which shall be defined to have the following meanings.

[0047] **Definitions**

[0048] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art. In case of conflict, the present document, including definitions, will control. Preferred methods and materials are described below, although methods and materials similar or equivalent to those described herein can be used in practice or testing of the present invention. All publications, patent applications, patents and other references mentioned herein are incorporated by reference in their entirety. The materials, methods, and examples disclosed herein are illustrative only and not intended to be limiting.

[0049] The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

[0050] As used in the specification and in the claims, the term "comprising" may include the embodiments "consisting of" and "consisting essentially of." The terms “comprise(s),” “include(s),” “having,” “has,” “can,” “contain(s),” and variants thereof, as used herein, are intended to be open-ended transitional phrases, terms, or words that do not preclude the possibility of additional acts or structures.

[0051] Numerical values in the specification and claims of this application, particularly as they relate to polymers or polymer compositions, reflect average values for a composition that may contain individual polymers of different characteristics. Furthermore, unless indicated to the contrary, the numerical values should be understood to include numerical values which are the same when reduced to the same number of significant figures and numerical values which differ from the stated value by less than the experimental error of conventional measurement technique of the type described in the present application to determine the value.

[0052] All ranges disclosed herein are inclusive of the recited endpoint and independently combinable (for example, the range of “from 2 grams to 10 grams” is inclusive of the endpoints, 2 grams and 10 grams, and all the intermediate values). The endpoints of the ranges and any values disclosed herein are not limited to the precise range or value; they are sufficiently imprecise to include values approximating these ranges and/or values.

[0053] As used herein, approximating language may be applied to modify any quantitative representation that may vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about” and “substantially,” may not be limited to the precise value specified, in

some cases. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. The modifier "about" should also be considered as disclosing the range defined by the absolute values of the two endpoints. For example, the expression "from about 2 to about 4" also discloses the range "from 2 to 4." The term "about" may refer to plus or minus 10% of the indicated number. For example, "about 10%" may indicate a range of 9% to 11%, and "about 1" may mean from 0.9-1.1. Other meanings of "about" may be apparent from the context, such as rounding off, so, for example "about 1" may also mean from 0.5 to 1.4.

[0054] For the recitation of numeric ranges herein, each intervening number there between with the same degree of precision is explicitly contemplated. For example, for the range of 6-9, the numbers 7 and 8 are contemplated in addition to 6 and 9, and for the range 6.0-7.0, the number 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, and 7.0 are explicitly contemplated.

[0055] Compounds are described using standard nomenclature. For example, any position not substituted by any indicated group is understood to have its valency filled by a bond as indicated, or a hydrogen atom. A dash ("-") that is not between two letters or symbols is used to indicate a point of attachment for a substituent. For example, the aldehyde group -CHO is attached through the carbon of the carbonyl group.

[0056] The term "aliphatic" refers to an linear or branched array of atoms that is not aromatic. The backbone of an aliphatic group is composed exclusively of carbon. The aliphatic group may be substituted or unsubstituted. Exemplary aliphatic groups include, but are not limited to, methyl, ethyl, isopropyl, hexyl, and cyclohexyl.

[0057] The term "aromatic" refers to a radical having a ring system containing a delocalized conjugated pi system with a number of pi-electrons that obeys Hückel's Rule. The ring system may include heteroatoms such as nitrogen, sulfur, selenium, silicon and oxygen, or may be composed exclusively of carbon and hydrogen. Aromatic groups are not substituted. Exemplary aromatic groups include, but are not limited to, phenyl, pyridyl, furanyl, thienyl, naphthyl and biphenyl.

[0058] The term "ester" refers to a radical of the formula –CO-O-, wherein the carbon atom and the oxygen atom are both covalently bonded to carbon atoms.

[0059] The term “carbonate” refers to a radical of the formula –O-CO-O-, wherein the oxygen atoms are both covalently bonded to carbon atoms. Note that a carbonate group is not an ester group, and an ester group is not a carbonate group.

[0060] The terms “carboxy” or “carboxyl” refers to a radical of the formula -COOH, wherein the carbon atom is covalently bonded to another carbon atom.

[0061] The term “alkyl” refers to a radical composed entirely of carbon atoms and hydrogen atoms which is fully saturated. The alkyl radical may be linear, branched, or cyclic.

[0062] The term “aryl” refers to an aromatic radical that is composed exclusively of carbon and hydrogen. Exemplary aryl groups include phenyl, naphthyl, and biphenyl. Note that “aryl” is a subset of aromatic.

[0063] The term “heteroaryl” refers to an aromatic radical having a ring system that is composed of carbon, hydrogen, and at least one heteroatom. Exemplary heteroaryl groups include pyridyl, furanyl, and thienyl. Note that “heteroaryl” is a subset of aromatic, and is exclusive of “aryl”.

[0064] The term “halogen” refers to fluorine, chlorine, bromine, and iodine.

[0065] The term “alkoxy” refers to an alkyl radical which is attached to an oxygen atom, i.e. -O-C_nH_{2n+1}.

[0066] The term “aryloxy” refers to an aryl radical which is attached to an oxygen atom, e.g. -O-C_6H_5.

[0067] The term “hydrocarbon” refers to a radical which is composed exclusively of carbon and hydrogen. Both alkyl and aryl groups are considered hydrocarbon groups.

[0068] The term “alkenyl” refers to a radical composed entirely of carbon atoms and hydrogen atoms which contains at least one carbon-carbon double bond that is not part of an aryl or heteroaryl structure. The alkenyl radical may be linear, branched, or cyclic. An exemplary alkenyl radical is vinyl (-CH=CH_2).

[0069] The term “alkenyloxy” refers to a alkenyl radical which is attached to an oxygen atom, e.g. –O-CH=CH_2.

[0070] The term “arylalkyl” refers to an aryl radical which is attached to an alkyl radical, with the aryl radical being appended to the parent molecular moiety through the alkyl radical, e.g. benzyl (-CH_2-C_6H_5).

[0071] The term "alkylaryl" refers to an alkyl radical which is attached to an aryl radical, with the alkyl radical being appended to the parent molecular moiety through the aryl radical, e.g. tolyl ($-C_6H_4-CH_3$).

[0072] The term "copolymer" refers to a polymer derived from two or more structural unit or monomeric species, as opposed to a homopolymer, which is derived from only one structural unit or monomer.

[0073] The term "C_3-C_6 cycloalkyl" refers to cyclopropyl, cyclobutyl, cyclopentyl or cyclohexyl.

[0074] The terms "Glass Transition Temperature" or "Tg" refer to the maximum temperature that a polymer, such as a polycarbonate, will have one or more useful properties. These properties include impact resistance, stiffness, strength, and shape retention. The Tg of a polycarbonate therefore may be an indicator of its useful upper temperature limit, particularly in plastics applications. The Tg may be measured using a differential scanning calorimetry method and expressed in degrees Celsius.

[0075] The glass transition temperature of a polymer, such as a polycarbonate, may depend primarily on the composition of the polymer. Polycarbonates that are formed from monomers having more rigid and less flexible chemical structures than Bisphenol-A generally have higher glass transition temperatures than Bisphenol-A polycarbonate, while polycarbonates that are formed from monomers having less rigid and more flexible chemical structures than Bisphenol-A generally have lower glass transition temperatures than Bisphenol-A polycarbonate. For example, a polycarbonate formed from 33 mole % of a rigid monomer, 3,3-bis(4-hydroxyphenyl)-2-phenylisoindolin-1-one ("PPPBP"), and 67 mole % Bisphenol-A has a glass transition temperature of 198 ºC, while a polycarbonate formed from Bisphenol-A, but also having 6 wt % of siloxane units, a flexible monomer, has a glass transition temperature of 145 ºC.

[0076] Mixing of two or more polycarbonates having different glass transition temperatures may result in a glass transition temperature value for the mixture that is intermediate between the glass transition temperatures of the polycarbonates that are mixed.

[0077] The glass transition temperature of a polycarbonate may also be an indicator of the molding or extrusion temperatures required to form polycarbonate

parts. The higher the glass transition temperature of the polycarbonate the higher the molding or extrusion temperatures that are needed to form polycarbonate parts.

[0078] The glass transition temperatures (Tg) described herein are measures of heat resistance of, for example, polycarbonate and polycarbonate blends. The Tg can be determined by differential scanning calorimetry. The calorimetry method may use a TA Instruments Q1000 instrument, for example, with setting of 20 ºC/min ramp rate and 40 ºC start temperature and 200 ºC end temperature.

[0079] The term "halo" means that the substituent to which the prefix is attached is substituted with one or more independently selected halogen radicals. For example, "C_1-C_6 haloalkyl" means a C_1-C_6 alkyl substituent wherein one or more hydrogen atoms are replaced with independently selected halogen radicals. Non-limiting examples of C_1-C_6 haloalkyl include chloromethyl, 1-bromoethyl, fluoromethyl, difluoromethyl, trifluoromethyl, and 1,1,1-trifluoroethyl. It should be recognized that if a substituent is substituted by more than one halogen radical, those halogen radicals may be identical or different (unless otherwise stated).

[0080] The term "haze" refers to the percentage of transmitted light, which in passing through a specimen deviates from the incident beam by forward scattering. Percent (%) haze may be measured according to ASTM D 1003-07.

[0081] The term "Melt Volume Rate" (MVR) refers to the flow rate of a polymer in a melt phase as determined using the method of ASTM 1238-10. The MVR of a molten polymer is measured by determining the amount of polymer that flows through a capillary of a specific temperature over a specified time using standard weights at a fixed temperature. MVR is expressed in cubic centimeter per 10 minutes. The higher the MVR value of a polymer at a specific temperature, the greater the flow of that polymer at that specific temperature.

[0082] The term "Peak melt viscosity" refers to the highest melt viscosity value (in poise) achieved between 350 °C and 450 °C during rheological testing of a polycarbonate resin.

[0083] The term "Percent transmission" or "% transmission" refers to the ratio of transmitted light to incident light, and may be measured according to ASTM D 1003-07.

[0084] "Polycarbonate" as used herein refers to an oligomer or a polymer comprising residues of one or more monomers, joined by carbonate linkages.

[0085] "Thermal stability" as used herein refers to resistance of a polymer to molecular weight degradation under thermal conditions. Thus, a polymer with poor thermal stability may show significant molecular weight degradation under thermal conditions, such as during extrusion, molding, thermoforming, hot-pressing, and like conditions. Molecular weight degradation may also be manifest through color formation and/or in the degradation of other properties such as weatherability, gloss, mechanical properties, and/or thermal properties. Molecular weight degradation can also cause significant variation in processing conditions such as melt viscosity changes.

[0086] The present disclosure refers to "polymers," "oligomers", and "compounds". A polymer is a large molecule composed of multiple repeating units chained together, the repeating units being derived from a monomer. One characteristic of a polymer is that different molecules of a polymer will have different lengths, and a polymer is described as having a molecular weight that is based on the average value of the chains (e.g. weight average or number average molecular weight). The art also distinguishes between an "oligomer" and a "polymer", with an oligomer having only a few repeating units, while a polymer has many repeating units. For purposes of this disclosure, the term "oligomer" refers to such molecules having a weight average molecular weight of less than 15,000, and the term "polymer" refers to molecules having a weight average molecular weight of 15,000 of more, as measured by GPC using polycarbonate molecular weight standards. In contrast, for a compound, all molecules will have the same molecular weight. Compared to a polymer, a compound is a small molecule.

[0087] **Compositions**

[0088] The present disclosure relates to photoactive additives (PAA), and to compositions containing such additives. When the photoactive additive is added to one or more base resins and is then exposed to the appropriate wavelength of light, the resulting composition will have improved anti-drip and flame retardant properties compared to the base resins alone or to the composition prior to the light exposure. For example, the chemical resistance, propensity to drip during burning, or the propensity to form a hole when exposed to a flame can be improved. Improved flame resistance performance characteristics may include flame out time (FOT) and time to drip (TTD). The compositions, blended or neat, can be used to provide thin-walled materials that are UL94 5VA compliant. The compositions can be used to

provide thin-walled materials that are 5VA compliant and highly transparent. The compositions may also exhibit good chemical resistance, scratch resistance, tear resistance, impact strength, ductility, hydrolytic stability, and/or weatherability. Compositions comprising a cross-linked polycarbonate formed from the PAA are also contemplated

[0089] The PAA can be blended with the base resins by melt blending or solution blending. The PAA-containing blend can be then be formed into an article by a variety of known processes such as solution casting, profile extrusion, film and/or sheet extrusion, sheet-foam extrusion, injection molding, blow molding, thermoforming, and the like.



[0090] The article is then exposed to ultraviolet (UV) light at an appropriate wavelength and in an appropriate dosage that brings about the desired amount of crosslinking for the given application. Depending on the end use application and the desired properties, the UV exposure can be performed on one or more sides of the article.

[0091] The exposure can be accomplished using standard methods known in the art. For example, in some embodiments, the article is exposed by using natural sunlight. The exposure time will be dependent on the application and color of material. It can range from a few minutes to several days. Alternatively, the crosslinking can be accomplished by using a UV-emitting light source such as a mercury vapor, High-Intensity Discharge (HID), or various UV lamps. For example, commercial UV lamps are sold with different wavelength radiation lines for UV curing from manufacturers such as Fusion UV. Non-limiting examples of UV-emitting electrodeless mercury light bulbs include H bulbs, D bulbs, H+ bulbs, and V bulbs. An H bulb has strong output in the range of 200 nm to 320 nm. The D bulb has strong output in the 320 nm to 400 nm range. The V bulb has strong output in the 400 nm to 420 nm range. Both electrodeless and arc lamps are contemplated for use, as are other metal halide combinations for the bulb type.

[0092] A long pass filter (with a cut on wavelength) or band pass filter can be used to remove specific wavelengths of light from the irradiation spectra that damage the article. Such filters are commercially available. In addition, borosilicate glass

can be used to block the shorter wavelengths of light that may cause resin degradation.

[0093] The exposed article will have a cross-linked outer surface and an inner surface that is either lightly cross-linked or not cross-linked. The outer surface will be cross-linked to such a degree that the outer surface is substantially insoluble in the common solvents for the starting resins. The percentage of the insolubles will be dependent on the part geometry and surface-to-volume ratio, but will generally be from 2% to 95%. For a 1/8" ASTM Izod bar exposed on one side, the percentage of insoluble will be from 1% to 75%. For most 1/8" articles exposed on one side, the insolubles will be from 2% to 10%.

[0094] The amount of PAA added to the blend can be used to fine-tune the final properties of the article. For example, articles requiring high chemical resistance and FR drip inhibition would need increased PAA content. In general, depending on the application, the overall molar percentage of the PAA should be from 0.5 mole% to 15 mole%, based on the weight of the polymeric resin. In more specific applications, the overall percentage is from 1 mole% to 10 mole%.

[0095] The PAAs are suitable for blending with a variety of resins. Such blends can still be sufficiently cross-linked to provide compositions that exhibit one or more of UL94 5VA compliance, extreme chemical resistance, scratch resistance, tear resistance, impact strength, ductility, hydrolytic stability, and weatherability. The PAAs are suitable for blending with polycarbonate homopolymers, polycarbonate copolymers, and polycarbonate blends. They are also suitable for blending with polyesters, polyarylates, polyestercarbonates, and polyetherimides. One advantage of using the PAAs with polymeric resins is that polymers with relatively higher Mw's generally retain their mechanical properties better, while polymers with relatively lower Mw's generally have better flow properties. The PAAs can be used to produce complex or thin molded articles that are difficult to mold using higher molecular weight polymers. Upon irradiation of the molded article, crosslinks can be formed that extend the molecular weight and improve physical properties such as impact strength, tensile strength, flame retardance, or chemical resistance.

[0096] The compositions disclosed herein are useful in the manufacture of a wide variety of articles, particularly thin-walled articles, including highly transparent thin-walled articles, having improved flame retardance and good physical properties. The compositions can be used to provide materials and articles such as, but not limited

to, injection molded articles, films, extruded sheets, fibers, pellets, flex-films, tear-resistant films, and PVD laminates. The compositions can be used to provide materials and articles having scratch resistance. The compositions can be used to provide materials and articles that have self-sealing properties (e.g., a scratched article may undergo cross-linking upon UV-exposure, thereby sealing the scratch).

[0097] Generally, the photoactive additives (PAA) of the present disclosure include photoactive moieties that are covalently linked together through a first linker moiety and possibly a secondary linker moiety. The photoactive moieties contain a photoactive ketone group that, when exposed to the appropriate wavelength(s) of light, will form a stable covalent bond between the PAA and the polymeric resin. The PAA should be stable at conventional blending, forming, and processing temperatures (i.e. stable at 350°C or above). The PAA also should not induce the degradation of the polymeric resin with which it is blended.

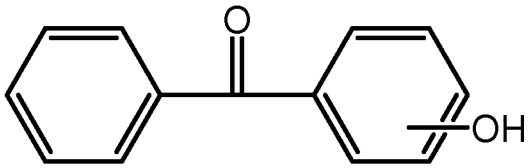
[0098] The term "photoactive moiety" refers to a moiety that, when exposed to light of the appropriate wavelength, crosslinks with another molecule. Thus, for example, the bisphenol-A monomer in a bisphenol-A homopolymer would not be considered a photoactive moiety, even though photo-Fries rearrangement can occur upon exposure to light, because the atoms do not participate in crosslinking but merely in rearrangement of the polymer backbone.

[0099] The photoactive additive is formed from a reaction mixture containing at least a first photoactive moiety and a first linker moiety. The photoactive moiety comprises (i) a ketone group and (ii) one phenolic group. The linker moiety comprises a plurality of functional groups that can react with the phenolic group of the photoactive moiety. The reaction product is the photoactive additive (PAA). The molar ratio of the photoactive moiety to the linker moiety can be from 1:2 to 20:1. . A second end-capping agent may also be included. As desired, a diol chain extender can also be included. The second end-capping agent and the diol chain extender do not have photoactive properties.

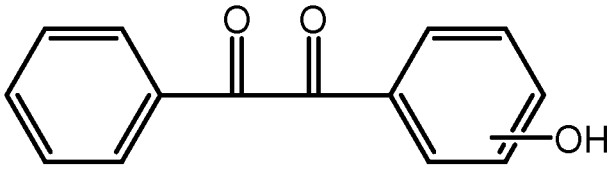
[0100] The term "ketone group" refers to a carbonyl group (-CO-) that is bonded to two other carbon atoms (i.e. –R-CO-R'-). The two other carbon atoms can be in an aliphatic group or in an aromatic group. An ester group and a carboxylic acid group are not considered to be a ketone group because the carbonyl group is bonded to one carbon atom and an oxygen atom.

[0101] The term "phenolic group" refers to a phenyl group (-C_6H_4-) with a hydroxyl group (-OH) covalently bonded to a carbon atom in the phenyl group.

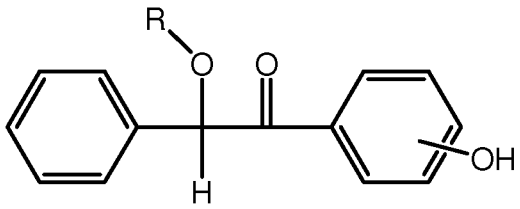
[0102] The photoactive moiety can be a hydroxyphenone, wherein the phenolic group is directly bonded to the ketone group. In some embodiments, the photoactive moiety contains only one phenolic group. Examples of such photoactive moieties include those having the structure of one of Formulas (1), (3), or (5)-(10):



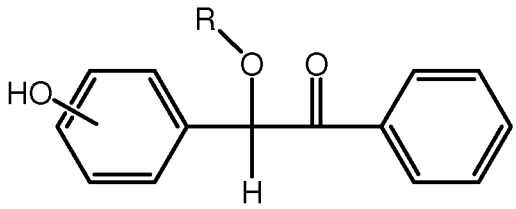
Formula (1)



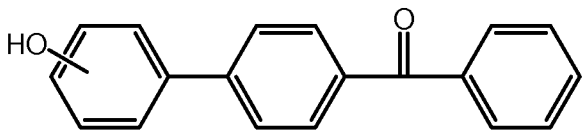
Formula (3)



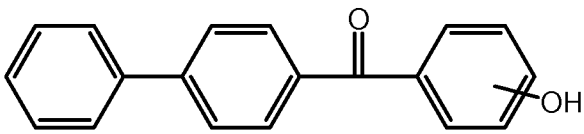
Formula (5)



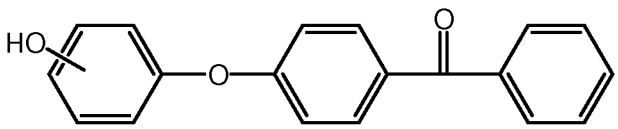
Formula (6)



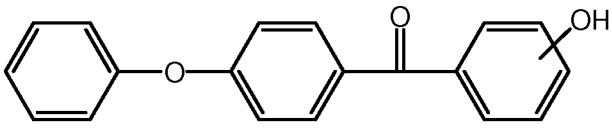
Formula (7)



Formula (8)



Formula (9)

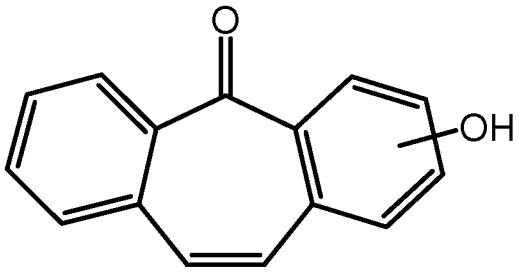


Formula (10)

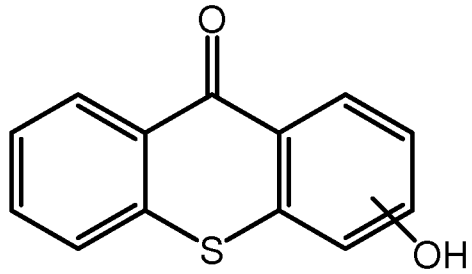
wherein R is H, alkyl, or aryl.

[0103] The compound of Formula (1) is a hydroxybenzophenone. The compound of Formula (3) is a 1-hydroxyphenyl-2-phenylethane-1,2-dione. The compound of Formula (5) is a 1-(hydroxyphenyl)-2-hydrocarboxy-2-phenylethanone. The compound of Formula (6) is a 2-(hydroxyphenyl)-2-hydrocarboxy-1-phenylethanone. The compound of Formula (7) is a 4-(hydroxyphenyl)-benzophenone. The compound of Formula (8) is a 4-hydroxy-4'-phenylbenzophenone. The compound of Formula (9) is a 4-[(hydroxy)phenoxy]-benzophenone. The compound of Formula (10) is a 4-hydroxy-4'-phenoxy-benzophenone.

[0104] In some other embodiments, the R and R' groups attached to the ketone group form a ring structure. In such embodiments, the aromatic rings can include both aryl rings or heteroaryl rings. Examples of such photoactive moieties include those having the structure of one of Formulas (13)-(14):



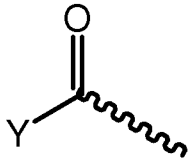
Formula (13)



Formula (14)

[0105] The compound of Formula (13) is a hydroxydibenzo[1,3-e:1',2'-f][7]annulen-11-one. The compound of Formula (14) is a hydroxythioxanthen-9-one.

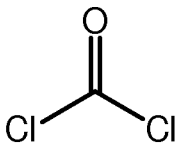
[0106] The photoactive moiety is reacted with one or more linker moieties. At least one of the linker moieties comprises a plurality of functional groups that can react with the single phenolic group of the photoactive moiety. Examples of such functional groups include a carboxylic acid (and anhydrides thereof), an acyl halide, an alkyl ester, and an aryl ester. These functional groups are illustrated below in general formula (A):



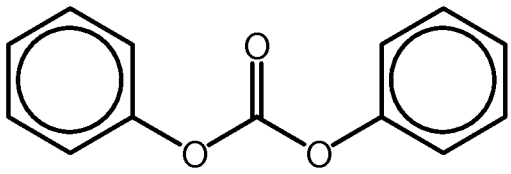
Formula (A)

where Y is hydroxyl, halogen, alkoxy, or aryloxy. The functional groups can be joined to an aliphatic group or an aromatic group which serves as a "backbone" for the linker moiety. In particular embodiments, the linker moiety can have two, three, four, or even more functional groups.

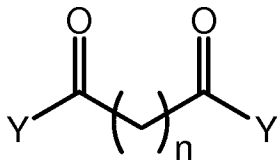
[0107] Some examples of linker moieties which have two functional groups and can react with the photoactive moieties include those having the structure of one of Formulas (30)-(35):



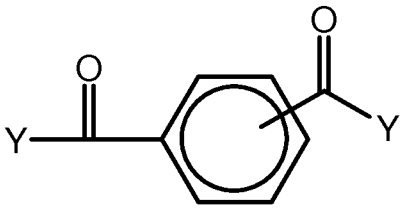
Formula (30)



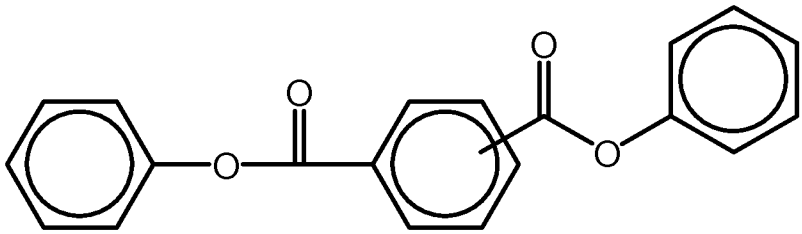
Formula (31)



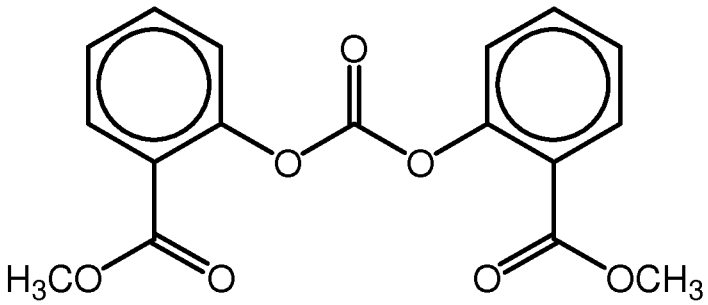
Formula (32)



Formula (33)



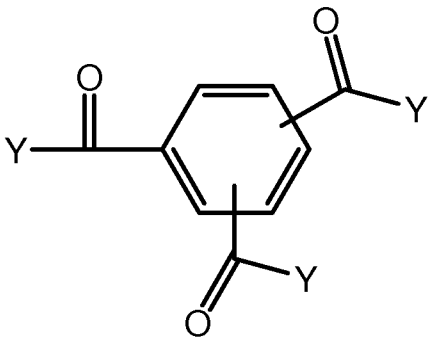
Formula (34)



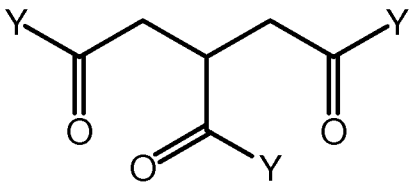
Formula (35)

where Y is hydroxyl, halogen, alkoxy, or aryloxy; and where n is 1 to 20. It should be noted that Formula (33) encompasses isophthalic acid and terephthalic acid.

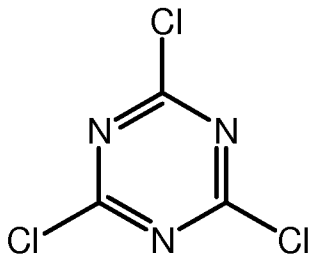
[0108] Some examples of linker moieties which have three functional groups and can react with the photoactive moieties include those having the structure of one of Formulas (36)-(38):



Formula (36)



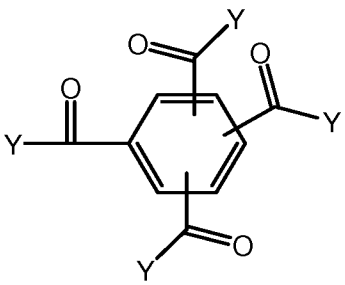
Formula (37)



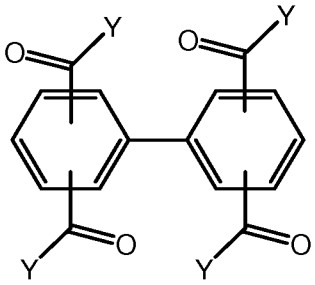
Formula (38)

where Y is hydroxyl, halogen, alkoxy, or aryloxy.

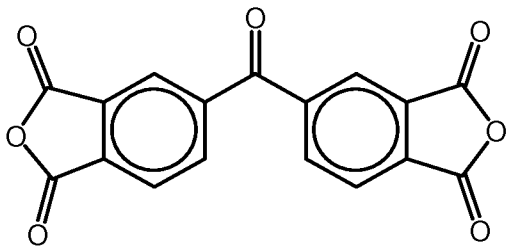
[0109] Some examples of linker moieties which have four functional groups and can react with the photoactive moieties include those having the structure of one of Formulas (39)-(41):



Formula (39)



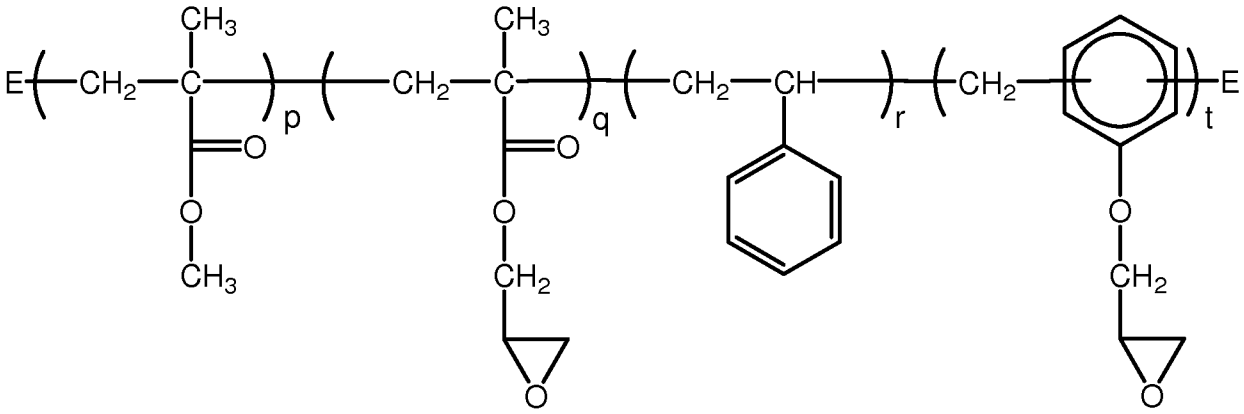
Formula (40)



Formula (41)

where Y is hydroxyl, halogen, alkoxy, or aryloxy.

[0110] In some embodiments, functional groups can be provided by short oligomers, including oligomers containing glycidyl methacrylate monomers with styrene or methacrylate monomers, or epoxidized novolac resins. These oligomers can permit the desired the number of functional groups to be provided. Such oligomers are generalized by the structure of Formula (42):



Formula (42)

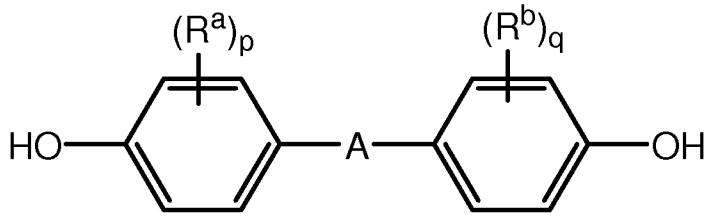
where E is hydrogen or an endcapping agent, p is the number of methacrylate monomers, q is the number of methacrylate monomers, r is the number of styrene monomers, and t is the number of epoxidized novolac (phenol-formaldehyde) monomers. Generally, $p+q+r+t \leq 20$. When the oligomer contains glycidyl methacrylate monomers with styrene or methacrylate monomers, generally $t=0$ and $q \geq 1$. Similarly, for novolac resins, $p=q=r=0$. The epoxy groups can be reacted with the phenolic group of the photoactive moiety.

[0111] As discussed above, the photoactive moiety has one phenolic group and the linker moiety has two or more functional groups. In embodiments that use only the photoactive moiety and the linker moiety in the reaction mixture, the resulting photoactive additive (PAA) will be a compound, each molecule having the same molecular weight. Again, the molar ratio of the photoactive moiety to the linker moiety can be from 1:2 to 20:1, though in these embodiments the molar ratio is usually 1:1 or greater. The two diagrams of **FIG. 1** are illustrative of such photoactive additives. In the first diagram, two moles of 4-hydroxybenzophenone are reacted with one mole of phosgene to obtain the photoactive additive. In the second diagram, two moles of 4-hydroxybenzophenone are reacted with one mole of a diphthalic acid to obtain the photoactive additive. The product of the first diagram contains carbonate linkages, while the product of the second diagram contains ester linkages.

[0112] In particularly desired embodiments, the photoactive additive can be formed from a reaction mixture containing the photoactive moiety, the first linker moiety, and one or more chain extenders. The chain extender is a molecule that

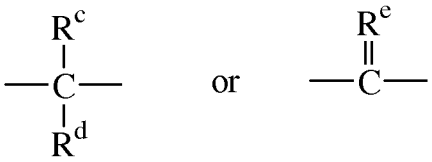
contains only two hydroxyl groups and is not photoactive when exposed to light. The chain extender can be used to provide a desired level of miscibility when the additive is mixed with other polymeric resins.

[0113] A first exemplary chain extender is a bisphenol of Formula (B):



(B)

wherein R^a and R^b each represent a halogen atom or a monovalent hydrocarbon group and may be the same or different; p and q are each independently integers of 0 to 4; and A represents one of the groups of formula (B-1):

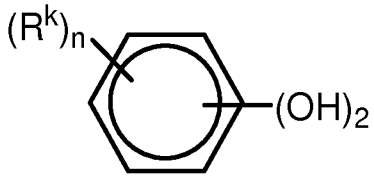


(B-1)

wherein R^c and R^d each independently represent a hydrogen atom or a monovalent linear or cyclic hydrocarbon group and R^e is a divalent hydrocarbon group. For example, A can be a substituted or unsubstituted C_3-C_{18} cycloalkylidene.

[0114] Specific examples of the types of bisphenol compounds that may be represented by Formula (B) include 1,1-bis(4-hydroxyphenyl) methane, 1,1-bis(4-hydroxyphenyl) ethane, 2,2-bis(4-hydroxyphenyl) propane (hereinafter "bisphenol-A" or "BPA"), 2,2-bis(4-hydroxyphenyl) butane, 2,2-bis(4-hydroxyphenyl) octane, 1,1-bis(4-hydroxyphenyl) propane, 1,1-bis(4-hydroxyphenyl) n-butane, 2,2-bis(4-hydroxy-1-methylphenyl) propane, and 1,1-bis(4-hydroxy-t-butylphenyl) propane.

[0115] A second exemplary chain extender is a bisphenol of Formula (C):

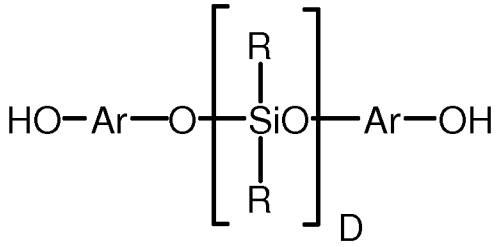


(C)

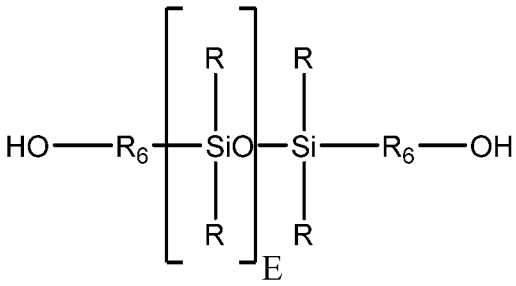
wherein each R^k is independently a C_{1-10} hydrocarbon group, and n is 0 to 4. The halogen is usually bromine. Examples of compounds that may be represented by Formula (C) include resorcinol, substituted resorcinol compounds such as 5-methyl resorcinol, 5-phenyl resorcinol, or 5-cumyl resorcinol; catechol; hydroquinone; and

substituted hydroquinones such as 2-methyl hydroquinone, 2-t-butyl hydroquinone, 2-phenyl hydroquinone, 2-cumyl hydroquinone, or 2,3,5,6-tetramethyl hydroquinone.

[0116] A third exemplary chain extender is a bisphenolpolydiorganosiloxane of Formula (D-1) or (D-2):



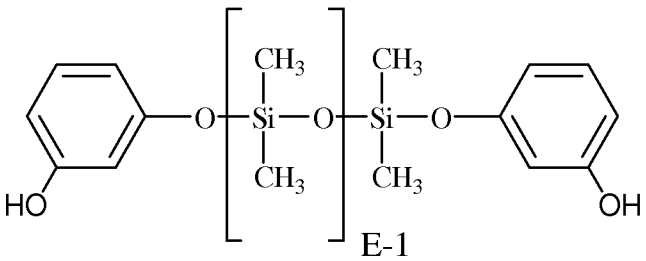
(D-1)



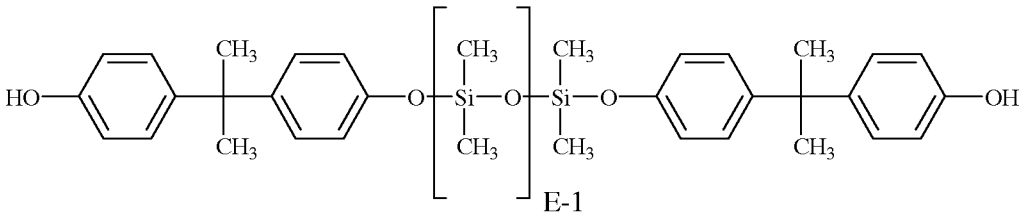
(D-2)

wherein each Ar is independently aryl; each R is independently alkyl, alkoxy, alkenyl, alkenyloxy, aryl, aryloxy, arylalkyl, or alkylaryl; each R_6 is independently a divalent C_1-C_{30} organic group such as a C_1-C_{30} alkyl, C_1-C_{30} aryl, or C_1-C_{30} alkylaryl; and D and E are an average value of 2 to about 1000, specifically about 2 to about 500, or about 10 to about 200, or more specifically about 10 to about 75.

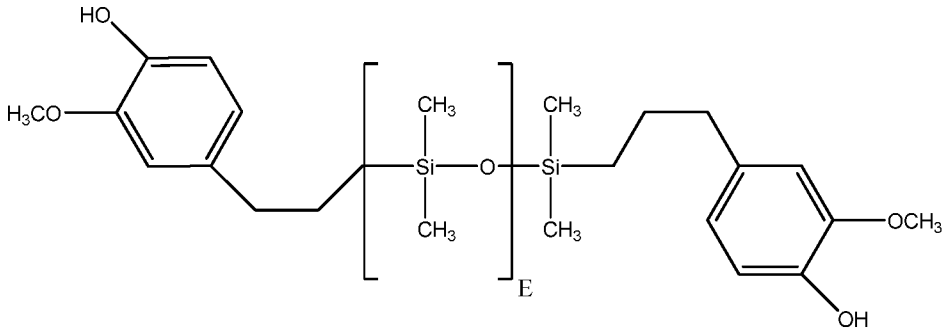
[0117] Specific examples of Formulas (D-1) or (D-2) are illustrated below as Formulas (D-a) through (D-d):



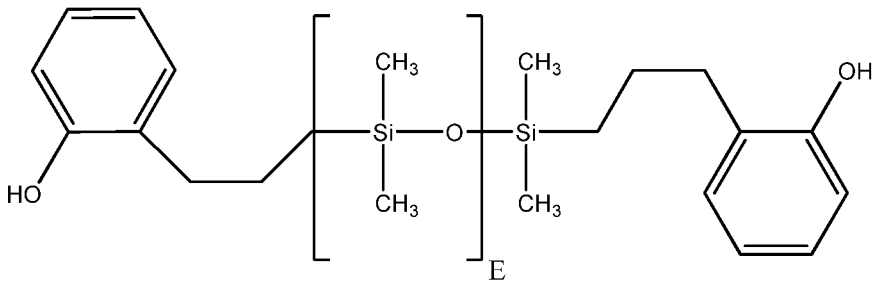
(D-a)



(D-b)



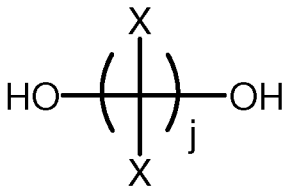
(D-c)



(D-d)

where E is an average value from 10 to 200.

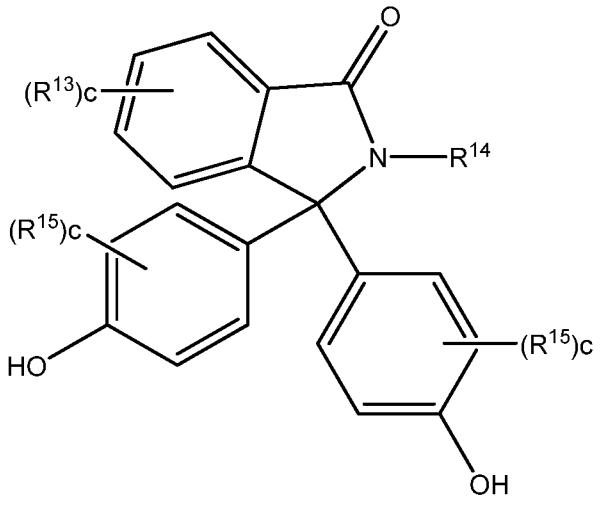
[0118] A fourth exemplary chain extender is an aliphatic diol of Formula (E):



(E)

wherein each X is independently hydrogen, halogen, or alkyl; and j is an integer from 1 to 20. Examples of an aliphatic diol include ethylene glycol, propanediol, 2,2-dimethyl-propanediol, 1,6-hexanediol, and 1,12-dodecanediol.

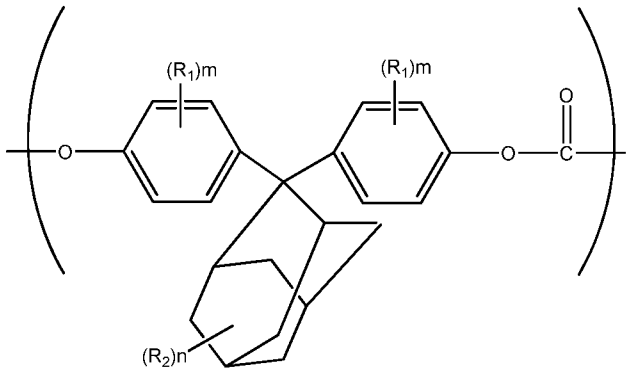
[0119] A fifth exemplary chain extender is a dihydroxy compound of Formula (F), which may be useful for high heat applications:



(F)

wherein R^{13} and R^{15} are each independently a halogen or a C_1-C_6 alkyl group, R^{14} is a C_1-C_6 alkyl, phenyl, or phenyl substituted with up to five halogens or C_1-C_6 alkyl groups, and c is 0 to 4. In a specific embodiment, R^{14} is a C_1-C_6 alkyl or phenyl group. In still another embodiment, R^{14} is a methyl or phenyl group. In another specific embodiment, each c is 0. Compounds of Formula (F) include 3,3-bis(4-hydroxyphenyl)-2-phenylisoindolin-1-one (PPPBP); 4,4'-(1-phenylethane-1,1-diyl)diphenol or 1,1-bis(4-hydroxyphenyl)-1-phenyl-ethane (bisphenol-AP); and 1,1-bis(4-hydroxyphenyl)-3,3,5-trimethylcyclohexane) (bisphenol TMC).

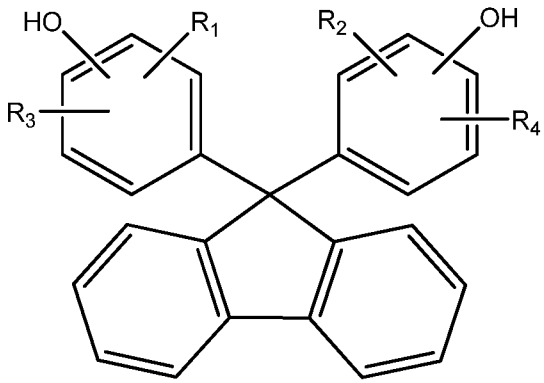
[0120] Other dihydroxy compounds (i.e. diol chain extenders) that might impart high Tgs to the polycarbonate as a copolycarbonate are dihydroxy compounds having adamantane units, as described in U.S. Patent No. 7,112,644 and U.S. Patent No. 3,516,968, which are fully incorporated herein by reference. A compound having adamantane units may have repetitive units of the following formula (G) for high heat applications:



(G)

wherein R_1 represents a halogen atom, an alkyl group having 1 to 6 carbon atoms, an alkoxy group having 1 to 6 carbon atoms, an aryl group having 6 to 12 carbon atoms, an aryl-substituted alkenyl group having 7 to 13 carbon atoms, or a fluoroalkyl group having 1 to 6 carbon atoms; R_2 represents a halogen atom, an alkyl group having 1 to 12 carbon atoms, an alkoxy group having 1 to 12 carbon atoms, an aryl group having 6 to 12 carbon atoms, an aryl-substituted alkenyl group having 7 to 13 carbon atoms, or a fluoroalkyl group having 1 to 12 carbon atoms; m represents an integer of 0 to 4; and n represents an integer of 0 to 14.

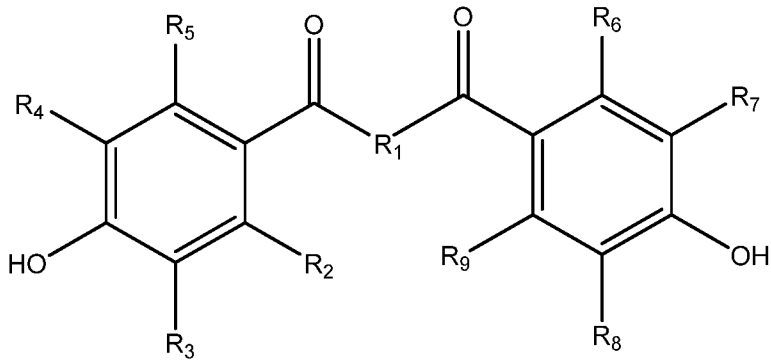
[0121] Other dihydroxy compounds that might impart high Tgs to the polycarbonate as a copolycarbonate are dihydroxy compounds having fluorene-units, as described in U.S. Patent No. 7,244,804. One such fluorene-unit containing dihydroxy compound is represented by the following formula (H) for high heat applications:



(H)

wherein R_1 to R_4 are each independently a hydrogen atom, a hydrocarbon group with 1 to 9 carbon atoms which may contain an aromatic group, or a halogen atom.

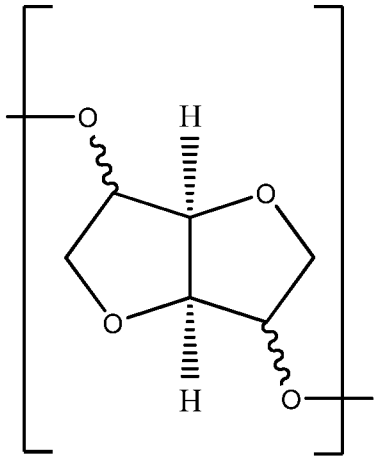
[0122] Another chain extender that could be used is an isosorbide. A monomer unit derived from isosorbide may be an isorbide-bisphenol unit of Formula (I):



(I)

wherein R_1 is an isosorbide unit and R_2-R_9 are each independently a hydrogen, a halogen, a C_1-C_6 alkyl, a methoxy, an ethoxy, or an alkyl ester.

[0123] The R_1 isosorbide unit may be represented by Formula (I-a):



(I-a).

[0124] The isosorbide unit may be derived from an isosorbide, a mixture of isosorbide, a mixture of isomers of isosorbide, and/or from individual isomers of isosorbide. The stereochemistry for the isosorbide-based carbonate units of Formula (I) is not particularly limited. These diols may be prepared by the dehydration of the corresponding hexitols. Hexitols are produced commercially from the corresponding sugars (aldohexose). Aliphatic diols of formula (16) include 1,4:3,6-dianhydro-D glucitol, of formula (17); 1,4:3,6-dianhydro-D mannitol, of formula (18); and 1,4:3,6-dianhydro-L iditol, of formula (19), and any combination thereof. Isosorbides are available commercially from various chemical suppliers including Cargill, Roquette, and Shanxi. The isosorbide-bisphenol may have a pKa of between 8 and 11.

[0125] The cross-linkable polycarbonate of the present disclosure may be a polyester-polycarbonate copolymer. The molar ratio of ester units to carbonate units in the polyester-polycarbonate may vary broadly, for example 1:99 to 99:1, specifically 10:90 to 90:10, more specifically 25:75 to 75:25, optionally expanded depending on the desired properties of the final composition. The polyester units may be derived from a dicarboxylic acid, and may be, for example, a C_2-C_{10} alkylene group, a C_6-C_{20} alicyclic group, a C_6-C_{20} alkyl aromatic group, a C_6-C_{20} aromatic group, or a C_6-C_{36} divalent organic group derived from a dihydroxy compound or chemical equivalent thereof.

[0126] The polyester units can be derived from aliphatic dicarboxylic acids having from 6 to about 36 carbon atoms, optionally from 6 to 20 carbon atoms. The C_6-C_{20}

linear aliphatic alpha-omega (α-ω) dicarboxylic acids may be adipic acid, sebacic acid, 3,3-dimethyl adipic acid, 3,3,6-trimethyl sebacic acid, 3,3,5,5-tetramethyl sebacic acid, azelaic acid, dodecanedioic acid, dimer acids, cyclohexane dicarboxylic acids, dimethyl cyclohexane dicarboxylic acid, norbornane dicarboxylic acids, adamantane dicarboxylic acids, cyclohexene dicarboxylic acids, or C_{14}, C_{18} and C_{20} diacids.

[0127] Saturated aliphatic alpha-omega dicarboxylic acids may be adipic acid, sebacic or dodecanedioic acid. Sebacic acid has a molecular mass of 202.25 Daltons, a density of 1.209 g/cm^3 (25 °C), and a melting point of 294.4 °C at 100 mmHg. Sebacic acid is extracted from castor bean oil found in naturally occurring castor beans.

[0128] Other examples of aromatic dicarboxylic acids that may be used to prepare the polyester units include isophthalic or terephthalic acid, 1,2-di(p-carboxyphenyl)ethane, 4,4'-dicarboxydiphenyl ether, 4,4'-bisbenzoic acid, and combinations comprising at least one of the foregoing acids. Acids containing fused rings can also be present, such as in 1,4-, 1,5-, or 2,6-naphthalenedicarboxylic acids. Specific dicarboxylic acids may be terephthalic acid, isophthalic acid, naphthalene dicarboxylic acid, cyclohexane dicarboxylic acid, or combinations thereof. A specific dicarboxylic acid comprises a combination of isophthalic acid and terephthalic acid wherein the weight ratio of isophthalic acid to terephthalic acid is about 91:9 to about 2:98.

[0129] Mixtures of the diacids can also be employed. It should be noted that although referred to as diacids, any ester precursor could be employed such as acid halides, specifically acid chlorides, and diaromatic esters of the diacid such as diphenyl, for example the diphenyl ester of sebacic acid. With reference to the diacid carbon atom number earlier mentioned, this does not include any carbon atoms which may be included in the ester precursor portion, for example diphenyl. It may be desirable that at least four, five or six carbon bonds separate the acid groups. This may reduce the formation of undesirable and unwanted cyclic species.

[0130] The polyester unit of a polyester-polycarbonate may be derived from the reaction of a combination of isophthalic and terephthalic diacids (or derivatives thereof) with resorcinol. In another embodiment, the polyester unit of a polyester-polycarbonate may be derived from the reaction of a combination of isophthalic acid and terephthalic acid with bisphenol-A. In an embodiment, the polycarbonate units

may be derived from bisphenol-A. In another specific embodiment, the polycarbonate units may be derived from resorcinol and bisphenol-A in a molar ratio of resorcinol carbonate units to bisphenol-A carbonate units of 1:99 to 99:1.

[0131] The polyester-polycarbonate may have a biocontent according to ASTM-D-6866 of at least 2 weight %, at least 3 weight %, at least 4 weight %, at least 5 weight %, at least 6 weight %, at least 7 weight %, at least 8 weight %, at least 9 weight %, at least 10 weight %, at least 11 weight %, at least 12 weight %, at least 13 weight %, at least 14 weight %, at least 15 weight %, at least 16 weight %, at least 17 weight %, at least 18 weight %, at least 19 weight %, at least 20 weight %, at least 25 weight %, at least 30 weight %, at least 35 weight %, at least 40 weight %, at least 45 weight %, at least 50 weight %, at least 55 weight %, at least 60 weight %, or at least 65 weight % of the composition derived therefrom. The polymer, or any composition derived therefrom, may have at least 5.0 weight percent of sebacic acid content.

[0132] In such embodiments, a second end-capping agent can also be used to terminate any chains (in addition to the photoactive moiety with only one phenolic group). The second end-capping agent (i.e. chain stopper) is a monohydroxy compound, a mono-acid compound, or a mono-ester compound. Exemplary endcapping agents include p-cumylphenol (PCP), resorcinol monobenzoate, p-tert-butylphenol, octylphenol, and p-methoxyphenol. The term “end-capping agent” is used herein to denote a compound that is not photoactive when exposed to light. For example, the end-capping agent does not contain a ketone group. The photoactive additive may comprise about 0.5 mole% to about 5.0 mole% endcap groups derived from the second end-capping agent.

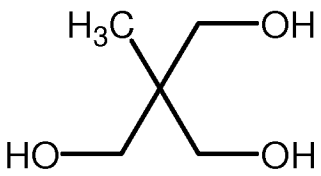
[0133] The resulting photoactive additive (PAA) may be an oligomer or a polymer with a weight average molecular weight and a polydispersity index. The product resulting from the reaction in **FIG. 2** is illustrative of such photoactive additives. Here, bisphenol-A is reacted with phosgene, 4-hydroxybenzophenone, and p-cumylphenol (endcap) to obtain the photoactive additive. Some chains will have two 4-hydroxybenzophenone endcaps, some will have only one 4-hydroxybenzophenone endcap, and some will have none, distributed in a statistical fashion.

[0134] Another example of a photoactive additive formed from a first photoactive moiety, a first linker moiety, and a diol chain extender is seen in **FIG. 3**. Here, 4-hydroxybenzophenone (first photoactive moiety) is reacted with phosgene (first linker

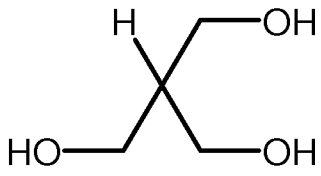
moiety) and bisphenol-A (chain extender) to obtain the photoactive additive. The resulting photoactive additive (PAA) may be an oligomer or a polymer with a weight average molecular weight and a polydispersity index.

[0135] As previously explained, a first photoactive moiety is reacted with a first linker moiety to obtain the photoactive additive. In some embodiments, a secondary linker moiety is included in the reaction mixture. The secondary linker moiety has at least three functional groups, each of which can react with the functional groups of the first linker moiety, and acts as a branching agent. Generally, the functional groups of the secondary linker moiety are hydroxyl groups. When the photoactive moiety has one phenolic group, the resulting photoactive additive (PAA) will be a compound, each molecule having the same molecular weight.

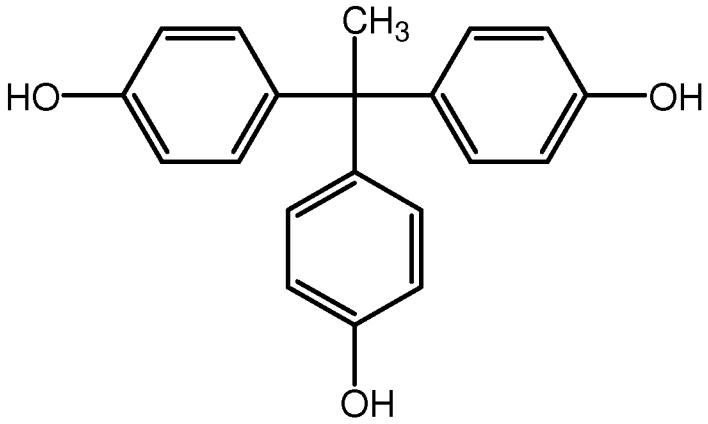
[0136] Some examples of secondary linker moieties which have three functional groups and can react with the first linker moiety include those having the structure of one of Formulas (43)-(46):



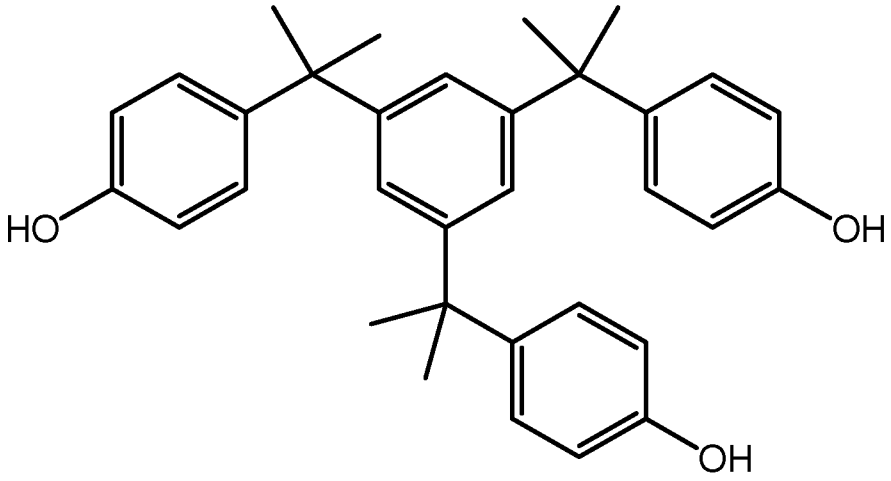
Formula (43)



Formula (44)

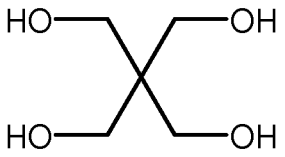


Formula (45)

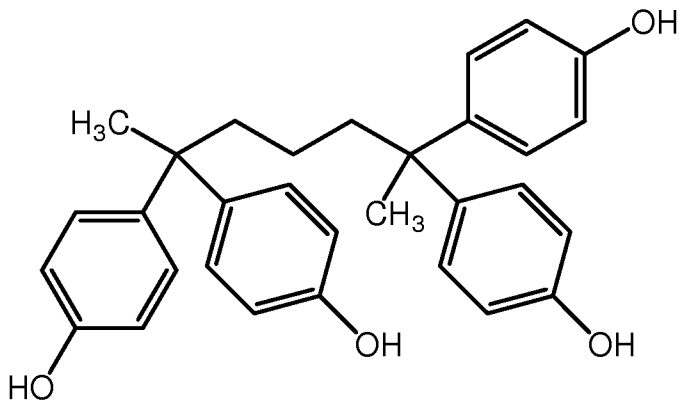


Formula (46)

[0137] Some examples of secondary linker moieties which have four functional groups and can react with the first linker moiety include those having the structure of one of Formulas (47)-(48):

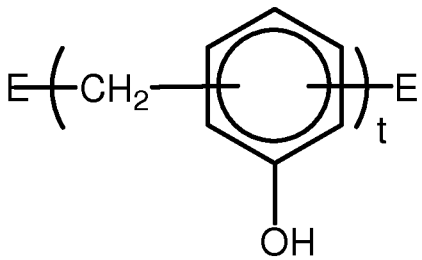


Formula (47)



Formula (48)

[0138] In some embodiments, the secondary linker moiety can be an oligomer, made from an epoxidized novolac monomer. These oligomers can permit the desired number of functional groups to be provided. Such oligomers are generalized by the structure of Formula (49):



Formula (49)

wherein E is hydrogen or an endcapping agent; and t is an integer from 1 to 20.

[0139] An example of a photoactive additive formed from a first photoactive moiety, a first linker moiety, and a secondary linker moiety is seen in **FIG. 4**. Here, two moles of 4-hydroxybenzophenone are reacted with three moles of phosgene (first linker moiety) and one mole of tris(hydroxyphenyl)ethane (THPE, secondary linker moiety) to obtain the photoactive additive. Note that the secondary linker moiety reacts with the first linker moiety, not with the photoactive moiety.

[0140] Some photoactive additives of the present disclosure can be formed from the reaction of a first photoactive moiety, a diol chain extender, a first linker moiety, and a secondary linker moiety. Such a reaction is seen in **FIG. 5**. Here, 4-hydroxybenzophenone, bisphenol-A, phosgene, and THPE are reacted to obtain the photoactive additive. The resulting photoactive additive (PAA) may be an oligomer or a polymer with a weight average molecular weight and a polydispersity index.

[0141] The photoactive additives of the present disclosure can be a compound, an oligomer, or a polymer. The oligomer has a weight average molecular weight (Mw) of less than 15,000, including 10,000 or less. The polymeric photoactive additives of the present disclosure have a Mw of 15,000 or higher. In particular embodiments, the Mw is between 17,000 and 80,000 Daltons, or between 17,000 and 35,000 Daltons. The Mw may be varied as desired. Polymers/oligomers with relatively higher Mw's generally retain their mechanical properties better, while polymers/oligomers with relatively lower Mw's generally have better flow properties. In some particular embodiments, the Mw of the photoactive additives is about 5,000 or less. During melt processing, oligomers are more likely to rise to the surface of the article. Long chain aliphatic diols (C_6 or higher) can also be used for this purpose. This may increase the concentration of the additive at the surface, and thus increase the crosslinking density at the surface upon exposure to UV light as well.

[0142] The crosslinking mechanism of the additives is believed to be due to hydrogen abstraction by the ketone group from an alkyl group that acts as a hydrogen donor and subsequent coupling of the resulting radicals. This mechanism is illustrated in **FIG. 6** with reference to a benzophenone (the photoactive moiety) and a bisphenol-A (BPA) monomer. Upon exposure to UV, the oxygen atom of the benzophenone abstracts a hydrogen atom from a methyl group on the BPA monomer and becomes a hydroxyl group. The methylene group then forms a covalent bond with the carbon of the ketone group. Put another way, the ketone

group of the benzophenone could be considered to be a photoactive group. It should be noted that the presence of hydrogen is critical for the reaction to occur.

[0143] The additives, when used, can improve the chemical resistance of the final molded article. It is contemplated that molded articles can be of any desired shape (e.g. film, sheet, etc.) and be used in many different applications, for example in the medical, automotive, and consumer electronics fields. Increased chemical resistance may be found against 409 Glass and Surface Cleaner; Alcohol Prep Pad; CaviCide liquid/CaviWipes; CaviWipes; Cidex Plus liquid; Clorox Bleach; Clorox Wipes; Envirocide liquid; ForPro liquid; Gentle dish soap and water; Hydrogen Peroxide Cleaner Disinfectant Wipes; Isopropyl Alcohol wipes; MadaCide-1 liquid; Mar-V-Cide liquid to dilute; Sani-Cloth Bleach Wipes; Sani-Cloth HB Wipes; Sani-Cloth Plus Wipes; Sodium Hypochlorite liquid; Super Sani-Cloth Wipes; Viraguard liquid and Wipes; Virex 256; Windex Blue; Fuel C; Toluene; Heptane; Ethanol; Isopropanol; Windex; Engine oil; WD40; Transmission fluid; Break fluid; Glass wash; Diesel; Gasoline; Banana Boat Sunscreen (SPF 30); Sebum; Ivory Dish Soap; SC Johnson Fantastik Cleaner; French's Yellow Mustard; Coca-Cola; 70% Isopropyl Alcohol; Extra Virgin Olive Oil; Vaseline Intensive Care Hand Lotion; Heinz Ketchup; Kraft Mayonnaise; Chlorox Formula 409 Cleaner; SC Johnson Windex Cleaner with Ammonia; Acetone; Artificial Sweat; Fruits & Passion Cucina Coriander & Olive Hand Cream; Loreal Studioline Megagel Hair Gel; Maybelline Lip Polish; Maybelline Expert Wear Blush - Beach Plum Rouge; Purell Hand Sanitizer; Hot coffee, black; iKlear; Chlorox Wipes; Squalene; Palmitic Acid; Oleic Acid; Palmitoleic Acid; Stearic Acid; and Olive Oil.

[0144] In particular embodiments, the photoactive additives (PAAs) disclosed herein are cross-linkable polycarbonates comprising monohydroxybenzophenone-derived endcaps (i.e. of Formula (1)). These polycarbonates, prior to cross-linking, can be provided as thermally stable high melt-flow polymers, and can thus be used to fabricate a variety of thin-walled articles (e.g., 3 mm or less). These articles may subsequently be treated (e.g., with UV-radiation) to affect cross-linking, thereby providing thin-walled materials that meet desired performance requirements (e.g., 5VA performance, chemical resistance, transparency). The cross-linked materials, in addition to flame resistance and chemical resistance, may retain or exhibit superior mechanical properites (e.g., impact resistance, ductility) as compared to the composition prior to cross-linking.

[0145] The use of monohydroxybenzophenone derived endcaps provides several advantages over polycarbonates incorporating repeating units derived from dihydroxybenzophenone monomers. Specifically, the monohydroxybenzophenone endcap is more economical, as less monomer is typically used. In addition, incorporation of the monohydroxybenzophenone into the polycarbonate can be particularly controlled, as the monohydroxybenzophenone will only react as a chain stopper. Accordingly, use of monohydroxybenzophenone eliminates the need for careful monitoring of polymerization kinetics or how the monomer is incorporated, as compared with a corresponding dihydroxybenzophenone monomer.

[0146] The monohydroxybenzophenone endcaps of the cross-linkable polycarbonates provide a reactive functional group for cross-linking the polycarbonates. For example, treatment of a cross-linkable polycarbonate of the invention with a suitable dose of ultra-violet radiation, as further described herein, may initiate cross-linking reaction between the monohydroxybenzophenone carbonyl carbon and a carbon atom of another functional group (e.g., a methylene carbon atom, such as in bisphenol-A) in the same polymer or another polymer in the composition.

[0147] Suitable monohydroxybenzophenone chain-stoppers include, but are not limited to, 2-hydroxybenzophenone, 3-hydroxybenzophenone, 4-hydroxybenzophenone, 4-hydroxybenzoylbenzophenone, 2-hydroxy-4-methoxybenzophenone, 2-hydroxy-4-methoxy-2'-carboxybenzophenone, 2-hydroxy-4-octoxybenzophenone, 2-hydroxy-4-stearoxybenzophenone, 4-dodecyloxy-2-hydroxybenzophenone, 2-hydroxy-4-methoxy-5-sulfobenzophenone trihydrate, and 2-hydroxy-4-methoxybenzophenone-5-sulfonic acid. In one preferred embodiment, the monohydroxybenzophenone chain stopper is a 2-hydroxybenzophenone, 3-hydroxybenzophenone, or 4-hydroxybenzophenone, each of which may be further substituted with one or more additional substituents, provided the monohydroxybenzophenone still functions as a chain-stopper. In another preferred embodiment, the monohydroxybenzophenone is 4-hydroxybenzophenone.

[0148] The cross-linkable polycarbonates (also referred to as “non-cross-linked polycarbonates”) may comprise about 0.5 mol% to about 5 mol% endcap groups derived from a monohydroxybenzophenone, about 1 mol% to about 3 mol% endcap groups derived from a monohydroxybenzophenone, about 1.7 mol% to about 2.5 mol% endcap groups derived from a monohydroxybenzophenone, about 2 mol% to

about 2.5 mol% endcap groups derived from a monohydroxybenzophenone, or about 2.5 mol% to about 3.0 mol% endcap groups derived from a monohydroxybenzophenone. The cross-linkable polycarbonates may have a monohydroxybenzophenone derived endcap content of: 0.5 mol%, 0.6 mol%, 0.7 mol%, 0.8 mol%, 0.9 mol%, 1.0 mol%, 1.1 mol%, 1.2 mol%, 1.3 mol%, 1.4 mol%, 1.5 mol%, 1.6 mol%, 1.7 mol%, 1.8 mol%, 1.9 mol%, 2.0 mol%, 2.1 mol%, 2.2 mol%, 2.3 mol%, 2.4 mol%, 2.5 mol%, 2.6 mol%, 2.7 mol%, 2.8 mol%, 2.9 mol%, 3.0 mol%, 3.1 mol%, 3.2 mol%, 3.3 mol%, 3.4 mol%, 3.5 mol%, 3.6 mol%, 3.7 mol%, 3.8 mol%, 3.9 mol%, 4.0 mol%, 4.1 mol%, 4.2 mol%, 4.3 mol%, 4.4 mol%, 4.5 mol%, 4.6 mol%, 4.7 mol%, 4.8 mol%, 4.9 mol%, or 5.0 mol%.

[0149] As described above, other end-capping agents can be incorporated into the cross-linkable polycarbonates. Exemplary chain-stoppers include certain monophenolic compounds (i.e., phenyl compounds having a single free hydroxy group), monocarboxylic acid chlorides, monocarboxylic acids, and/or monochloroformates. Phenolic chain-stoppers are exemplified by phenol and C_1-C_{22} alkyl-substituted phenols such as p-cumyl-phenol, octylphenol, resorcinol monobenzoate, and p-tertiary-butylphenol, cresol, and monoethers of diphenols, such as p-methoxyphenol. Exemplary chain-stoppers also include cyanophenols, such as for example, 4-cyanophenol, 3-cyanophenol, 2-cyanophenol, and polycyanophenols. Alkyl-substituted phenols with branched chain alkyl substituents having 8 to 9 carbon atoms can be specifically be used.

[0150] Endgroups can be derived from the carbonyl source (i.e., the diaryl carbonate or carbonate precursor, or first linker moiety), from selection of monomer ratios, incomplete polymerization, chain scission, and the like, as well as any added endcapping groups, and can include derivatizable functional groups such as hydroxy groups, carboxylic acid groups, or the like. In an embodiment, the endgroup of a polycarbonate can comprise a structural unit derived from a diaryl carbonate, where the structural unit can be an endgroup. In a further embodiment, the endgroup is derived from an activated carbonate. Such endgroups can derive from the transesterification reaction of the alkyl ester of an appropriately substituted activated carbonate, with a hydroxy group at the end of a polycarbonate polymer chain, under conditions in which the hydroxy group reacts with the ester carbonyl from the activated carbonate, instead of with the carbonate carbonyl of the activated carbonate. In this way, structural units derived from ester containing compounds or

substructures derived from the activated carbonate and present in the melt polymerization reaction can form ester endgroups. In an embodiment, the ester endgroup derived from a salicylic ester can be a residue of bis(methyl salicyl) carbonate (BMSC) or other substituted or unsubstituted bis(alkyl salicyl) carbonate such as bis(ethyl salicyl) carbonate, bis(propyl salicyl) carbonate, bis(phenyl salicyl) carbonate, bis(benzyl salicyl) carbonate, or the like. In a specific embodiment, where BMSC is used as the activated carbonyl source, the endgroup is derived from and is a residue of BMSC.

[0151] The cross-linkable polycarbonates of the present disclosure include homopolycarbonates, copolymers comprising different moieties in the carbonate (referred as "copolycarbonates"), copolymers comprising carbonate units and other types of polymer units such as polyester units, polysiloxane units, and combinations comprising at least one homopolycarbonate and copolycarbonate. For reference, the term "dipolymer" refers to copolymers derived specifically from two different monomers, and the term "terpolymer" refers to copolymers derived specifically from three different monomers

[0152] The cross-linkable polycarbonate may thus comprise identical or different repeating units derived from one or more monomers (e.g. a second, third, fourth, fifth, sixth, etc., other monomer compound). The monomers of the cross-linkable polycarbonate may be randomly incorporated into the polycarbonate. For example, a cross-linkable polycarbonate copolymer of the present disclosure may be arranged in an alternating sequence following a statistical distribution, which is independent of the mole ratio of the structural units present in the polymer chain. A random cross-linkable polycarbonate copolymer may have a structure, which can be indicated by the presence of several block sequences (I-I) and (O-O) and alternate sequences (I-O) or (O-I), that follow a statistical distribution. In a random x:(1-x) copolymer, wherein x is the mole percent of a first monomer(s) and 1-x is the mole percent of the monomers, one can calculate the distribution of each monomer using peak area values determined by ^{13}C NMR, for example.

[0153] A cross-linkable polycarbonate copolymer of the present disclosure may have alternating I and O units (-I-O-I-O-I-O-I-O-), or I and O units arranged in a repeating sequence (e.g. a periodic copolymer having the formula: (I-O-I-O-O-I-I-I-I-O-O-O)n). The cross-linkable polycarbonate copolymer may be a statistical copolymer in which the sequence of monomer residues follows a statistical rule. For

example, if the probability of finding a given type monomer residue at a particular point in the chain is equal to the mole fraction of that monomer residue in the chain, then the polymer may be referred to as a truly random copolymer. The cross-linkable polycarbonate copolymer may be a block copolymer that comprises two or more homopolymer subunits linked by covalent bonds (-I-I-I-I-I-O-O-O-O-O-). The union of the homopolymer subunits may require an intermediate non-repeating subunit, known as a junction block. Block copolymers with two or three distinct blocks are called diblock copolymers and triblock copolymers, respectively.

[0154] The cross-linkable polycarbonates of the present disclosure may include any suitable mole % of selected monomer units, with the proviso that the polycarbonates comprise a mol% (e.g., about 0.5 mol% to about 5 mol%) of endcap groups derived from a monohydroxybenzophenone. The polymers may comprise about 1% to about 99.5%, about 5% to about 95%, about 10% to about 90%, about 15% to about 85%, about 20% to about 80%, about 25% to about 75%, about 30% to about 70%, about 35% to about 65%, about 40% to about 60%, or about 45% to about 55% mole % of a selected monomer unit.

[0155] The cross-linkable polycarbonates of the present disclosure may have a glass transition temperature (Tg) of greater than 120 ºC, 125 ºC, 130 ºC, 135 ºC, 140 ºC, 145 ºC, 150 ºC, 155 ºC, 160 ºC, 165 ºC, 170 ºC, 175 ºC, 180 ºC, 185 ºC, 190 ºC, 200 ºC, 210 ºC, 220 ºC, 230 ºC, 240 ºC, 250 ºC, 260 ºC, 270 ºC, 280 ºC, 290 ºC, or 300 ºC, as measured using a differential scanning calorimetry method. In certain embodiments, the polycarbonates have glass transition temperatures ranging from about 120 ºC to about 230 ºC, about 140 ºC to about 160 ºC, about 145 ºC to about 155 ºC, about 148 ºC to about 152 ºC, or about 149 ºC to about 151 ºC. In certain embodiments, the polycarbonates have glass transition temperatures of 149.0 ºC, 149.1 ºC, 149.2 ºC, 149.3 ºC, 149.4 ºC, 149.5 ºC, 149.6 ºC, 149.7 ºC, 149.8 ºC, 149.9 ºC, 150.0 ºC, 150.1 ºC, 150.2 ºC, 150.3 ºC, 150.4 ºC, 150.5 ºC, 150.6 ºC, 150.7 ºC, 150.8 ºC, 150.9 ºC, 151.0 ºC, 151.1 ºC, 151.2 ºC, 151.3 ºC, 151.4 ºC, 151.5 ºC, 151.6 ºC, 151.7 ºC, 151.8 ºC, 151.9 ºC, 152.0 ºC, 152.1 ºC, 152.2 ºC, 152.3 ºC, 152.4 ºC, 152.5 ºC, 152.6 ºC, 152.7 ºC, 152.8 ºC, 152.9 ºC, or 153.0 ºC.

[0156] The cross-linkable polycarbonates of the present disclosure may have a weight average molecular weight (Mw) of 15,000 to about 80,000 Daltons [± 1,000 Daltons], or of 15,000 to about 35,000 Daltons [± 1,000 Daltons], or of about 20,000 to about 30,000 Daltons [± 1,000 Daltons]. In certain embodiments, the cross-

linkable polycarbonates have weight average molecular weights of about 16,000 Daltons [± 1,000 Daltons], about 17,000 Daltons [± 1,000 Daltons], about 18,000 Daltons [± 1,000 Daltons], about 19,000 Daltons [± 1,000 Daltons], about 20,000 Daltons [± 1,000 Daltons], about 21,000 Daltons [± 1,000 Daltons], about 22,000 Daltons [± 1,000 Daltons], about 23,000 Daltons [± 1,000 Daltons], about 24,000 Daltons [± 1,000 Daltons], about 25,000 Daltons [± 1,000 Daltons], about 26,000 Daltons [± 1,000 Daltons], about 27,000 Daltons [± 1,000 Daltons], about 28,000 Daltons [± 1,000 Daltons], about 29,000 Daltons [± 1,000 Daltons], about 30,000 Daltons [± 1,000 Daltons], about 31,000 Daltons [± 1,000 Daltons], about 32,000 Daltons [± 1,000 Daltons], about 33,000 Daltons [± 1,000 Daltons], about 34,000 Daltons [± 1,000 Daltons], or about 35,000 Daltons [± 1,000 Daltons]. In additional embodiments, the cross-linkable polycarbonates have a Mw of 17,000 to about 80,000 Daltons. Molecular weight determinations may be performed using gel permeation chromatography (GPC), using a cross-linked styrene-divinylbenzene column and calibrated to polycarbonate references using a UV-VIS detector set at 264 nm. Samples may be prepared at a concentration of about 1 mg/ml, and eluted at a flow rate of about 1.0 ml/min.

[0157] The cross-linkable polycarbonates of the present disclosure may have a polydispersity index (PDI) of about 1.0 to about 10.0, about 2.0 to about 7.0, or about 3.0 to about 6.0, or about 3.0 to about 7.3, or about 2.4 to about 5.2. In certain embodiments, the polycarbonates have PDIs of about 2.50, about 3.00, about 3.50, about 4.00, about 4.50, about 5.00, about 5.50, about 6.00, about 6.50, about 7.00, or about 7.50.

[0158] It is noted that the molecular weight (both weight-average and number-average) of the photoactive additive / cross-linkable polycarbonate can be measured using two different kinds of detectors. More specifically, the molecular weight can be measured using an ultraviolet (UV) detector or using a refractive index (RI) detector, using GPC and calibrated to polycarbonate standards for both detectors. In this regard, the UV detector overweights the presence of low-molecular-weight chains due to the higher extinction coefficient of the monohydroxybenzophenone in the UV detector. This does not occur in the RI detector, and so the PDI as measured by the RI detector is always lower than the PDI as measured by the UV detector.

[0159] In embodiments, the ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector is 1.8 or less, when using a

GPC method and polycarbonate molecular weight standards. The ratio may also be 1.5 or less, or 1.2 or less. The PDI ratio has a minimum value of 1.0. As described further herein, the process by which the cross-linkable polycarbonate is made can affect the PDI ratio between the UV detector and the RI detector.

[0160] The cross-linkable polycarbonates of the present disclosure may have a melt volume flow rate (often abbreviated MVR), which measures the rate of extrusion of a composition through an orifice at a prescribed temperature and load. In certain embodiments, the polycarbonates may have an MVR of 2 to 4 cm^3/10 min, 2 to 12 cm^3/10 min, 2 to 70 cm^3/10 min, 2 to 50 cm^3/10 min, 2 to 40 cm^3/10 min, 2 to 30 cm^3/10 min, 2 to 25 cm^3/10 min, 2 to 20 cm^3/10 min, 5 to 70 cm^3/10 min, 5 to 50 cm^3/10 min, 5 to 40 cm^3/10 min, 5 to 30 cm^3/10 min, 5 to 25 cm^3/10 min, 5 to 20 cm^3/10 min, 8 to 10 cm^3/10 min, 8 to 12 cm^3/10 min, 10 to 170 cm^3/10 min, 10 to 50 cm^3/10 min, 10 to 40 cm^3/10 min, 10 to 30 cm^3/10 min, 10 to 25 cm^3/10 min, or 10 to 20 cm^3/10 min, using the ASTM D1238 method, 1.2 kg load, 300 °C temperature, 360 second dwell. In certain embodiments, the polycarbonates may have an MVR measured using the ASTM D1238 method, 1.2 kg load, 300 °C temperature, 360 second dwell, of: 2.0 cm^3/10 min, 2.1 cm^3/10 min, 2.2 cm^3/10 min, 2.3 cm^3/10 min, 2.4 cm^3/10 min, 2.5 cm^3/10 min, 2.6 cm^3/10 min, 2.7 cm^3/10 min, 2.8 cm^3/10 min, 2.9 cm^3/10 min, 3.0 cm^3/10 min, 3.1 cm^3/10 min, 3.2 cm^3/10 min, 3.3 cm^3/10 min, 3.4 cm^3/10 min, 3.5 cm^3/10 min, 3.6 cm^3/10 min, 3.7 cm^3/10 min, 3.8 cm^3/10 min, 3.9 cm^3/10 min, 4.0 cm^3/10 min, 4.1 cm^3/10 min, 4.2 cm^3/10 min, 4.3 cm^3/10 min, 4.4 cm^3/10 min, 4.5 cm^3/10 min, 4.6 cm^3/10 min, 4.7 cm^3/10 min, 4.8 cm^3/10 min, 4.9 cm^3/10 min, 5.0 cm^3/10 min, 5.1 cm^3/10 min, 5.2 cm^3/10 min, 5.3 cm^3/10 min, 5.4 cm^3/10 min, 5.5 cm^3/10 min, 5.6 cm^3/10 min, 5.7 cm^3/10 min, 5.8 cm^3/10 min, 5.9 cm^3/10 min, 6.0 cm^3/10 min, 6.1 cm^3/10 min, 6.2 cm^3/10 min, 6.3 cm^3/10 min, 6.4 cm^3/10 min, 6.5 cm^3/10 min, 6.6 cm^3/10 min, 6.7 cm^3/10 min, 6.8 cm^3/10 min, 6.9 cm^3/10 min, 7.0 cm^3/10 min, 7.1 cm^3/10 min, 7.2 cm^3/10 min 7.3 cm^3/10 min, 7.4 cm^3/10 min, 7.5 cm^3/10 min, 7.6 cm^3/10 min, 7.7 cm^3/10 min, 7.8 cm^3/10 min, 7.9 cm^3/10 min, 8.0 cm^3/10 min, 8.1 cm^3/10 min, 8.2 cm^3/10 min, 8.3 cm^3/10 min, 8.4 cm^3/10 min, 8.5 cm^3/10 min, 8.6 cm^3/10 min, 8.7 cm^3/10 min, 8.8 cm^3/10 min, 8.9 cm^3/10 min, 9.0 cm^3/10 min, 9.1 cm^3/10 min, 9.2 cm^3/10 min, 9.3 cm^3/10 min, 9.4 cm^3/10 min, 9.5 cm^3/10 min, 9.6 cm^3/10 min, 9.7 cm^3/10 min, 9.8 cm^3/10 min, 9.9 cm^3/10 min, 10.0 cm^3/10 min, 10.1 cm^3/10 min, 10.2 cm^3/10 min, 10.3 cm^3/10 min, 10.4 cm^3/10 min, 10.5 cm^3/10 min, 10.6 cm^3/10 min, 10.7 cm^3/10 min, 10.8 cm^3/10

min, 10.9 cm^3/10 min, 11.0 cm^3/10 min, 11.1 cm^3/10 min, 11.2 cm^3/10 min, 11.3 cm^3/10 min, 11.4 cm^3/10 min, 11.5 cm^3/10 min, 11.6 cm^3/10 min, 11.7 cm^3/10 min, 11.8 cm^3/10 min, 11.9 cm^3/10 min, 12.0 cm^3/10 min, 12.1 cm^3/10 min, 12.2 cm^3/10 min, 12.3 cm^3/10 min, 12.4 cm^3/10 min, 12.5 cm^3/10 min, 12.6 cm^3/10 min, 12.7 cm^3/10 min, 12.8 cm^3/10 min, 12.9 cm^3/10 min, 13.0 cm^3/10 min, 13.1 cm^3/10 min, 13.2 cm^3/10 min, 13.3 cm^3/10 min, 13.4 cm^3/10 min, 13.5 cm^3/10 min, 13.6 cm^3/10 min, 13.7 cm^3/10 min, 13.8 cm^3/10 min, 13.9 cm^3/10 min, 14.0 cm^3/10 min, 14.1 cm^3/10 min, 14.2 cm^3/10 min, 14.3 cm^3/10 min, 14.4 cm^3/10 min. 14.5 cm^3/10 min, 14.6 cm^3/10 min, 14.7 cm^3/10 min, 14.8 cm^3/10 min, 14.9 cm^3/10 min, 15.0 cm^3/10 min, 15.1 cm^3/10 min, 15.2 cm^3/10 min, 15.3 cm^3/10 min, 15.4 cm^3/10 min, 15.5 cm^3/10 min, 15.6 cm^3/10 min, 15.7 cm^3/10 min, 15.8 cm^3/10 min, 15.9 cm^3/10 min, 16.0 cm^3/10 min, 16.1 cm^3/10 min, 16.2 cm^3/10 min, 16.3 cm^3/10 min, 16.4 cm^3/10 min, 16.5 cm^3/10 min, 16.6 cm^3/10 min, 16.7 cm^3/10 min, 16.8 cm^3/10 min, 16.9 cm^3/10 min, 17.0 cm^3/10 min, 17.1 cm^3/10 min, 17.2 cm^3/10 min, 17.3 cm^3/10 min, 17.4 cm^3/10 min, 17.5 cm^3/10 min, 17.6 cm^3/10 min, 17.7 cm^3/10 min, 17.8 cm^3/10 min, 17.9 cm^3/10 min, 18.0 cm^3/10 min, 18.1 cm^3/10 min, 18.2 cm^3/10 min, 18.3 cm^3/10 min, 18.4 cm^3/10 min, 18.5 cm^3/10 min, 18.6 cm^3/10 min 18.7 cm^3/10 min, 18.8 cm^3/10 min, 18.9 cm^3/10 min, 19.0 cm^3/10 min, 19.1 cm^3/10 min, 19.2 cm^3/10 min, 19.3 cm^3/10 min, 19.4 cm^3/10 min, 19.5 cm^3/10 min, 19.6 cm^3/10 min, 19.7 cm^3/10 min, 19.8 cm^3/10 min, 19.9 cm^3/10 min, 20.0 cm^3/10 min, 20.1 cm^3/10 min, 20.2 cm^3/10 min, 20.3 cm^3/10 min, 20.4 cm^3/10 min, 20.5 cm^3/10 min, 20.6 cm^3/10 min, 20.7 cm^3/10 min, 20.8 cm^3/10 min, 20.9 cm^3/10 min, 21.0 cm^3/10 min, 21.1 cm^3/10 min, 21.2 cm^3/10 min, 21.3 cm^3/10 min, 21.4 cm^3/10 min, 21.5 cm^3/10 min, 21.6 cm^3/10 min, 21.7 cm^3/10 min, 21.8 cm^3/10 min, 21.9 cm^3/10 min, 22.0 cm^3/10 min, 22.1 cm^3/10 min, 22.2 cm^3/10 min, 22.3 cm^3/10 min, 22.4 cm^3/10 min, 22.5 cm^3/10 min, 22.6 cm^3/10 min, 22.7 cm^3/10 min, 22.8 cm^3/10 min, 22.9 cm^3/10 min, 23.0 cm^3/10 min, 23.1 cm^3/10 min, 23.2 cm^3/10 min, 23.3 cm^3/10 min, 23.4 cm^3/10 min, 23.5 cm^3/10 min, 23.6 cm^3/10 min, 23.7 cm^3/10 min, 23.8 cm^3/10 min, 23.9 cm^3/10 min, 24.0 cm^3/10 min, 24.1 cm^3/10 min, 24.2 cm^3/10 min, 24.3 cm^3/10 min, 24.4 cm^3/10 min, 24.5 cm^3/10 min, 24.6 cm^3/10 min, 24.7 cm^3/10 min, 24.8 cm^3/10 min, 24.9 cm^3/10 min, 25.0 cm^3/10 min, 25.1 cm^3/10 min, 25.2 cm^3/10 min, 25.3 cm^3/10 min, 25.4 cm^3/10 min, 25.5 cm^3/10 min, 25.6 cm^3/10 min, 25.7 cm^3/10 min, 25.8 cm^3/10 min, 25.9 cm^3/10 min, 26.0 cm^3/10 min, 26.1 cm^3/10 min, 26.2 cm^3/10 min, 26.3 cm^3/10 min, 26.4 cm^3/10 min, 26.5 cm^3/10 min, 26.6 cm^3/10 min, 26.7

cm^3/10 min, 26.8 cm^3/10 min, 26.9 cm^3/10 min, 27.0 cm^3/10 min, 27.1 cm^3/10 min, 27.2 cm^3/10 min, 27.3 cm^3/10 min, 27.4 cm^3/10 min, 27.5 cm^3/10 min, 27.6 cm^3/10 min, 27.7 cm^3/10 min, 27.8 cm^3/10 min, 27.9 cm^3/10 min, 28.0 cm^3/10 min, 28.1 cm^3/10 min, 28.2 cm^3/10 min, 28.3 cm^3/10 min, 28.4 cm^3/10 min, 28.5 cm^3/10 min, 28.6 cm^3/10 min, 28.7 cm^3/10 min, 28.8 cm^3/10 min, 28.9 cm^3/10 min, 29.0 cm^3/10 min, 29.1 cm^3/10 min, 29.2 cm^3/10 min, 29.3 cm^3/10 min, 29.4 cm^3/10 min, 29.5 cm^3/10 min, 29.6 cm^3/10 min, 29.7 cm^3/10 min, 29.8 cm^3/10 min, 29.9 cm^3/10 min, 30.0 cm^3/10 min, 30.1 cm^3/10 min, 30.2 cm^3/10 min, 30.3 cm^3/10 min, 30.4 cm^3/10 min, 30.5 cm^3/10 min, 30.6 cm^3/10 min, 30.7 cm^3/10 min, 30.8 cm^3/10 min, 30.9 cm^3/10 min, 31.0 cm^3/10 min, 31.1 cm^3/10 min, 31.2 cm^3/10 min, 31.3 cm^3/10 min, 31.4 cm^3/10 min, 31.5 cm^3/10 min, 31.6 cm^3/10 min, 31.7 cm^3/10 min, 31.8 cm^3/10 min, 31.9 cm^3/10 min, 32.0 cm^3/10 min, 32.1 cm^3/10 min, 32.2 cm^3/10 min, 32.3 cm^3/10 min, 32.4 cm^3/10 min, 32.5 cm^3/10 min, 32.6 cm^3/10 min, 32.7 cm^3/10 min, 32.8 cm^3/10 min, 32.9 cm^3/10 min, 33.0 cm^3/10 min, 33.1 cm^3/10 min, 33.2 cm^3/10 min, 33.3 cm^3/10 min, 33.4 cm^3/10 min, 33.5 cm^3/10 min, 33.6 cm^3/10 min, 33.7 cm^3/10 min, 33.8 cm^3/10 min, 33.9 cm^3/10 min, 34.0 cm^3/10 min, 34.1 cm^3/10 min, 34.2 cm^3/10 min, 34.3 cm^3/10 min, 34.4 cm^3/10 min, 34.5 cm^3/10 min, 34.6 cm^3/10 min, 34.7 cm^3/10 min, 34.8 cm^3/10 min, 34.9 cm^3/10 min, or 35.0 cm^3/10 min.

[0161] The cross-linkable polycarbonates of the present disclosure may have a biocontent of 2 weight % to 90 weight %; 5 weight % to 25 weight %; 10 weight % to 30 weight %; 15 weight % to 35 weight %; 20 weight % to 40 weight %; 25 weight % to 45 weight %; 30 weight % to 50 weight %; 35 weight % to 55 weight %; 40 weight % to 60 weight %; 45 weight % to 65 weight %; 55 weight % to 70% weight %; 60 weight % to 75 weight %; 50 weight % to 80 weight %; or 50 weight % to 90 weight %. The biocontent may be measured according to ASTM D6866.

[0162] The cross-linkable polycarbonates of the present disclosure may have a modulus of elasticity of greater than or equal to 2200 megapascals (MPa), greater than or equal to 2310 MPa, greater than or equal to 2320 MPa, greater than or equal to 2330 MPa, greater than or equal to 2340 MPa, greater than or equal to 2350 MPa, greater than or equal to 2360 MPa, greater than or equal to 2370 MPa, greater than or equal to 2380 MPa, greater than or equal to 2390 MPa, greater than or equal to 2400 MPa, greater than or equal to 2420 MPa, greater than or equal to 2440 MPa, greater than or equal to 2460 MPa, greater than or equal to 2480 MPa, greater than

or equal to 2500 MPa, or greater than or equal to 2520 MPa as measured by ASTM D 790 at 1.3 mm/min, 50 mm span.

[0163] In an embodiment the cross-linkable polycarbonates of the present disclosure may have a flexural modulus of 2,200 to 2,500, preferably 2,250 to 2,450, more preferably 2,300 to 2,400 MPa. The flexural modulus is also measured by ASTM D790.

[0164] In another embodiment the cross-linkable polycarbonates of the present disclosure may have a flexural modulus of 2,300 to 2,600, preferably 2,400 to 2,600, more preferably 2,450 to 2,550 MPa.

[0165] The cross-linkable polycarbonates of the present disclosure may have a tensile strength at break of greater than or equal to 60 megapascals (MPa), greater than or equal to 61 MPa, greater than or equal to 62 MPa, greater than or equal to 63 MPa, greater than or equal to 64 MPa, greater than or equal to 65 MPa, greater than or equal to 66 MPa, greater than or equal to 67 MPa, greater than or equal to 68 MPa, greater than or equal to 69 MPa, greater than or equal to 70 MPa, greater than or equal to 71 MPa, greater than or equal to 72 MPa, greater than or equal to 73 MPa, greater than or equal to 74 MPa, greater than or equal to 75 MPa as measured by ASTM D 638 Type I at 50 mm/min.

[0166] The cross-linkable polycarbonates of the present disclosure may possess a ductility of greater than or equal to 60%, greater than or equal to 65%, greater than or equal to 70%, greater than or equal to 75%, greater than or equal to 80%, greater than or equal to 85%, greater than or equal to 90%, greater than or equal to 95%, or 100% in a notched izod test at -20 ºC, -15 ºC, -10 ºC, 0 ºC, 5 ºC, 10 ºC, 15 ºC, 20 ºC, 23 ºC, 25 ºC, 30 ºC, or 35 ºC at a thickness of 3.2 mm according to ASTM D 256-10.

[0167] The cross-linkable polycarbonates of the present disclosure may have a notched Izod impact strength (NII) of greater than or equal to 500 J/m, greater than or equal to 550 J/m, greater than or equal to 600 J/m, greater than or equal to 650 J/m, greater than or equal to 700 J/m, greater than or equal to 750 J/m, greater than or equal to 800 J/m, greater than or equal to 850 J/m, greater than or equal to 900 J/m, greater than or equal to 950 J/m, or greater than or equal to 1000 J/m, measured at 23 ºC according to ASTM D 256.

[0168] The cross-linkable polycarbonates of the present disclosure may have a heat distortion temperature of greater than or equal to 110 °C, 111 °C, 112°C,

113°C, 114°C, 115°C, 116°C, 117°C, 118 °C, 119°C, 120 °C, 121°C, 122°C, 123°C, 124°C, 125°C, 126°C, 127°C, 128 °C, 129°C, 130°C, 131°C, 132°C, 133°C, 134°C, 135°C, 136°C, 137°C, 138 °C, 139°C, 140 °C,141 °C, 142°C, 143°C, 144°C, 145°C, 146°C, 147°C, 148 °C, 149°C, 150 °C, 151 °C, 152°C, 153°C, 154°C, 155°C, 156°C, 157°C, 158 °C, 159°C, 160, 161 °C, 162°C, 163°C, 164°C, 165°C, 166°C, 167°C, 168 °C, 169°C, or 170 °C, as measured according to ASTM D 648 at 1.82 MPa, with 3.2 mm thick unannealed mm bar.

[0169] The cross-linkable polycarbonates of the present disclosure may have a percent haze value of less than or equal to 10.0%, less than or equal to 8.0%, less than or equal to 6.0%, less than or equal to 5.0%, less than or equal to 4.0%, less than or equal to 3.0%, less than or equal to 2.0%, less than or equal to 1.5%, less than or equal to 1.0%, or less than or equal to 0.5% as measured at a certain thickness according to ASTM D 1003-07. The polycarbonate haze may be measured at a 2.0, 2.2, 2.4, 2.54, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, or a 4.0 millimeter thickness. The polycarbonate may be measured at a 0.125 inch thickness.

[0170] The polycarbonate may have a light transmittance greater than or equal to 50%, greater than or equal to 60%, greater than or equal to 65%, greater than or equal to 70%, greater than or equal to 75%, greater than or equal to 80%, greater than or equal to 85%, greater than or equal to 90%, greater than or equal to 95%, greater than or equal to 96%, greater than or equal to 97%, greater than or equal to 98%, greater than or equal to 99%, greater than or equal to 99.1%, greater than or equal to 99.2%, greater than or equal to 99.3%, greater than or equal to 99.4%, greater than or equal to 99.5%, greater than or equal to 99.6%, greater than or equal to 99.7%, greater than or equal to 99.8%, or greater than or equal to 99.9%, as measured at certain thicknesses according to ASTM D 1003-07. The polycarbonate transparency may be measured at a 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, or a 4.0 millimeter thickness.

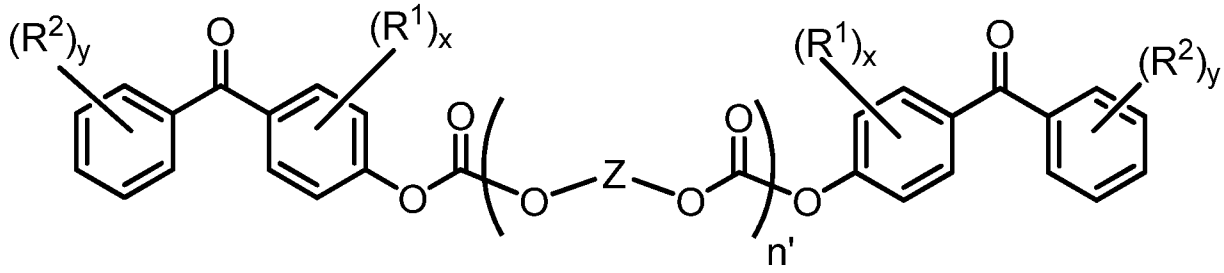
[0171] In certain embodiments, the cross-linkable polycarbonates of the present disclosure do not include soft block or soft aliphatic segments in the polycarbonate chain. For example, the following aliphatic soft segments that may be excluded from the cross-linkable polycarbonates of the present disclosure include aliphatic polyesters, aliphatic polyethers, aliphatic polythioeithers, aliphatic polyacetals, aliphatic polycarbonates, C-C linked polymers and polysiloxanes. The soft segments of aliphatic polyesters, aliphatic polyethers, aliphatic polythioeithers, aliphatic

polyacetals, aliphatic polycarbonates may be characterized as having Number Average MWs (Mns) of greater than 600.

[0172] In certain embodiments, the cross-linkable polycarbonates of the present disclosure do not include units derived from aromatic di-, tri-, or tetrahydroxyketones.

[0173] In certain embodiments, the cross-linkable polycarbonates of the present disclosure do not include units derived from dihydroxybenzophenone monomers, trihydroxybenzophenone monomers, tetrahydroxybenzophenone monomers, or other multiple-hydroxybenzophenone monomers. For example, the following monomer units may be excluded from use in the cross-linkable and cross-linked polycarbonates of the present disclosure: 4,4'-dihydroxybenzophenone, 2,4-dihydroxybenzophenone, and 4-(α,α-bis(4-hydroxyphenyl)ethyl-benzophenone.

[0174] In particular embodiments, the non-cross-linked (i.e. cross-linkable) polycarbonate has the structure of Formula (I):

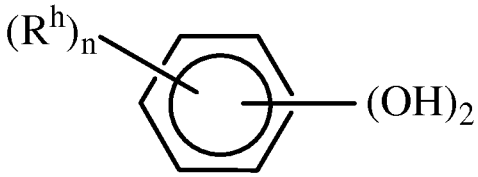


Formula (I)

wherein each repeating unit -O-Z-OC(=O)- is independently derived from a carbonate precursor or source and

(i) a monomer having the structure HO—A1—Y1—A2—OH wherein each of A_1 and A_2 comprise a monocyclic divalent arylene group, and Y_1 is a bridging group having one or more atoms; or

(ii) a monomer having the structure



wherein each R^h is independently a halogen atom, a C_1-C_{10} hydrocarbyl, or a halogen substituted C_1-C_{10} hydrocarbyl, and n is 0 to 4;

R^1 is halogen, C_1-C_6 alkyl, C_3-C_8 cycloalkyl, aryl, or arylalkyl;

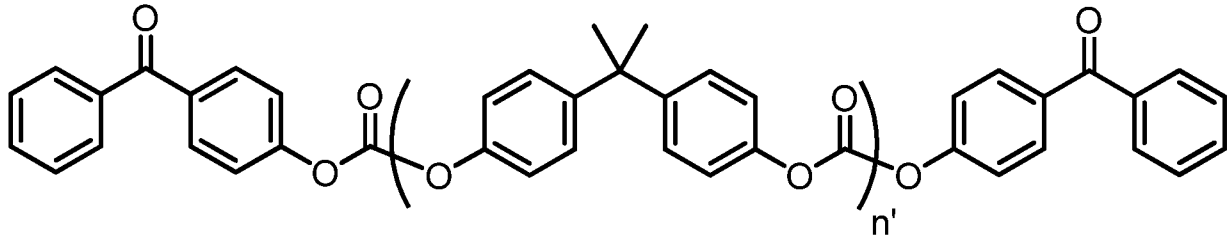
R^2 is halogen, C_1-C_6 alkyl, C_3-C_8 cycloalkyl, aryl, or arylalkyl;

x is 0, 1, 2, 3, or 4;

y is 0, 1, 2, 3, 4, or 5; and

n' ranges from 29 to 65.

[0175] In more specific embodiments, the non-cross-linked (i.e. cross-linkable) polycarbonate has the structure of Formula (II):



Formula (II)

wherein n' ranges from 29 to 65.

[0176] In particular embodiments, the photoactive cross-linkable polycarbonate contains about 0.5 mol% of endcaps derived from a monohydroxybenzophenone, and has a weight-average molecular weight (Mw) from 17,000 to 30,000 Daltons. In other specific embodiments, the photoactive cross-linkable polycarbonate contains about 2.5 mol% of endcaps derived from a monohydroxybenzophenone, and has a weight-average molecular weight (Mw) from 24,000 to 31,000 Daltons. In still other definite embodiments, the photoactive cross-linkable polycarbonate has an MVR of 8 to 10 cc/10 min at 300°C/1.2 kg, and can achieve UL94 V0 performance at a thickness of 2.0 mm.

[0177] An interfacial polycondensation polymerization process for bisphenol-A (BPA) based polycarbonates can be used to prepare the photoactive additives (PAAs) of the present disclosure. Although the reaction conditions for interfacial polymerization can vary, an exemplary process generally involves dissolving or dispersing one or more dihydric phenol reactants (e.g. bisphenol-A) in aqueous caustic soda or potash, adding the resulting mixture to a water-immiscible solvent medium, and contacting the reactants with a carbonate precursor (e.g. phosgene) in the presence of a catalyst (e.g. triethylamine, TEA) under controlled pH conditions, e.g., 8 to 11.

[0178] This process typically produces polycarbonates with a polydispersity index (PDI) of less than 3. In experiments, benzophenone-containing molecules have exhibited slower reaction kinetics compared to BPA during interfacial polymerization using phosgene. These reduced reaction kinetics have resulted in an increased formation of lower molecular weight compounds and an accompanying increase in the PDI compared to BPA polycarbonate. Conventional polymerization methods have resulted in benzophenone-containing polycarbonate generally having a PDI greater than 3. Increased PDI can indicate an increased low molecular weight fraction in the product. Increased low molecular weight fraction can lead to difficulties in extrusion and injection molding processes by altering the flow behavior or causing the low molecular weight components to volatilize out of the material. A reaction methodology to control the formation of low molecular weight compounds and the resultant PDI would be desirable for the production of oligomers and polymers containing a photoactive moiety, such as a benzophenone.

[0179] Four different processes are disclosed herein for producing some embodiments of the photoactive additive which contain carbonate linkages. Each process includes the following ingredients: a monohydroxy compound, a polyhydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent. The monohydroxy compound is the photoactive moiety. It should be noted that more than one of each ingredient can be used to produce the photoactive additive. For example, both bisphenol-A and trishydroxyphenylethane (THPE) would be considered polyhydroxy compounds (though one is a diol chain extender and the other is a branching agent). Some information on each ingredient is first provided below.

[0180] The monohydroxy compound is the photoactive moiety previously described. For example, the monohydroxy compound can have the structure of any one of Formulas (1), (3), or (5)-(10). The monohydroxy compound acts as an endcapping agent, and the previously described endcapping agents (e.g. p-cumyl phenol) could also be used. If desired, more than one monohydroxy compound can be used. In particular embodiments for producing a cross-linkable polycarbonate, the monohydroxy compound is a monohydroxybenzophenone of Formula (1).

[0181] The term “polyhydroxy compound” here refers to a compound having two or more hydroxyl groups. In contrast, the term “dihydroxy compound” refers to a compound having only two hydroxyl groups. The polyhydroxy compound can be a

dihydroxy compound having the structure of any one of Formulas (B)-(H), which are chain extenders, and include monomers such as bisphenol-A. In addition, the secondary linker moieties of any one of Formulas (43)-(49) can be considered a polyhydroxy compound, and are useful as branching agents. If desired, more than one polyhydroxy compound can be used. See, for example, the reaction in **FIG. 5**. In the cross-linkable polycarbonates of the present disclosure, bisphenol-A is typically used.

[0182] The carbonate precursor may be, for example, a carbonyl halide such as carbonyl dibromide or carbonyl dichloride (also known as phosgene), or a haloformate such as a bishaloformate of a dihydric phenol (e.g., the bischloroformate of bisphenol-A, hydroquinone, or the like) or a glycol (e.g., the bishaloformate of ethylene glycol, neopentyl glycol, polyethylene glycol, or the like). Combinations comprising at least one of the foregoing types of carbonate precursors can also be used. In certain embodiments, the carbonate precursor is phosgene, a triphosgene, diacyl halide, dihaloformate, dicyanate, diester, diepoxy, diarylcarbonate, dianhydride, dicarboxylic acid, diacid chloride, or any combination thereof. An interfacial polymerization reaction to form carbonate linkages may use phosgene as a carbonate precursor, and is referred to as a phosgenation reaction. Many such carbonate precursors correspond to a structure of Formulas (30)-(35).

[0183] A tertiary amine catalyst is used for polymerization. Exemplary tertiary amine catalysts that can be used are aliphatic tertiary amines such as triethylamine (TEA), tributylamine, cycloaliphatic amines such as N,N-diethyl-cyclohexylamine and aromatic tertiary amines such as N,N-dimethylaniline.

[0184] Sometimes, a phase transfer catalyst is also used. Among the phase transfer catalysts that can be used are catalysts of the formula $(R^{30})_4Q^+X$, wherein each R^{30} is the same or different, and is a C_1-C_{10} alkyl group; Q is a nitrogen or phosphorus atom; and X is a halogen atom, C_1-C_8 alkoxy group, or C_6-C_{18} aryloxy group. Exemplary phase transfer catalysts include, for example, $[CH_3(CH_2)_3]_4NX$, $[CH_3(CH_2)_3]_4PX$, $[CH_3(CH_2)_5]_4NX$, $[CH_3(CH_2)_6]_4NX$, $[CH_3(CH_2)_4]_4NX$, $CH_3[CH_3(CH_2)_3]_3NX$, and $CH_3[CH_3(CH_2)_2]_3NX$, wherein X is Cl^-, Br^-, a C_1-C_8 alkoxy group or a C_6-C_{18} aryloxy group, such as methyltributylammonium chloride.

[0185] The most commonly used water-immiscible solvents include methylene chloride, 1,2-dichloroethane, chlorobenzene, toluene, and the like.

[0186] In the first process, sometimes referred to as the "upfront" process, all of the hydroxy compounds, catalysts, water, and water-immiscible solvent are combined upfront in a vessel to form a reaction mixture. The reaction mixture is then exposed to the carbonate precursor, for example by phosgenation, to obtain the photoactive additive.

[0187] To form a cross-linkable polycarbonate using this upfront process, the reaction mixture comprises a monohydroxybenzophenone, a dihydroxy compound, a tertiary amine catalyst, water, and water-immiscible solvent. In more specific embodiments, the monohydroxybenzophenone is 4-hydroxybenzophenone, the dihydroxy compound is bisphenol-A, and water-immiscible solvent is methylene chloride. The phase transfer catalyst, when used, is methyltributylammonium chloride. A second end-capping agent is usually present in the reaction mixture as well, such as phenol, p-t-butylphenol, p-cumylphenol, octylphenol, or p-cyanophenol. The pH of the reaction mixture is usually from about 8 to about 9, and can be maintained by using a basic solution (e.g. aqueous NaOH). The reaction mixture is then charged with the carbonate precursor, which is usually phosgene. The carbonate precursor is added to the reaction mixture over a period of about 30 minutes to about 40 minutes. While the carbonate precursor is being added, the pH is also maintained in the range of about 8.5 to about 10, again by addition of a basic solution as needed. The cross-linkable polycarbonate is thus obtained, and is then isolated from the reaction mixture.

[0188] The resulting photoactive additive (e.g. the cross-linkable polycarbonate) contains only a small amount of low-molecular-weight components. This can be measured in two different ways: the level of diarylcarbonates and the lows percentage can be measured. Diarylcarbonates are formed by the reaction of two monohydroxybenzophenones with phosgene, creating a small molecule that contains no chain extender (e.g. bisphenol-A). In embodiments, the resulting photoactive additive contains less than 1900 ppm of diarylcarbonates. In more specific embodiments, the photoactive additive contains about 100 ppm or less of diarylcarbonates. The lows percentage is the percentage by weight of oligomeric chains having a molecular weight of less than 1000. In embodiments, the lows percentage is 2.0 wt% or less, including from about 1.0 wt% to 2.0 wt%. Also of note is that the resulting photoactive additive does not contain any residual pyridine, because pyridine is not used in the manufacture of the photoactive additive.

[0189] The resulting photoactive additive made using the "upfront" process may have, in particular embodiments, a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards, including from 17,000 to 35,000 Daltons.

[0190] The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector may be 1.8 or less, when using a GPC method and polycarbonate molecular weight standards, or may be 1.5 or less.

[0191] In the second process, also known as the "solution addition" process, the polyhydroxy compound(s), tertiary amine catalyst, water, and water-immiscible solvent are combined in a vessel to form a reaction mixture. The carbonate precursor is then added to this reaction mixture in the vessel over a first time period. During this time period, the monohydroxy compound is added in a controlled manner to the reaction mixture as well, also referred to as programmed addition. The addition of the monohydroxy compound occurs throughout the first time period, rather than as a bolus at one time point (as in the upfront process). Put another way, the carbonate precursor and the monohydroxy compound are added concurrently. The photoactive additive is thus obtained. The first and second processes are illustrated in **FIG. 7** using 4-hydroxybenzophenone, bisphenol-A, and phosgene. The main difference is in the addition of the monohydroxy compound over time, which is not illustratable.

[0192] To form a cross-linkable polycarbonate using this solution addition process, the reaction mixture comprises the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent. In more specific embodiments, the monohydroxybenzophenone is 4-hydroxybenzophenone, the dihydroxy compound is bisphenol-A, and water-immiscible solvent is methylene chloride. Again, a second end-capping agent can be present in the reaction mixture as well, such as phenol, p-t-butylphenol, p-cumylphenol, octylphenol, or p-cyanophenol. The pH of the reaction mixture is usually from about 8 to about 9, and can be maintained by using a basic solution (e.g. aqueous NaOH).

[0193] The monohydroxy compound is, in particular embodiments, 4-hydroxybenzophenone. The monohydroxy compound is separately dissolved in a solvent to form a solution which is then added to the reaction mixture. The solvent in this solution can be the same as the water-immiscible solvent (e.g. methylene chloride). Alternatively, the solvent can be water that contains a base, so that the

solution is a dilute aqueous basic solution. The base may be, for example, NaOH, or other similar bases. In embodiments, the dilute aqueous basic solution contains from about 1 to about 2 moles of the base per mole of the monohydroxy compound, and contains from about 5 wt% to about 20 wt% of the monohydroxy compound.

[0194] The reaction mixture is then charged with the carbonate precursor, which is usually phosgene. The carbonate precursor is added to the reaction mixture over a first time period, which may be for example from about 30 minutes to about 40 minutes. While the carbonate precursor is being added, the pH is also maintained in the range of about 8.5 to about 10, again by addition of a basic solution as needed. It is contemplated that the carbonate precursor is added at a constant rate over the first time period.

[0195] The solution containing the monohydroxy compound is concurrently added to the reaction mixture during the first time period in which the carbonate precursor is being added. It is contemplated that the solution is added at a constant rate, and that the time in which the solution is added will be shorter than the first time period. In particular embodiments, the solution containing the monohydroxy compound is added to the reaction mixture over a portion of the first time period corresponding to from 10% to about 40% of the total charge of the carbonate precursor (measured either by weight or by moles). For example, if the carbonate precursor is added at a constant rate for 40 minutes, the monohydroxy compound would begin to be added 4 minutes (i.e. 10% of 40 minutes) after the start of addition of the carbonate precursor. Addition of the monohydroxy compound would end 16 minutes (i.e. 40% of 40 minutes) after the start of addition of the carbonate precursor. The carbonate precursor then continues to be charged for an additional 24 minutes afterwards. The cross-linkable polycarbonate is thus obtained, and is then isolated from the reaction mixture.

[0196] Again, the resulting photoactive additive (e.g. the cross-linkable polycarbonate) contains only a small amount of low-molecular-weight components. In embodiments, the resulting photoactive additive contains less than 700 ppm of diarylcarbonates. In embodiments, the lows percentage can be 1.5 wt% or less, including from about 1.0 wt% to 1.5 wt%. Again, the resulting photoactive additive does not contain any residual pyridine.

[0197] The resulting photoactive additive made using the “solution addition” process may have, in particular embodiments, a weight-average molecular weight of

between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards, including from 17,000 to 35,000 Daltons. The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector may be 1.5 or less, when using a GPC method and polycarbonate molecular weight standards.

[0198] The third process is also referred to as a bis-chloroformate or chlorofomate (BCF) process. Chloroformate oligomers are prepared by reacting the carbonate precursor, specifically phosgene, with the polyhydroxy compound(s) in the absence of the tertiary amine catalyst. The chloroformate oligomers can contain a mixture of monochloroformates, bischloroformates, and bisphenol terminated oligomers. After the chloroformate oligomers are generated, the phosgene can optionally be allowed to substantially condense or hydrolyze, then the monohydroxy compound is added to the chloroformate mixture. The reaction is allowed to proceed, and the tertiary amine catalyst is added to complete the reaction. This process is illustrated in **FIG. 8**.

[0199] To form a cross-linkable polycarbonate using the BCF addition process, the reaction mixture comprises the dihydroxy compound, water, and water-immiscible solvent. In more specific embodiments, the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and water-immiscible solvent is methylene chloride. Again, a second end-capping agent can be present in the reaction mixture as well, such as phenol, p-t-butylphenol, p-cumylphenol, octylphenol, or p-cyanophenol. The pH of the reaction mixture is usually from about 8 to about 9 prior to the addition of the phosgene. During the addition of the phosgene, the pH is maintained between about 8.5 and about 10, by using a basic solution (e.g. aqueous NaOH).

[0200] The monohydroxy compound is, in particular embodiments, 4-hydroxybenzophenone. The monohydroxy compound can be dissolved in a solvent to form a solution which is then added to the reaction mixture. Again, the solvent in this solution can be the same as the water-immiscible solvent (e.g. methylene chloride), or can be a dilute aqueous basic solution as described above. The solution containing the monohydroxy compound is added to the reaction mixture and allowed to react. Next, a solution containing the tertiary amine catalyst is added to the reaction mixture, which catalyzes the polymerization.

[0201] The resulting photoactive additive (e.g. the cross-linkable polycarbonate) contains only a small amount of low-molecular-weight components. In embodiments, the resulting photoactive additive contains about 100 ppm or less of diarylcarbonates. In embodiments, the lows percentage can be 2.0 wt% or less, including from about 1.0 wt% to 1.7 wt%. Again, the resulting photoactive additive does not contain any residual pyridine.

[0202] The resulting photoactive additive made using the BCF process may have, in particular embodiments, a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards, including from 17,000 to 35,000 Daltons. The ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector may be 1.2 or less, when using a GPC method and polycarbonate molecular weight standards.

[0203] The fourth process uses a tubular reactor. In the tubular reactor, the monohydroxy compound is pre-reacted with the carbonate precursor (specifically phosgene) to form chloroformates. The water-immiscible solvent is used as a solvent in the tubular reactor. In a separate reactor, the polyhydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent are combined to form a reaction mixture. The chloroformates in the tubular reactor are then fed into the reactor over a first time period along with additional carbonate precursor to complete the reaction. This process is illustrated in **FIG. 9**.

[0204] To form a cross-linkable polycarbonate using the tubular reactor process, the reaction mixture comprises the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent. In more specific embodiments, the dihydroxy compound is bisphenol-A, the tertiary amine catalyst is triethylamine, and the water-immiscible solvent is methylene chloride. In the tubular reactor, the monohydroxybenzophenone is pre-reacted with phosgene. A second end-capping agent can be present in the reaction mixture (batch reactor) as well, such as phenol, p-t-butylphenol, p-cumylphenol, octylphenol, or p-cyanophenol. The pH of the reaction mixture is usually from about 8 to about 9 prior to the addition of the chloroformates. During the addition of the chloroformates, the pH is maintained between about 8.5 and about 10, by using a basic solution (e.g. aqueous NaOH).

[0205] The resulting photoactive additive (e.g. the cross-linkable polycarbonate) contains only a small amount of low-molecular-weight components. In

embodiments, the resulting photoactive additive contains less than 1900 ppm or less of diarylcarbonates. In embodiments, the lows percentage can be 2.0 wt% or less. Again, the resulting photoactive additive does not contain any residual pyridine.

[0206] The resulting photoactive additive made using the tubular reactor process may have, in particular embodiments, a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards, including from 17,000 to 35,000 Daltons.

[0207] The present disclosure has multiple aspects, illustrated by the following non-limiting examples.

EXAMPLES

[0208] All solvents and reagents used were analytical grade.

[0209] Molecular weight determinations were performed using gel permeation chromatography (GPC), using a cross-linked styrene-divinylbenzene column and calibrated to polycarbonate references using a UV-VIS detector set at 264 nm. Samples were prepared at a concentration of about 1 mg/ml, and eluted at a flow rate of about 1.0 ml/min.

[0210] Differential scanning calorimetry (DSC) employing a temperature sweep rate of 20 °C/min was used to determine glass transition temperatures of polycarbonates.

[0211] (A) Preparation of Cross-linkable Polycarbonates

Example 1

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 23k"

[0212] The following were added into a 2 liter glass reactor equipped with an overhead condenser, a phosgene inlet and a pH probe allowing monitoring pH during the course of the reaction: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (30 g, 131.6 mmol); (b) 4-hydroxybenzophenone (0.13 g, 0.7 mmol); (c) para-cumylphenol (0.7 g, 3.3 mmol); (d) triethylamine (0.18 g, 1.3 mmol); (e) methylene chloride (500 mL); (f) de-ionized water (300 mL). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 8 by the addition of 30 wt-% NaOH solution. The mixture was charged with phosgene (18.6 g, 2 g/min, 0.188 mol). During the addition of phosgene, base (30 wt-% NaOH) was simultaneously charged

to the reactor to maintain the pH of the reaction between 9-10. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot water. The polymer was dried in an oven at 110 ºC before analysis. Gel permeation chromatography (GPC) allowed for a determination of the molecular weight of the resulting polymer. The Mw of the polycarbonate was measured to be 22,877 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.11.

Example 2

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 2.5 mol% - 30k"

[0213] The following were added into a 2 liter glass reactor equipped with an overhead condenser, a phosgene inlet and a pH probe allowing monitoring pH during the course of the reaction: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (30 g, 131.6 mmol); (b) 4-hydroxybenzophenone (0.65 g, 3.3 mmol); (c) para-cumylphenol (0.14 g, 0.7 mmol); (d) triethylamine (0.18 g, 1.3 mmol); (e) methylene chloride (500 mL); (f) de-ionized water (300 mL). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 8 by the addition of 30 wt-% NaOH solution. The mixture was charged with phosgene (18.74 g, 2 g/min, 0.189 mol). During the addition of phosgene, base (30 wt-% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 9-10. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot water. The polymer was dried in an oven at 110 ºC before analysis. Gel permeation chromatography (GPC) allowed for a determination of the molecular weight of the resulting polymer. The Mw of the polycarbonate was measured to be 30,255 Daltons (referenced to polycarbonate standards) and polydispersity index = 2.09.

Example 3

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 1.7 mol% - 28k"

[0214] The following were added into a 70 L continuous stirred-tank reactor (CSTR) equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (59 g, 0.297 mol); (c) para-cumylphenol (45 g, 0.212 mol); (d) triethylamine (42 mL, 0.415 mol); (e) methylene chloride (23.4 L); (f) de-ionized water (10.8 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2500 g, 80 g/min, 25.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 28,366 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.78.

Example 4

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 2.5 mol% - 27k"

[0215] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (87 g, 0.438 mol); (c) para-cumylphenol (28 g, 0.132 mol); (d) triethylamine (60 mL, 0.593 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2500 g, 80 g/min, 25.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl),

and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 27,106 Daltons (referenced to polycarbonate standards) and polydispersity index = 6.19.

Example 5

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 28k"

[0216] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (18 g, 0.09 mol); (c) para-cumylphenol (105 g, 0.494 mol); (d) triethylamine (60 mL, 0.593 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2500 g, 80 g/min, 25.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 27,482 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.40.

Example 6

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 24k"

[0217] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (18 g, 0.09 mol); (c) para-cumylphenol (120 g, 0.565 mol); (d)

triethylamine (60 mL, 0.593 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2500 g, 80 g/min, 25.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 24,379 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.30.

Example 7

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 21k"

[0218] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (18 g, 0.09 mol); (c) para-cumylphenol (148 g, 0.697 mol); (d) triethylamine (60 mL, 0.593 mol); (e) methylene chloride (24.4 L); (f) de-ionized water (10.8 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2500 g, 80 g/min, 25.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 21,171 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.22.

Example 8

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 2.5 mol% - 26k"

[0219] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (87 g, 0.438 mol); (c) para-cumylphenol (35 g, 0.165 mol); (d) triethylamine (80 mL, 0.79 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2700 g, 80 g/min, 27.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition

of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 25,916 Daltons (referenced to polycarbonate standards) and polydispersity index = 5.21.

Example 9

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 27k"

[0220] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (18 g, 0.09 mol); (c) para-cumylphenol (105 g, 0.49 mol); (d) triethylamine (60 mL, 0.59 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2700 g, 80 g/min, 27.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 27,055 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.19.

Example 10

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 0.5 mol% - 27k"

[0221] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (18 g, 0.09 mol); (c) para-cumylphenol (148 g, 0.698 mol); (d) triethylamine (42 mL, 0.41 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2700 g, 80 g/min, 27.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 27,256 Daltons (referenced to polycarbonate standards) and polydispersity index = 3.23.

Example 11

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 2.5 mol% - 26k"

[0222] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (87 g, 0.439 mol); (c) para-cumylphenol (35 g, 0.165 mol); (d) triethylamine (42 mL, 0.41 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2700 g, 80 g/min, 27.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition

of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 25,999 Daltons (referenced to polycarbonate standards) and polydispersity index = 6.98.

Example 12

4-Hydroxybenzophenone endcapped polycarbonate

"Benzophenone-BPA Copolymer - 2.5 mol% - 27k"

[0223] The following were added into a 70 L CSTR equipped with an overhead condenser and a recirculation pump with a flow rate of 40 L/minute: (a) 4,4-bis-(hydroxyphenyl)-2,2-propane (BPA) (4000 g, 17.52 mol); (b) 4-hydroxybenzophenone (87 g, 0.439 mol); (c) para-cumylphenol (28 g, 0.132 mol); (d) triethylamine (42 mL, 0.41 mol); (e) methylene chloride (23 L); (f) de-ionized water (10 L), and (g) sodium gluconate (10 g). The reaction was allowed to stir for 10 minutes and the pH was maintained at pH = 9 by the addition of 30% NaOH solution. The mixture was charged with phosgene (2700 g, 80 g/min, 27.3 mol). During the addition of phosgene, base (30 wt% NaOH) was simultaneously charged to the reactor to maintain the pH of the reaction between 8.5-9. After the complete addition of phosgene, the reaction was purged with nitrogen gas, and the organic layer was separated. The organic extract was washed once with dilute hydrochloric acid (HCl), and subsequently washed with de-ionized water three times. The organic layer was precipitated from methylene chloride into hot steam. The polymer was dried in an oven at 110 ºC before analysis. The Mw of the polycarbonate was measured to be 27,084 Daltons (referenced to polycarbonate standards) and polydispersity index = 7.26.

[0224] Table 1 summarizes the constituents and the weight average molecular weights of the polycarbonates of Examples 1-12.

Table 1.

Component	Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6	Ex. 7	Ex. 8	Ex. 9	Ex. 10	Ex. 11	Ex. 12
BPA (kg)	0.03	0.03	4	4	4	4	4	4	4	4	4	4
HBP (g)	0.13	0.65	59	87	18	18	18	87	18	18	87	87
PCP (g)	0.7	0.14	45	28	105	120	148	35	105	148	35	28
Na glu (g)	-	-	10	10	10	10	10	10	10	10	10	10
NEt_3 (mL)	0.18 g	0.18 g	42	60	60	60	60	80	60	60	42	42
Phosgene (kg)	18.6 g	18.74 g	2.5	2.5	2.5	2.5	2.5	2.7	2.7	2.7	2.7	2.7
Water (L)	0.3	0.3	10.8	10	10	10	10.8	10	10	10	10	10
CH_2Cl_2 (L)	0.5	0.5	23.4	23	23	23	24.4	23	23	23	23	23
Mw, Daltons	22,877	30,255	28,366	27,106	27,482	24,379	21,171	25,916	27,055	27,256	25,999	27,084
PDI	-	-	3.78	6.19	3.40	3.30	3.22	5.21	3.19	3.23	6.98	7.26
mol% HBP endcap	0.5%	2.5%	1.7%	2.5%	0.5%	0.5%	0.5%	2.5%	0.5%	0.5%	2.5%	2.5%

BPA = bisphenol-A; HBP = 4-hydroxybenzophenone; PCP = p-cumylphenol; Na glu = sodium gluconate; NEt_3 = triethylamine; CH_2Cl_2 = methylene chloride; PDI = polydispersity index

[0225] The 4-hydroxybenzophenone endcapped polycarbonates of Examples 1-12 were prepared as compositions optionally using one or more of the components shown in Table 2. Comparative Examples were also prepared using the components of Table 2. The referenced compositions were prepared by mixing together the selected constituents and pre-blending. Extrusion and molding was carried out under normal polycarbonate processing conditions.

Table 2.

Component	Description	Trade name, Source
20:80 ITR-PC	Poly(19 mol% isophthalate-terephthalate-resorcinol ester)-co-(75 mol% bisphenol-A carbonate)-co-(6 mol % resorcinol carbonate) copolymer (Mw = 31,000, PC standards)	SABIC-IP
HF-PC or High-Flow PC	Bisphenol-A based polycarbonate resin (Mw = 22,000 Daltons, PC standards)	SABIC-IP
LF-PC or Low-Flow PC	Bisphenol-A based polycarbonate resin (Mw = 30,000 Daltons, PC standards)	SABIC-IP
KSS	Potassium diphenylsulphon-3-sulphonate	Arichem LLC
Rimar Salt	Potassium perfluorobutanesulfonate	Lanxess
PETS	pentaerythritol tetrastearate	Faci
UV stabilizer	2-(2′-hydroxy-5′-t-octylphenyl)benzotriazole	CYASORB UV 5411, Cytec
Heat stabilizer	Tetrakis(2,4-di-tert-butylphenyl)-4,4'-biphenylenediphosphonite	PEPQ, Ciba Specialty Chemicals
Hydrolytic stabilizer	Cycloaliphatic Epoxy Resin, 3,4-epoxy cyclohexyl methyl-3,4-epoxy cyclohexyl carboxylate	ERL4221, Various
	Colorant 1	
	Colorant 2	
Phosphite Stabilizer	Tris (2,4-di-tert-butylphenyl) phosphite	Irgaphos 168
	Hindered Phenol	

[0226] (B) Cross-linking Results

[0227] Compositions of the 4-hydroxybenzophenone endcapped polycarbonates of Examples 1-12 were cross-linked with ultra-violet (UV) radiation. The polycarbonate compositions were treated with ultra-violet radiation generated from a UV-lamp, or irradiative energy (including UV) received upon sun exposure.

[0228] (i) Cross-linking of 4-hydroxybenzophenone endcapped polycarbonates using a UV-lamp

[0229] Ultra-violet radiation was used to cross-link the neat resin compositions of Examples 1 and 2. First, films of Examples 1 and 2 were formed by melt-pressing the corresponding powder at 550 °F. The thickness of each film was about 0.5 mm. Each film was then irradiated with UV-radiation emitted from a D bulb having output specifications of about 796.5 Watts from 201 nm to 600 nm, as shown in Table 3. The film was placed on a conveyor belt having a total cycle time of 90 seconds per pass through the UV system, with the irradiation time being 20 seconds, providing an energy of irradiation of 3,000 mJ/cm^2 measured using an EIT UV Power Puck^{TM} aletro-optic radiometer.

Table 3.

Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)
201-210	2.3	251-260	17.7	301-310	28.6	351-360	50.8
211-220	4.2	261-270	13.6	311-320	21.5	361-370	57.5
221-230	4.9	271-280	20.3	321-330	21.0	371-380	74.9
231-240	5.8	281-290	11.6	331-340	11.0	381-390	72.2
241-250	10.8	291-300	24.3	341-350	24.4	391-400	27.9
Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)	Interval (nm)	Power (Watts)
401-410	30.6	451-460	4.9	501-510	7.2	551-560	5.3
411-420	26.2	461-470	3.5	511-520	12.7	561-570	3.8
421-430	34.8	471-480	2.7	521-530	16.7	571-580	8.7
431-440	40.4	481-490	9.0	531-540	17.2	581-590	3.4
441-450	19.5	491-500	15.3	541-550	27.3	591-600	2.2

[0230] Table 4 demonstrates the progression of molecular weight as a function of irradiation time of Example 1 and Example 2. These data show that the molecular weight of each film increased dramatically as a function of UV dosage. The data shows also that the more 4-hydroxybenzophenone endcap present in the resin, the greater is the molecular weight increase, as Example 2 (2.5 mol% HBP endcap) showed a 144% increase in molecular weight after 5 passes under the UV-lamp, compared with a 30% increase in molecular weight for Example 1 (0.5 mol% HBP endcap) after 5 passes.

Table 4.

	Unit	Example 1	Example 2

4-Hydroxybenzophenone amount	mol-%	0.5	2.5
Unexposed film MW	Daltons	22,877	30,255
1 pass @ 3 J/cm^2, MW	Daltons	25,784	53,346
5 passes @ 3 J/cm^2, MW	Daltons	29,664	73,945
MW increase after 5 passes	%	30	144

[0231] **FIG. 10** and **FIG. 11** also demonstrate the progression of molecular weight as a function of irradiation time for 4-hydroxybenzophenone endcapped polycarbonates of the invention. The figures show molecular weight progression upon cross-linking of 4-hydroxybenzophenone-BPA polycarbonates at 0.5 mol% hydroxybenzophenone endcap, 1.5 mol% hydroxybenzophenone endcap, and 2.5 mol% hydroxybenzophenone endcap. Each of the three polycarbonates included sufficient p-cumylphenol endcap to bring the total endcap mol% to 3 mol%.

[0232] The cross-linking reaction of Example 2 (benzophenone-BPA copolymer - 2.5 mol% - 30k) was monitored by ^{1}H-nuclear magnetic resonance spectroscopy (NMR), as shown in **FIG. 12** and **FIG. 13**. Without being bound by theory, it is believed that cross-linking occurs between benzophenone carbonyl carbon atoms and methyl carbon atoms as found in repeating bisphenol-A units. The cross-linking reaction can be monitored by following the peak intensity increase at 3.48 ppm in the NMR spectrum of the composition, which peak corresponds to the methylene hydrogens at the newly formed carbon-carbon bond. **FIG. 12** and **FIG. 13** illustrate that with each pass under the UV-lamp, the peak intensity increased at 3.48 ppm, indicating progression of the cross-linking process.

[0233] (ii) Cross-linking of 4-hydroxybenzophenone endcapped polycarbonates via sun exposure

[0234] Sun exposure was used to cross-link the polycarbonates. Films were formed of the cross-linkable polycarbonates by melt-pressing the corresponding powder at 550 °F. The thickness of each film was about 0.5 mm. Each film was then exposed to UV-radiation emitted from the sun over a period of 360 hours.

[0235] Table 5, shown below, and **FIG. 14** demonstrate that upon exposure to irradiative energy from the sun, the 4-hydroxybenzophenone endcapped polycarbonates underwent cross-linking and an increase in molecular weight. Accordingly, sun exposure can be used as a method of cross-linking the herein disclosed polycarbonates comprising monohydroxybenzophenone derived endcaps.

[0236] The % Gel data indicates the extent of crosslinking as function of the sun exposure time. The % Gel is measured by dividing the dry weight of the crosslinked portion of the exposed material by the total weight of the sample. The crosslinked portion corresponds to the insoluble part of the sample soaked in methylene chloride for 12 hours. This data shows that higher the amount of HBP, greater will be the amount of crosslinked material after sun exposure.

Table 5.

	Sun Exposure Time (Hours)								
	0	4	24	48	72	144	360		
HBP (%)	MW	MW	MW	MW	MW	MW	MW	Delta MW (%)	%Gel
0.5	21620	25900	25098	25324	25703	26202	26013	16	0
0.5	26118	31130	33305	36826	32371	35363	34994	28	1
0.5	27549	31145	34172	36231	34756	36235	36517	24	1
2.5	25458	41086	59852	60745	60224	69605	78980	135	15
2.5	24245	46183	79350	65228	67150	45841	58211	227	27
2.5	26145	45112	64941	51008	63437	63819	34831	148	52

HBP = hydroxybenzophenone; MW = Molecular Weight

[0237] **(C) Flame Resistance**

[0238] Flammability tests were performed following the procedure of Underwriter's Laboratory Bulletin 94 entitled “Tests for Flammability of Plastic Materials, UL94”. Several ratings can be applied based on the rate of burning, time to extinguish, ability to resist dripping, and whether or not drips are burning. According to this procedure, materials may be classified as HB, V0, V1, V2, 5V, 5VA and/or 5VB on the basis of the test results obtained for five samples. The criteria for the flammability classifications or “flame retardance” are described below.

[0239] V0: A specimen is supported in a vertical position and a flame is applied to the bottom of the specimen. The flame is applied for ten seconds and then removed until flaming stops at which time the flame is reapplied for another ten seconds and then removed. Two sets of five specimens are tested. The two sets are conditioned under different conditions.

[0240] To achieve a V0 rating, specimens must not burn with flaming combustion for more than 10 seconds after either test flame application. Total flaming combustion time must not exceed 50 seconds for each set of 5 specimens. Specimens must not burn with flaming or glowing combustion up to the specimen holding clamp. Specimens must not drip flaming particles that ignite the cotton. No specimen can have glowing combustion remain for longer than 30 seconds after removal of the test flame

[0241] 5VA: Testing is done on both bar and plaque specimens. Procedure for Bars: A bar specimen is supported in a vertical position and a flame is applied to one of the lower corners of the specimen at a 20° angle. The flame is applied for 5 seconds and is removed for 5 seconds. The flame application and removal is repeated five times. Procedure for Plaques: The procedure for plaques is the same as for bars except that the plaque specimen is mounted horizontally and a flame is applied to the center of the lower surface of the plaque.

[0242] To achieve a 5VA rating, specimens must not have any flaming or glowing combustion for more than 60 seconds after the five flame applications. Specimens must not drip flaming particles that ignite the cotton. Plaque specimens must not exhibit burnthrough (a hole).

[0243] Compositions comprising cross-linked polycarbonates disclosed herein (neat and blended) were evaluated for UL 94 V0 and 5VA performance as compared to high-flow BPA-polycarbonate neat and blended compositions. The tested compositions and flame test results are provided in Tables 6-9, shown below.

[0244] **(i) V0 Performance**

[0245] Flammability testing was conducted on flame bars prepared from compositions labelled as Sample 1 (S1), Comparative Sample 2 (CS2), Sample 3 (S3), and Comparative Sample 4 (CS4), described in Table 6. S1 is a blend composition comprising the benzophenone-BPA copolymer of Example 8 and a p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer. CS2 is a blend composition comprising a high-flow BPA-polycarbonate and a p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer. S3 is a neat resin composition comprising the benzophenone-BPA copolymer of Example 8. CS4 is a neat resin composition comprising the high-flow BPA-polycarbonate.

Table 6.

Ingredient		Unit	Sample			
			S1	CS2	S3	CS4
Example 8	Benzophenone-BPA copolymer - 2.5 mol-% - 26k	%	55		100	
20:80 ITR-PC	p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer (Mw = 60,000, PS standards)	%	45	45		
HF-PC	Bisphenol-A based polycarbonate resin (Mw = 22,000 Daltons, PS standards)	%		55		100
UV stabilizer	2-(2′-hydroxy-5′-t-octylphenyl)benzotriazole	%	0.20	0.20	0.20	0.20
PEPQ Powder	Phosphonous Acid Ester (CAS # 119345-01-6)	%	0.06	0.06	0.06	0.06
	Cycloaliphatic Epoxy Resin (3,4-epoxy cyclohexyl methyl-3,4-epoxy cyclohexyl carboxylate), ERL4221	%	0.03	0.03	0.03	0.03
KSS	Potassium diphenylsulphon-3-sulphonate	%	0.03	0.03	0.03	0.03
PETS	pentaerythritol tetrastearate	%	0.30	0.30	0.30	0.30
	Colorant 1	%	0.13	0.13	0.13	0.13
	Colorant 2	%	0.13	0.13	0.13	0.13
MVR	Melt Volume Flow Rate	cc/10 min	9.5	15.9	8.1	25.9
Abusive MVR	Abusive Melt Volume Flow Rate	cc/10 min	11.4	21.7	8.5	27.7

[0246] Flammability testing was conducted using the standard Underwriters Laboratory UL 94 test method (7 day conditioning), except that 20 bars rather than the usual 5 bars were tested. Specimens are to be preconditioned in an air-circulating oven for 168 hours at 70±1 °C and then cooled in a desiccator for at least 4 hours at room temperature, prior to testing. Once removed from the desiccator, specimens are tested within 30 minutes. The data was analyzed by calculation of the average flame out time, standard deviation of the flame out time and the total number of drips. Statistical methods were used to convert the data to a probability that a specific formulation would achieve a first time V0 pass or “p(FTP)” in the standard UL 94 testing of 5 bars. Preferably p(FTP) values will be 1 or very close to

1 for high confidence that a sample formulation would achieve a V0 rating in UL 94 testing.

[0247] Table 7 presents p(FTP) values for the blend (S1) comprising the benzophenone-BPA copolymer and the p-cumylphenol capped ITR-PC; and the neat benzophenone-BPA copolymer (S3). p(FTP) values are provided for both before and after the flame bars are exposed to UV radiation. The results from S1 and S3 are compared with results from flame bars prepared from the blend (CS2) comprising the high-flow BPA polycarbonate and the p-cumylphenol capped ITR-PC; and the neat high-flow BPA-polycarbonate (CS4). S3 and CS4 were prepared in order to compare the flame behavior of the blends of S1 and CS2 with neat resin compositions. Potassium sulfone sulfonate was incorporated into the tested compositions as a flame poison.

Table 7.

	Flame Resistance	Sample			
		S1 (blend) (HBP-BPA / ITR-PC)	CS2 (blend) (HF-BPA / ITR-PC)	S3 (neat) (HBP-BPA)	CS4 (neat) (HF-BPA)
Before UV	p(FTP) @ 2.00 mm	0	0	0	0
After UV	p(FTP) @ 2.00 mm	0.99	0	0.8	0
	p(FTP) @ 1.50 mm	0.2	0	0.3	-
	p(FTP) @ 1.00 mm	0.1	0	-	-

HBP-BPA = Benzophenone-BPA copolymer - 2.5 mol-% - 26k;

HF-BPA = High-Flow Bisphenol-A based polycarbonate resin;

HBP-BPA / ITR-PC = Benzophenone-BPA copolymer - 2.5 mol-% - 26k / p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer;

HF-BPA / ITR-PC = High-Flow Bisphenol-A based polycarbonate resin / p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer.

[0248] The data of Table 7 shows a dramatic increase of the p(FTP) values for the UV-treated compositions incorporating 4-hydroxybenzophenone endcap,

whereas the corresponding controls with the high-flow polycarbonate do not show any variation in their respective probability values. Surprisingly, even in blends, the cross-linked benzophenone-BPA copolymers impart V0 performance to the test bars at 2 mm thickness.

[0249] (ii) 5VA Performance

[0250] Flammability testing was conducted on flame bars and plaques prepared from compositions labelled as Sample 5 (S5), Comparative Sample 6 (CS6), Sample 7 (S7), and Comparative Sample 8 (CS8), described in Table 8. S5 is a low-flow benzophenone-BPA copolymer composition having a melt volume flow rate (MVR) of 2.81 cm^3/10 minutes at 300 °C, 1.2 kg, 360 seconds, and an abusive MVR of 2.89 cm^3/10 minutes at 300 °C, 1.2 kg, 1080 seconds. CS6 is a low-flow BPA-polycarbonate composition having an MVR of 6.35 cm^3/10 minutes at 300 °C, 1.2 kg, 360 seconds, and an abusive MVR of 6.52 cm^3/10 minutes at 300 °C, 1.2 kg, 1080 seconds. S7 is a high-flow benzophenone-BPA copolymer composition having a melt volume flow rate (MVR) of 11.5 cm^3/10 minutes at 300 °C, 1.2 kg, 360 seconds, and an abusive MVR of 11.7 cm^3/10 minutes at 300 °C, 1.2 kg, 1080 seconds. CS8 is a high-flow BPA-polycarbonate composition having an MVR of 27.6 cm^3/10 minutes at 300 °C, 1.2 kg, 360 seconds, and an abusive MVR of 27.7 cm^3/10 minutes at 300 °C, 1.2 kg, 1080 seconds.

Table 8.

Ingredient	Unit	Sample			
		S5	CS6	S7	CS8
High-Flow Benzophenone-BPA copolymer	%			100	
Low-Flow Benzophenone-BPA copolymer	%	100			
High-Flow Bisphenol-A based polycarbonate resin	%				100
Low-Flow Bisphenol-A based polycarbonate resin	%		100		
Potassium Perfluorobutane Sulfonate	%	0.08	0.08	0.08	0.08
Irgaphos Stabilizer	%	0.06	0.06	0.06	0.06
Melt Volume Flow Rate	cc/10 min	2.81	6.35	11.5	27.6
Abusive Melt Volume Flow Rate	cc/10 min	2.89	6.52	11.7	27.7

[0251] Flammability testing was conducted using the standard Underwriters Laboratory UL 94 test method (7 day conditioning). 5 bars and 3 plaques were tested. Specimens are to be preconditioned in an air-circulating oven for 168 hours at 70±1 °C and then cooled in a desiccator for at least 4 hours at room temperature, prior to testing. Once removed from the desiccator, specimens are tested within 30 minutes. The data for the bars was analyzed by calculation of the average flame out time, standard deviation of the flame out time and the total number of drips. Statistical methods were used to convert the data to a probability that a specific formulation would achieve a first time pass or "p(FTP)" in the standard UL 94 testing of 5 bars. Preferably p(FTP) values will be 1 or very close to 1 for high confidence that a sample formulation would achieve a 5VA rating in UL 94 testing.

[0252] Table 9 presents the 5VA test results for the low-flow and high-flow benzophenone-BPA copolymer compositions S5 and S7 as compared with low-flow and high-flow BPA-polycarbonate compositions lacking benzophenone endcap. The data of Table 9 demonstrates that the UV-exposed high-flow and low-flow compositions incorporating 4-hydroxybenzophenone endcap (e.g., S5 and S7) can meet 5VA material requirements at thicknesses of 2.5 mm or less, 2.0 mm or less, and 1.5 mm or less, whereas corresponding controls with the high-flow and low-flow BPA-polycarbonate (e.g., CS6 and CS8) do not show any variation in their respective flame resistance after UV-treatment. The failure of UV-treated Sample 7

(S7) at 1.5 mm indicates that endcap mol% and polymer molecular weight may be balanced to achieve 5VA performance.

Table 9.

		Sample			
	Flame Resistance	S5	CS6	S7	CS8
Before UV	5VA @ 3 mm	F	F	F	F
	5VA @ 2.5 mm	F	F	F	F
	5VA @ 2 mm	F	F	F	F
	5VA @ 1.5 mm	F	F	F	F
After UV	5VA @ 2.5 mm	P	F	P	F
	5VA @ 2 mm	P	F	P	F
	5VA @ 1.5 mm	P	F	F	F

P = specimens that passed 5VA testing; F = specimens that failed 5VA testing

[0253] The results of Tables 7 and 9 demonstrate that the cross-linked polycarbonates disclosed herein, whether neat or within a blend composition, impart flame resistance (V0 and 5VA) to articles comprising the cross-linked polycarbonates. In particular, the compositions can be used to provide 5VA compliant materials and articles.

[0254] The results also demonstrate that even benzophenone-BPA compositions incorporating UV-absorbing polymers (e.g., p-cumylphenol capped ITR-PC) can undergo sufficient cross-linking to provide compositions that exhibit V0 and 5VA performance according to UL 94.

[0255] The results further demonstrate that 5VA performance can, surprisingly, be achieved using 0.08 wt% or less of a non-brominated, non-chlorinated flame retardant. This allows preparation of compositions comprising the cross-linked polycarbonates that have high transparency and low haze values. In particular, the cross-linked compositions can be used to provide 5VA compliant materials at 2.5 mm or less, 2 mm or less, and 1.5 mm or less, the materials having high transparencies and low haze values. In comparison, conventional polycarbonate cannot achieve 5VA performance without incorporation of significant quantities of flame retardant, which may lower the transparency of the resulting polycarbonate and effect overall physical properties.

[0256] **(D) Mechanical and Physical Properties**

[0257] Improved flame retardance as demonstrated above for the cross-linked compositions is generally not useful if the composition also has excessive loss of mechanical properties that are needed for end use applications. As demonstrated below, the cross-linked compositions retain impact and tensile properties subsequent to UV-treatment.

[0258] Table 10 provides mechanical and physical properties of the compositions of Sample 5 (S5), Comparative Sample 6 (CS6), Sample 7 (S7), and Comparative Sample 8 (CS8), the formulations for which are described above in Table 8. The properties provided in Table 10 relate to the samples before UV-treatment. Table 10 shows that the compositions that incorporate benzophenone endcapped-resin exhibit similar mechanical properties to the ones that incorporate conventional BPA-polycarbonate resin.

Table 10.

Property (before UV-treatment)	Unit	Sample			
		S5	CS6	S7	CS8
Modulus of Elasticity	MPa	2354	2332	2388	2372
Tensile Strength at Break	MPa	64	66	70.6	68
Flexural Modulus	MPa	2310	2290	2360	2360
Flexural Modulus	-	77.4	53.1	7.36	16.3
Flexural Modulus	%	3.35	2.32	0.312	0.692
NII Ductility	%	100	100	100	100
NII Impact Strength	J/m	920	911	845	685
HDT	°C	135.8	133.8	131.5	129.6
MVR	cm^3/10 min	2.81	6.35	11.5	27.6
Abusive MVR	cm^3/10 min	2.89	6.52	11.7	27.7

NII = Notched Izod Impact; HDT = Heat Distortion Temperature; MVR = Melt Volume Flow Rate

[0259] The dynamic oscillatory rheology curves of low-flow benzophenone-BPA copolymer resin (S5) and low-flow bisphenol-A based polycarbonate resin (CS6) were run on an ARES strain controlled rheometer using a frequency sweep method to determine the viscosity or modulus of the material as a function of frequency at a constant temperature (300 °C). Frequency sweep measurements were performed

using 25 mm parallel-plate geometry at a 20% strain (linear regime) with a fixed gap of 1 mm. The frequency was varied from 0.1 to 500 rad/s.

[0260] The dynamic oscillatory rheology curve of low-flow bisphenol-A based polycarbonate resin is shown in **FIG. 15**; the dynamic oscillatory rheology curve of cross-linkable low-flow benzophenone-BPA copolymer resin is shown in **FIG. 16**. The dynamic oscillatory rheology was determined on pellets of the resins as a function of passes through a UV Fusion FS300S with a LC-6B Benchtop Conveyor using a D bulb. The time of irradiation was ~90 seconds, providing energy of irradiation of ~3,000mJ/cm^2 for each pass through the conveyor. **FIG. 16** shows there is a dramatic increase in the elastic modulus for the benzophenone capped material. For example, at 0.1 rad/s the elastic modulus grows from 10 Pa to 10000 Pa (three orders of magnitude) from 0 to 5 passes, whereas in the low flow BPA poly-carbonate materials (**FIG. 15**) the elastic modulus is just 2 Pa irrespective of the UV passes. This dramatic increase in elastic modulus as a function UV exposure for the benzophenone capped material indicates the formation of crosslinking in the benzophenone end capped polycarbonate.

[0261] Table 11 shows multiaxial impact (MAI) data for the compositions both prior to and after UV-exposure. As shown in Table 11, the improved flame resistance of the present compositions comprising cross-linked polycarbonate is achieved without significant loss of important mechanical properties.

Table 11.

Test (3.2 mm disk)	Unit	Sample		
		S7	S7	S7
UV-dose	mJ/cm^2	0	7000	14000
MAI - Energy to max load	J	75.4	62.4	62.9
MAI - Energy to failure	J	80.5	69.1	67.5
MAI - Energy, Total	J	80.5	69.1	67.6
MAI - Max load	kN	7.14	6.653	6.209
MAI - Deflection at max load	mm	21.3	19.6	19.9
MAI – Ductility	%	100	100	100

[0262] Table 12 shows that tensile properties of the cross-linked polycarbonate compositions prepared by sun exposure are not affected by UV exposure. At T_0 (zero hours exposure) the compositions of Sample S5 had an elongation at break of 141.22% (50mm/min elongation speed). At 168 hours, the elongation break was 126.23%. By way of comparison, 100gr PC had an elongation at break of 119.21%

at T_0. Thus, the tensile strength of the cross-linked compositions is retained after UV-exposure.

Table 12.

	Elongation at Break (%)	
Sun Exposure (h)	Example S5	100gr PC
0	141.22%	119.21%
24	121.08%	-
48	123.04%	-
168	126.23%	-

[0263] (E) Chemical Resistance

[0264] Compositions comprising cross-linked polycarbonates disclosed herein were evaluated for chemical resistance. Powders of 4-hydroxybenzophenone-terminated polycarbonates (Examples 3-5), formulated with a phosphite stabilizer and a hindered phenol, were each stabilized and subsequently pelletized to provide composition samples S9-S11. The resulting pellets were molded in the form of 3.2 mm color chips. Table 13 presents the constituents, the glass transition temperature (Tg), and the melt volume flow rate (MVR) for each sample.

Table 13.

Ingredient		Unit	Sample		
			S9	S10	S11
Example 3	Benzophenone-BPA copolymer - 1.7 mol-% - 28k	%	100		
Example 4	Benzophenone-BPA copolymer - 2.5 mol-% - 27k	%		100	
Example 5	Benzophenone-BPA copolymer - 0.5 mol-% - 28k	%			100
	Phosphite Stabilizer	%	0.06	0.06	0.06
	Hindered Phenol Stabilizer	%	0.05	0.05	0.05
MVR	Melt Volume Flow Rate	cc/10 min	5.3	4.8	8.1
Abusive MVR	Abusive Melt Volume Flow Rate	cc/10 min	5.4	5.6	8.6
Tg	Glass Transition Temperature	°C	151.7	151.7	152.1

[0265] Colorchips of S9-S11 were plunged into a test fluid for a duration of 5 minutes to assess chemical resistance to the fluid. Table 14 shows the chemical resistance of each composition S9-S11 to toluene, acetone, and Windex®. Table 14 shows that higher amounts of 4-hydroxybenzophenone endcap (e.g., 2.5 mol% as in S10) led to improved chemical resistance, independently of the resin molecular weight. The non-UV treated colorchips, when treated with acetone or toluene, exhibited crystallization and shrinking on the colorchip surface.

Table 14.

	Chemical Resistance	Sample		
		S9	S10	S11
Before UV	toluene	-	-	-
	acetone	-	-	-
	Windex®	+++	+++	+++
After UV	toluene	+	++	+
	acetone	+	++	+
	Windex®	+++	+++	+++

"-" = cracking/blistering observed;

"+" = lowered gloss observed;

"++" = solvent mark observed;

"+++" = no visual change observed

[0266] Table 15 shows that UV-irradiated samples S1 and S3, the formulations for which are described above in Table 6, are resistant to chemical treatment after

exposure to UV radiation, as compared to the respective control samples CS2 and CS4. Surprisingly, even benzophenone-BPA blends including UV-absorbing polymers (e.g., p-cumylphenol capped ITR-PC) such as that of S1 underwent sufficient cross-linking to provide compositions that exhibit extreme chemical resistance (e.g., resistance to acetone).

Table 15.

	Chemical Resistance	Sample			
		S1 (blend) (HBP-BPA / ITR-PC)	CS2 (blend) (HF-BPA / ITR-PC)	S3 (neat) (HBP-BPA)	CS4 (neat) (HF-BPA)
Before UV	toluene	-	-	-	-
	acetone	-	-	-	-
	Windex®	+++	+++	+++	+++
After UV	toluene	+++	-	+++	-
	acetone	++	-	++	-
	Windex®	+++	+++	+++	+++

"-" = cracking/blistering observed; "+" = lowered gloss observed; "++" = solvent mark observed;

"+++" = no visual change observed;

HBP-BPA = Benzophenone-BPA copolymer - 2.5 mol-% - 26k;

HF-BPA = High-Flow Bisphenol-A based polycarbonate resin;

HBP-BPA / ITR-PC = Benzophenone-BPA copolymer - 2.5 mol-% - 26k / p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer;

HF-BPA / ITR-PC = High-Flow Bisphenol-A based polycarbonate resin / p-cumylphenol capped poly(20 wt% isophthalate-terephthalate-resorcinol ester)-co-(80 wt% bisphenol-A carbonate) copolymer.

[0267] The cross-linked polycarbonate composition S5 was further evaluated for chemical resistance under strain conditions. In a strain jig, four tensile bars were positioned. The tensile bars were molded at 550 °F barrel temperature, 180 °F mold temperature and 0.5 in/s injection speed. Two bars comprised the cross-linked polycarbonate composition S5, and two comprised the S5 composition prior to UV-treatment. The curvature of the jig induced a 1% stress level on the tensile bars. A portion of the bars was exposed to acetone by dripping the solvent on top of the tensile bars. As shown in Table 16, the tensile bars of the samples without UV-

treatment snapped upon exposure to acetone, whereas the tensile bars comprised of the cross-linked polycarbonate did not snap.

Table 16.

	Test Conditions				Sample
	Strain	Temperature	Exposure Time	Solvent	S5
Before UV	1%	23 °C	Until solvent evaporates	Acetone	Bars snapped
After UV	1%	23 °C	Until solvent evaporates	Acetone	Bars did not snap

[0268] The chemical resistance results of Tables 14-16 demonstrate that the cross-linked polycarbonates disclosed herein, whether neat or within a blend composition, impart chemical resistance to articles comprising the cross-linked polycarbonate. The results also demonstrate that even blends with UV-absorbing polymers can achieve sufficient cross-linking to provide compositions that exhibit extreme chemical resistance.

[0269] **(F) Haze**

[0270] Compositions comprising cross-linked polycarbonates disclosed herein were evaluated for haze value. Percent haze (% Haze) was determined for the compositions of samples S5 and S7, the formulations for which are described above in Table 8. The percent haze for each sample was less than 2%, the haze value measured on 2.54 mm thick color chips using a Color-Eye 7000A Spectrometer.

[0271] **(G) Process**

[0272] Polycarbonates were made that included 4-hydroxybenzophenone (4-HBP), bisphenol-A, and p-cumylphenol. Phosgene was used as the carbonate precursor. Triethylamine (TEA) was used as the tertiary amine catalyst. Methyltributylammonium chloride was used as the phase transfer catalyst (PTC). The upfront, solution addition, and BCF processes were used to make various polycarbonates. Solution addition was performed with the 4-HBP in either methylene chloride or in dilute aqueous NaOH.

[0273] **(i) Upfront with phase transfer catalyst**

[0274] Batch 537 was made using the upfront process with a phase transfer catalyst. To the formulation tank was added dichloromethane (18 L), DI water (10 L), bisphenol-A (4000 grams, 17.5 moles), triethylamine (30 grams, 0.30 moles), 4-hydroxybenzophenone (124 grams, 0.63 moles), 33 % sodium hydroxide solution

(500 grams, 4.1 moles), methyltributylammonium chloride (15 grams of 75 % aqueous solution, 0.05 mole) and sodium gluconate (10 grams, iron scavenger). The mixture was stirred for 5 minutes, then transferred to the 70 L batch reactor which was equipped with an overhead condenser, circulation loop, pH probe and various material addition nozzles. The formulation tank was rinsed with dichloromethane (5 L) which was transferred to the batch reactor. The reactor agitator was started and the circulation flow was set at 80 L/min. Phosgene vapor flow to the reactor was initiated by a Distributed Control System (DCS) (80 g/min rate). The pH of the reaction was maintained at a target of 9.75 by DCS-controlled addition of 33% aqueous NaOH. Phosgene addition continued until the total set point was reached (2500 grams, 25.3 moles). After completion of the phosgene addition, a sample of the reactor was obtained and verified to be free of un-reacted BPA and free of chloroformate. Mw of a reaction sample was determined by GPC using a UV detector (Mw = 21541, PDI = 3.3). An additional charge of phosgene was added (200 grams, 2.0 mole) to the reactor. The reactor was purged with nitrogen then the batch was transferred to the centrifuge feed tank.

[0275] To the batch in the centrifuge feed tank was added dilution dichloromethane (8 L), then the mixture was purified using a train of liquid – liquid centrifuges. Centrifuge one separated the brine phase. Centrifuge two removed the triethylamine catalyst by extracting the resin solution with aqueous hydrochloric acid (pH 1). Centrifuges three through eight removed residual ions by extracting the resin solution with DI water. A sample of the resin solution was tested and verified less than 5 ppm each of ionic chloride and residual triethylamine.

[0276] The resin solution was transferred to the precipitation feed tank. The resin was isolated as a white powder by steam precipitation followed by drying in a cone shaped vessel using heated nitrogen (210 F). Powder yield 2820 g. Mw = 21605, PDI = 3.2

[0277] (ii) Upfront

[0278] Batch 543 was made using the upfront process. To the formulation tank was added dichloromethane (18 L), DI water (10 L), bisphenol-A (4000 grams, 17.5 moles), triethylamine (30 grams, 0.30 moles, 1.7 mole %), 4-hydroxybenzophenone (124 grams, 0.63 moles), 33 % sodium hydroxide solution (500 grams, 4.1 moles) and sodium gluconate (10 grams, iron scavenger). The mixture was stirred for 5 minutes, then transferred to the 70 L batch reactor which was equipped with an

overhead condenser, circulation loop, pH probe and various material addition nozzles. The formulation tank was rinsed with dichloromethane (5 L) which was transferred to the batch reactor. The reactor agitator was started and the circulation flow was set at 80 L/min. Phosgene vapor flow to the reactor was initiated by the DCS (80 g/min rate). The pH of the reaction was maintained at a target of 9.75 by DCS-controlled addition of 33% aqueous NaOH. Phosgene addition continued until the total set point was reached (2500 grams, 25.3 moles). After completion of the phosgene addition, a sample of the reactor was obtained and verified to be free of un-reacted BPA and free of chloroformate. Mw of a reaction sample was determined by GPC using a UV detector (Mw = 23016, PDI = 5.2). An additional charge of phosgene was added (200 grams, 2.0 mole) to the reactor. The reactor was purged with nitrogen then the batch was transferred to the centrifuge feed tank.

[0279] To the batch in the centrifuge feed tank was added dilution dichloromethane (8 L) then the mixture was purified using a train of liquid – liquid centrifuges. Centrifuge one separated the brine phase. Centrifuge two removed the triethylamine catalyst by extracting the resin solution with aqueous hydrochloric acid (pH 1). Centrifuges three through eight removed residual ions by extracting the resin solution with DI water. A sample of the resin solution was tested and verified less than 5 ppm each of ionic chloride and residual triethylamine.

[0280] The resin solution was transferred to the precipitation feed tank. The resin was isolated as a white powder by steam precipitation followed by drying in a cone shaped vessel using heated nitrogen (210 F). Powder yield 2860 g. Mw = 22958, PDI = 5.2

[0281] (iii) Dichloromethane solution addition

[0282] Batch 806 was made using dichloromethane solution program addition. A solution of 4-hydroxybenzophenone (135 grams, 0.68 moles) was prepared in 2 L of dichloromethane. The 4-hydroxybenzophenone solution was placed in an addition pot connected to the reactor via a dosing pump. To the formulation tank was added dichloromethane (16 L), DI water (10 L), bisphenol-A (4500 grams, 19.7 moles), triethylamine (52 grams, 0.37 moles) and sodium gluconate (10 grams, iron scavenger). The mixture was stirred for 5 minutes then transferred to the 70 L batch reactor which was equipped with an overhead condenser, circulation loop, pH probe and various material addition nozzles. The formulation tank was rinsed with dichloromethane (5 L) which was transferred to the batch reactor. The reactor

agitator was started and the circulation flow was set at 80 L/min. Phosgene vapor flow to the reactor was initiated (80 g/L flow rate) by the DCS and an initial amount (250 grams, 2.5 moles) was added. The pH of the reaction was maintained at a target of 9.75 by DCS-controlled addition of 33% aqueous NaOH.

[0283] After addition of the initial amount of phosgene, the 4-hydroxybenzophenone solution was added to the reactor at 500 mL / min flow rate by DCS control while phosgene flow to the reactor continued. Phosgene addition continued until the total set point was reached (2500 grams, 25.3 moles). After completion of the phosgene addition, a sample of the reactor was obtained and verified to be free of un-reacted BPA and free of chloroformate. Mw of a reaction sample was determined by GPC using a UV detector (Mw = 22307, PDI = 3.7). An additional charge of phosgene was added (200 grams, 2.0 mole) to the reactor. The reactor was purged with nitrogen then the batch was transferred to the centrifuge feed tank.

[0284] To the batch in the centrifuge feed tank was added dilution dichloromethane (8 L) then the mixture was purified using a train of liquid – liquid centrifuges. Centrifuge one separated the brine phase. Centrifuge two removed the triethylamine catalyst by extracting the resin solution with aqueous hydrochloric acid (pH 1). Centrifuges three through eight removed residual ions by extracting the resin solution with DI water. A sample of the resin solution was tested and verified less than 5 ppm each of ionic chloride and residual triethylamine.

[0285] The resin solution was transferred to the precipitation feed tank. The resin was isolated as a white powder by steam precipitation followed by drying in a cone shaped vessel using heated nitrogen (210 F). Powder yield 3855 g. Mw = 22228, PDI = 3.5.

[0286] (iv) NaOH solution addition

[0287] Batch 359 was made using NaOH solution program addition. A solution of 4-hydroxybenzophenone (140 grams, 0.71 moles) was prepared in 33% sodium hydroxide (103 grams, 0.85 moles) diluted with DI water (2560 mL). The 4-hydroxybenzophenone solution was placed in an addition pot connected to the reactor via a dosing pump. To the formulation tank was added dichloromethane (18 L), DI water (10 L), bisphenol-A (4500 grams, 19.7 moles), triethylamine (52 grams, 0.37 mole, 1.8 mole %) and sodium gluconate (10 grams, iron scavenger). The mixture was stirred then transferred to the 70 L batch reactor which was equipped

with an overhead condenser, circulation loop, pH probe and various material addition nozzles. The formulation tank was rinsed with dichloromethane (5 L) which was transferred to the batch reactor. The reactor agitator was started and the circulation flow was set at 80 L/min. Phosgene vapor flow to the reactor was initiated (80 g/L flow rate) by the DCS and an initial amount (250 grams, 2.5 moles) was added. The pH of the reaction was maintained at a target of 8.75 by DCS-controlled addition of 33 % aqueous NaOH.

[0288] After addition of the initial amount of phosgene, the solution of 4-hydroxybenzophenone in dilute sodium hydroxide was added to the reactor at 500 mL / min flow rate by DCS control while phosgene flow to the reactor continued. Phosgene addition continued until the total set point was reached (2500 grams, 25.3 moles). After completion of the phosgene addition, a sample of the reactor was obtained and verified to be free of un-reacted BPA and free of chloroformate. Mw of a reaction sample was determined by GPC using a UV detector (Mw = 21258, PDI = 3.7). An additional charge of phosgene was added (200 grams, 2.0 mole) to the reactor. The reactor was purged with nitrogen then the batch was transferred to the centrifuge feed tank.

[0289] To the batch in the centrifuge feed tank was added dilution dichloromethane (8 L) then the mixture was purified using a train of liquid – liquid centrifuges. Centrifuge one separated the brine phase. Centrifuge two removed the triethylamine catalyst by extracting the resin solution with aqueous hydrochloric acid (pH 1). Centrifuges three through eight removed residual ions by extracting the resin solution with DI water. A sample of the resin solution was tested and verified less than 5 ppm each of ionic chloride and residual triethylamine.

[0290] The resin solution was transferred to the precipitation feed tank. The resin was isolated as a white powder by steam precipitation followed by drying in a cone shaped dryer using heated nitrogen (210 F). Powder yield 3855 g. Mw = 21272, PDI = 3.8.

[0291] (v) Bischloroformate

[0292] Batch 337 was made using the BCF process. A solution of 4-hydroxybenzophenone (135 grams, 0.68 moles) was prepared in 2 L of dichloromethane. The 4-hydroxybenzophenone solution was placed in a first addition pot connected to the reactor via a dosing pump. A solution of triethylamine (52 grams, 0.37 mole) was prepared in 1 L of dichloromethane. The TEA solution was

placed in a second addition pot connected to the reactor via a separate dosing pump. To the formulation tank was added dichloromethane (16 L), DI water (10 L), bisphenol-A (4500 grams, 19.7 moles) and sodium gluconate (10 grams, iron scavenger). The mixture was stirred then transferred to the 70 L batch reactor which was equipped with an overhead condenser, circulation loop, pH probe and various material addition nozzles. The formulation tank was rinsed with dichloromethane (5 L) which was transferred to the batch reactor. The reactor agitator was started and the circulation flow was set at 80 L/min. Phosgene vapor flow (80 g/min) to the reactor was initiated by the DCS. The pH of the reaction was maintained at a target of 7.0 by DCS-controlled addition of 33% aqueous NaOH. Phosgene addition continued until the first set point was reached (2500 grams, 25.3 moles). After completion of the initial phosgene addition, a sample of the reactor was obtained and verified to contain chloroformate by swabbing onto paper impregnated with 4-nitrobenzylpyridine and observing a strong, orange color.

[0293] The 4-hydroxybenzophenone solution was then charged to the reactor. The reaction pH was trimmed to a target of 9.0 by the addition of 33% sodium hydroxide and the mixture was allowed to stir for 10 minutes. After stirring, the TEA solution was added to the reactor. The pH was maintained at a target of 9.0 and the mixture was allowed to stir until there was no indication of chloroformate. An additional charge of phosgene (800 grams, 8.1 moles) was added to the reactor while maintaining a pH of 9.0. Then, the reactor was sampled and the batch was determined to be free of un-reacted BPA and free of chloroformate. Mw of a reaction sample was determined by GPC using a UV detector (Mw = 21794, PDI = 2.9). An additional charge of phosgene was added (200 grams, 2.0 moles) to the reactor. The reactor was purged with nitrogen, then the batch was transferred to the centrifuge feed tank.

[0294] To the batch in the centrifuge feed tank was added dilution dichloromethane (8 L) then the mixture was purified using a train of liquid – liquid centrifuges. Centrifuge one separated the brine phase. Centrifuge two removed the triethylamine catalyst by extracting the resin solution with aqueous hydrochloric acid (pH 1). Centrifuges three through eight removed residual ions by extracting the resin solution with DI water. A sample of the resin solution was tested and verified less than 5 ppm each of ionic chloride and residual triethylamine.

[0295] The resin solution was transferred to the precipitation feed tank. The resin was isolated as a white powder by steam precipitation followed by drying in a cone shaped vessel using heated nitrogen (210 F). Powder yield 3225 g. Mw = 21695, PDI = 2.9.

[0296] Additional polycarbonates were made using similar processes, and are described in Table 17. Various properties were measured using GPC and either a UV detector or an RI detector. The results are shown in Table 17. The "lows" columns indicate the weight percentage of chains with a molecular weight below 1000. The "DAC" indicates the amount of diarylcarbonates.

Table 17.

Batch ID	Process	mol% 4-HBP	Mw UV	PDI UV	Lows% UV	Mw RI	PDI RI	Lows% RI	DAC (ppm)	PDI ratio UV / RI
337	BCF	3.34	21794	2.9	-	-	-	-	-	-
533	BCF	3.45	21099	3.1	2.59	25301	2.7	1.7	44	1.2
537	Upfront (PTC and TEA)	3.45	21541	3.3	-	-	-	-	-	-
540	Upfront (PTC and TEA)	3.45	21837	3.1	2.46	26032	2.4	1.2	100	1.3
543	Upfront (TEA only)	3.45	23016	5.2	6.3	27487	2.9	1.6	1877	1.8
785	Soln addn (CH_2Cl_2)	3.34	22170	3.7	3.22	-	-	-	-	-
806	Soln addn (CH_2Cl_2)	3.34	22307	3.7	-	-	-	-	-	-
807	Soln addn (CH_2Cl_2)	3.34	22136	3.8	3.30	27345	2.5	1.2	678	1.5
801	Soln addn (CH_2Cl_2)	4.15	17224	3.4	3.9	23411	2.4	1.2	1003	1.4
771	Soln addn (CH_2Cl_2)	2.86	24159	3.6	2.6	31599	2.5	1.1	503	1.4
356	Soln addn (NaOH)	3.46	21630	4.1	4.1	-	-	-	-	-
359	Soln addn (NaOH)	3.48	21258	3.7	-	-	-	-	-	-

[0297] The present disclosure has been described with reference to exemplary embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the present disclosure be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A process for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising:

combining the monohydroxybenzophenone, dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent to form a reaction mixture; and

adding the carbonate precursor to the reaction mixture to obtain the photoactive additive.

2. The process of claim 1, wherein the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

3. The process of any one of claims 1-2, wherein a second end-capping agent is present in the reaction mixture in addition to the monohydroxybenzophenone.

4. The process of claim 3, wherein the second end-capping agent is selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol.

5. The process of any one of claims 1-4, wherein the reaction mixture further comprises a phase transfer catalyst.

6. The process of claim 5, wherein the phase transfer catalyst is methyltributylammonium chloride.

7. The process of any one of claims 1-6, wherein the pH of the reaction mixture is maintained from about 8.5 to about 10 while the carbonate precursor is added to the reaction mixture.

8. The process of any one of claims 1-7, wherein the carbonate precursor is added to the reaction mixture over a time period of about 30 minutes to about 40 minutes.

9. The process of any one of claims 1-8, wherein the resulting photoactive additive contains less than 1900 ppm of diarylcarbonates.

10. The process of claim 9, wherein the resulting photoactive additive contains about 100 ppm or less of diarylcarbonates.

11. The process of any one of claims 1-10, wherein the resulting photoactive additive does not contain residual pyridine.

12. The process of any one of claims 1-11, wherein the resulting photoactive additive comprises about 0.5 mole% to 5.0 mole% endcap groups derived from the monohydroxybenzophenone.

13. The process of any one of claims 1-12, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

14. The process of claim 13, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 35,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

15. The process of any one of claims 13-14, wherein the ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector is 1.8 or less, when using a GPC method and polycarbonate molecular weight standards.

16. The process of claim 15, wherein the ratio of the PDI measured using a UV detector to the PDI measured using an RI detector is 1.5 or less when using a GPC method and polycarbonate molecular weight standards.

17. The process of any one of claims 1-16, wherein the resulting photoactive additive has a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

18. The process of claim 1, wherein the resulting photoactive additive has a MVR of 8 to 12 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

19. A process for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising:

combining the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent to form a reaction mixture;

adding the carbonate precursor to the reaction mixture over a first time period; and

adding the monohydroxybenzophenone to the reaction mixture during the first time period to obtain the photoactive additive.

20. The process of claim 19, wherein the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

21. The process of any one of claims 19-20, wherein the monohydroxybenzophenone is dissolved in a solvent prior to being added to the reaction mixture, the solvent being either the water-immiscible organic solvent or water containing a base.

22. The process of claim 21, wherein the monohydroxybenzophenone is dissolved in a dilute aqueous sodium hydroxide solution.

23. The process of claim 22, wherein the solution contains from about 1 to about 2 moles of NaOH per mole of the monohydroxy compound, and contains from about 5 wt% to about 20 wt% of the monohydroxy compound.

24. The process of any one of claims 19-23, wherein the monohydroxybenzophenone is added to the reaction mixture over a portion of the

first time period corresponding to from 10% to about 40% of the total charge of the carbonate precursor.

25. The process of any one of claims 19-24, wherein a second end-capping agent is present in the reaction mixture in addition to the monohydroxybenzophenone.

26. The process of claim 25, wherein the second end-capping agent is selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol.

27. The process of any one of claims 19-26, wherein the resulting photoactive additive contains less than 700 ppm of diarylcarbonates.

28. The process of any one of claims 19-27, wherein the resulting photoactive additive comprises about 0.5 mole% to 5.0 mole% endcap groups derived from the monohydroxybenzophenone.

29. The process of any one of claims 19-28, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

30. The process of claim 29, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 35,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

31. The process of any one of claims 29-30, wherein the ratio of the PDI measured using a UV detector to the PDI measured using an RI detector is 1.5 or less when using a GPC method and polycarbonate molecular weight standards.

32. The process of any one of claims 19-31, wherein the resulting photoactive additive has a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

33. The process of any one of claims 19-31, wherein the resulting photoactive additive has a MVR of 8 to 12 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

34. A process for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising:

combining the dihydroxy compound, water, and water-immiscible solvent to form a reaction mixture;

adding the carbonate precursor to the reaction mixture to convert the dihydroxy compound into a chloroformate;

adding the monohydroxybenzophenone to the reaction mixture and reacting the reaction mixture; and

adding the tertiary amine catalyst to the reaction mixture and reacting the reaction mixture to obtain the photoactive additive.

35. The process of claim 34, wherein the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

36. The process of any one of claims 34-35, wherein a second end-capping agent is added to the reaction mixture along with the monohydroxybenzophenone.

37. The process of claim 36, wherein the second end-capping agent is selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol.

38. The process of any one of claims 34-37, wherein the resulting photoactive additive contains about 100 ppm or less of diarylcarbonates.

39. The process of any one of claims 34-38, wherein the resulting photoactive additive comprises about 0.5 mole% to 5.0 mole% endcap groups derived from the monohydroxybenzophenone.

40. The process of any one of claims 34-39, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

41. The process of claim 40, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 35,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

42. The process of any one of claims 40-41, wherein the ratio of the polydispersity index (PDI) measured using a UV detector to the PDI measured using an RI detector is 1.2 or less when using a GPC method and polycarbonate molecular weight standards.

43. The process of any one of claims 34-42, wherein the resulting photoactive additive has a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

44. The process of any one of claims 34-42, wherein the resulting photoactive additive has a MVR of 8 to 12 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

45. A process for preparing a photoactive additive from a monohydroxybenzophenone, a dihydroxy compound, a carbonate precursor, a tertiary amine catalyst, water, and a water-immiscible organic solvent, comprising:

pre-reacting the monohydroxybenzophenone with the carbonate precursor in a tubular reactor to convert the monohydroxybenzophenone into a monochloroformate;

combining the dihydroxy compound, tertiary amine catalyst, water, and water-immiscible solvent in a reaction mixture;

adding the carbonate precursor to the reaction mixture over a first time period; and

adding the monochloroformate compound to the reaction mixture throughout the first time period to obtain the photoactive additive.

46. The process of claim 45, wherein the carbonate precursor is phosgene, the dihydroxy compound is bisphenol-A, and the water-immiscible organic solvent is methylene chloride.

47. The process of any one of claims 45-46, wherein a second end-capping agent is added to the reaction mixture along with the monohydroxybenzophenone.

48. The process of claim 47, wherein the second end-capping agent is selected from the group consisting of phenol, p-t-butylphenol, p-cumylphenol, octylphenol, and p-cyanophenol.

49. The process of any one of claims 45-48, wherein the resulting photoactive additive comprises about 0.5 mole% to 5.0 mole% endcap groups derived from the monohydroxybenzophenone.

50. The process of any one of claims 45-49, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 80,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

51. The process of claim 50, wherein the resulting photoactive additive has a weight-average molecular weight of between 17,000 and 35,000 Daltons, as measured by GPC using a UV detector and polycarbonate molecular weight standards.

52. The process of any one of claims 45-51, wherein the resulting photoactive additive has a MVR of 2 to 4 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

53. The process of any one of claims 45-51, wherein the resulting photoactive additive has a MVR of 8 to 12 cc/10 min measured according to ASTM D1238 at 300°C/1.2 kg.

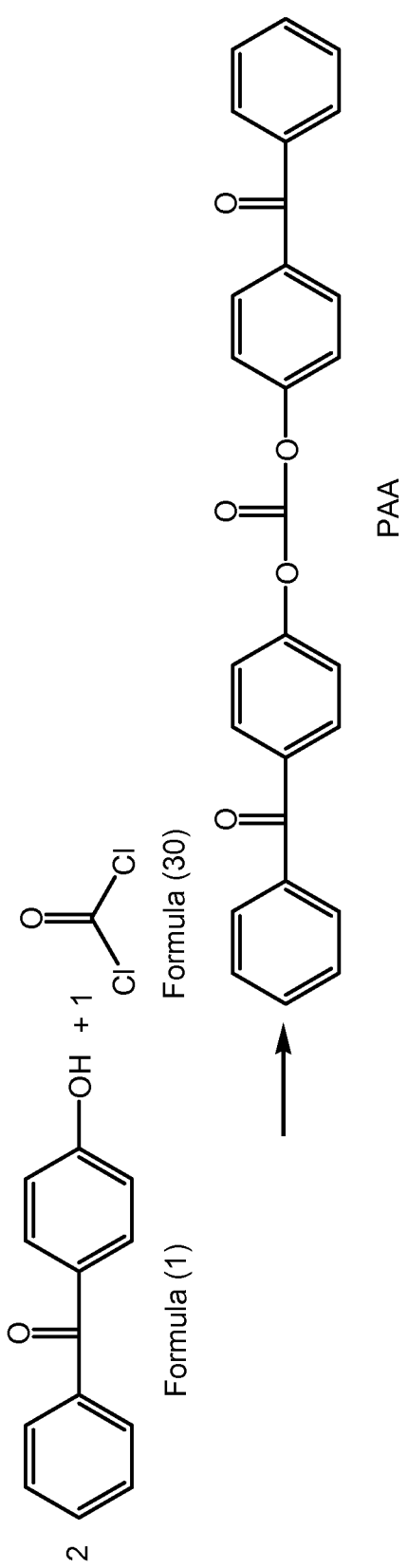


Diagram 1

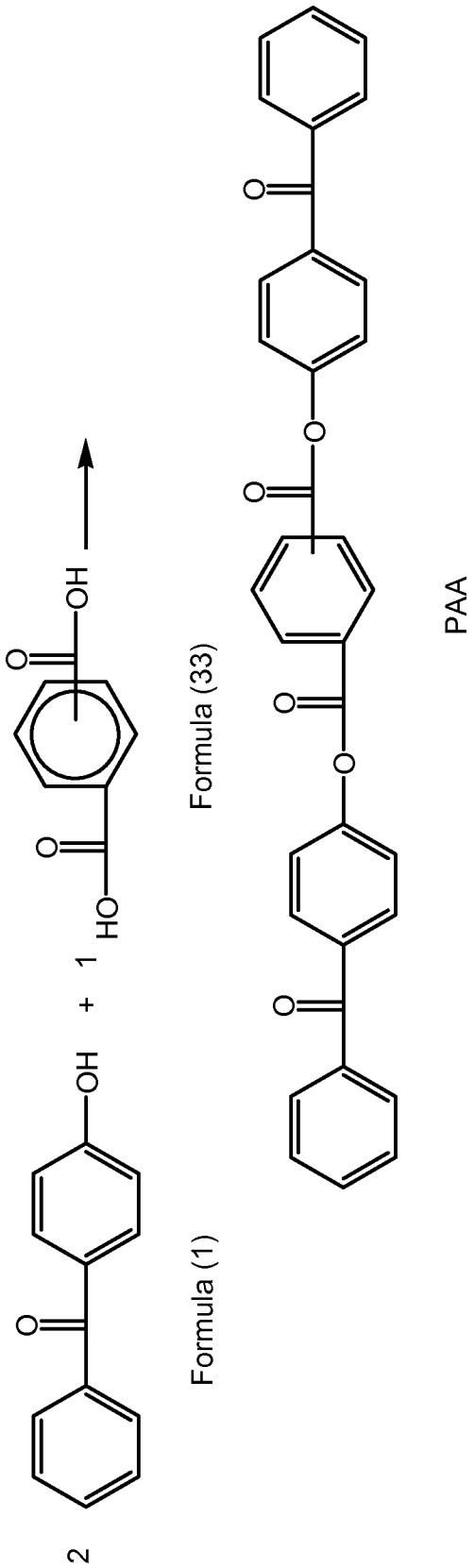


Diagram 2

FIG. 1

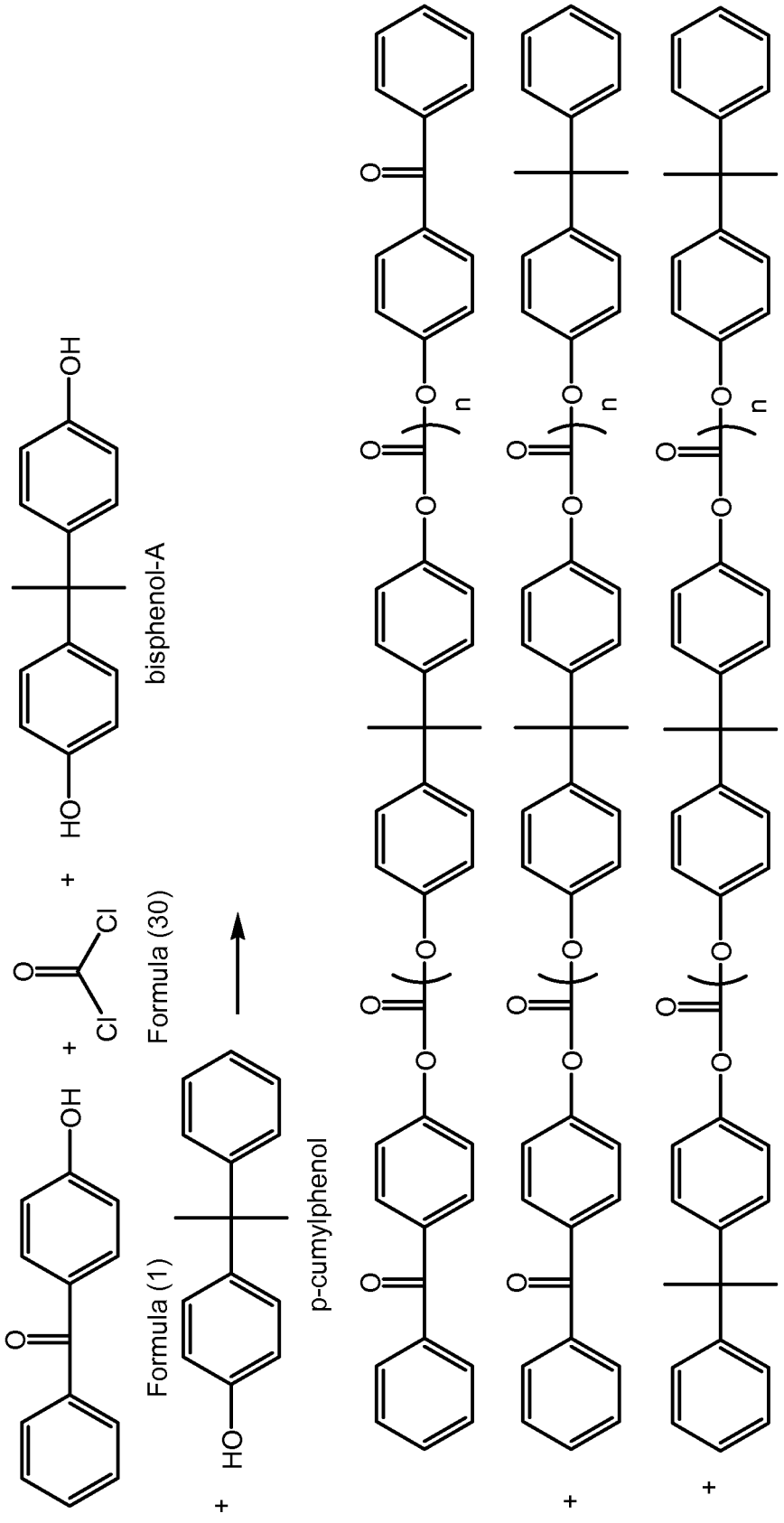


FIG. 2

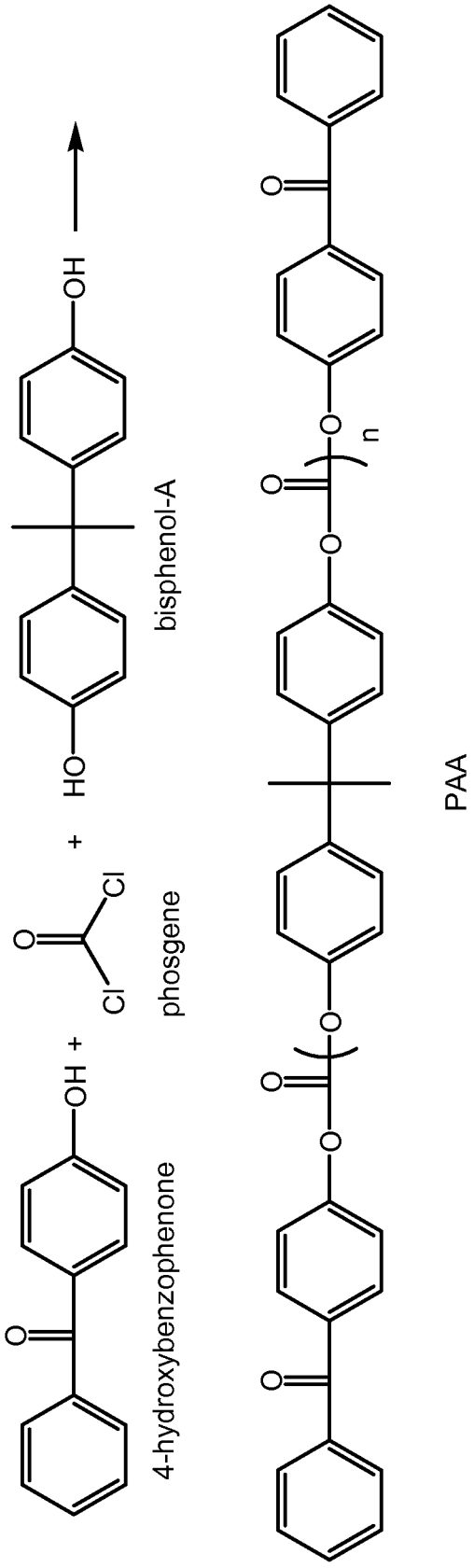


FIG. 3

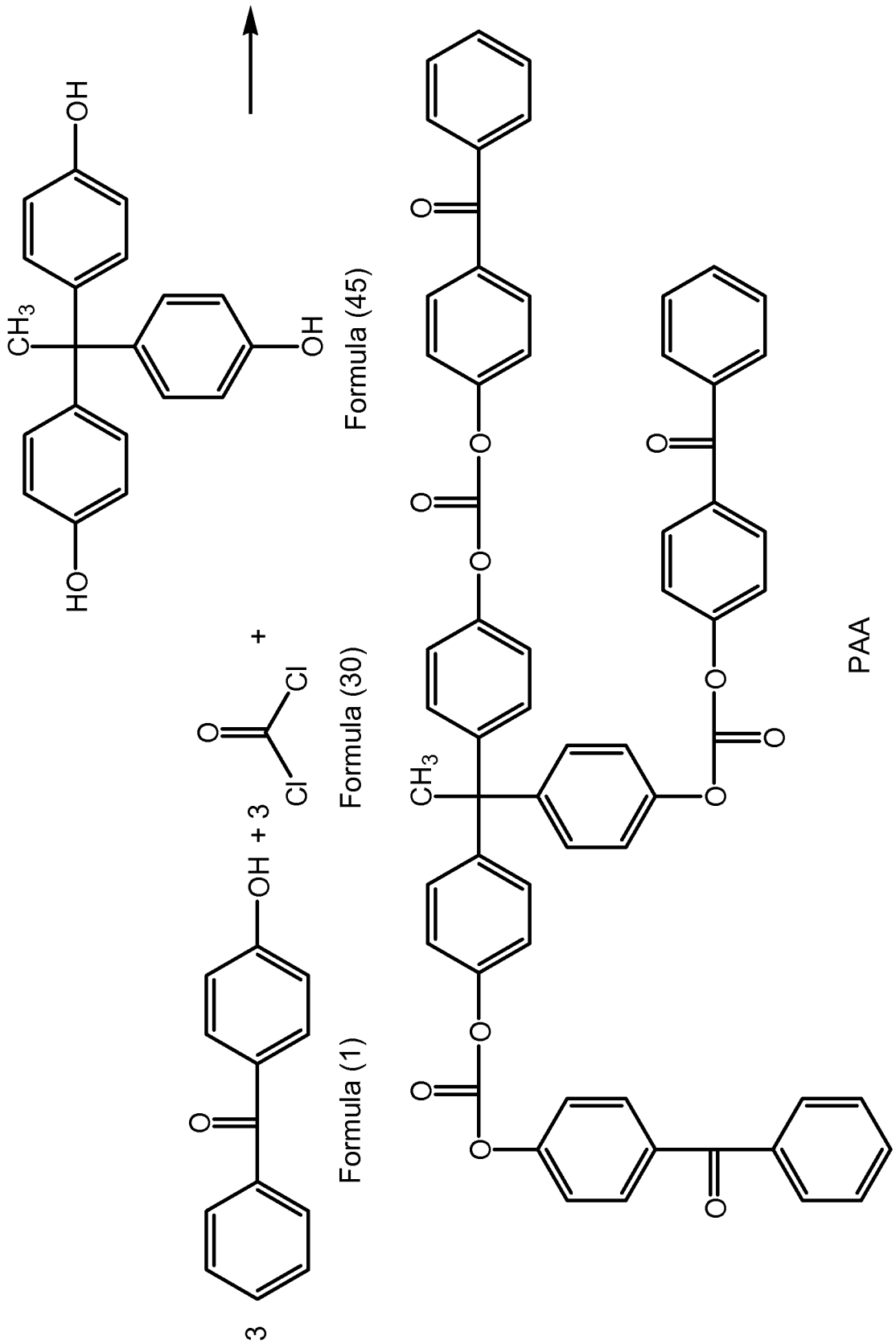

OH
CH3
OH
HO
Formula (45)
+
Cl
O
Cl
Formula (30)
OH + 3
O
Formula (1)
3
O
O
O
O
CH3
O
O
O
O
O
O
O
PAA

FIG. 4

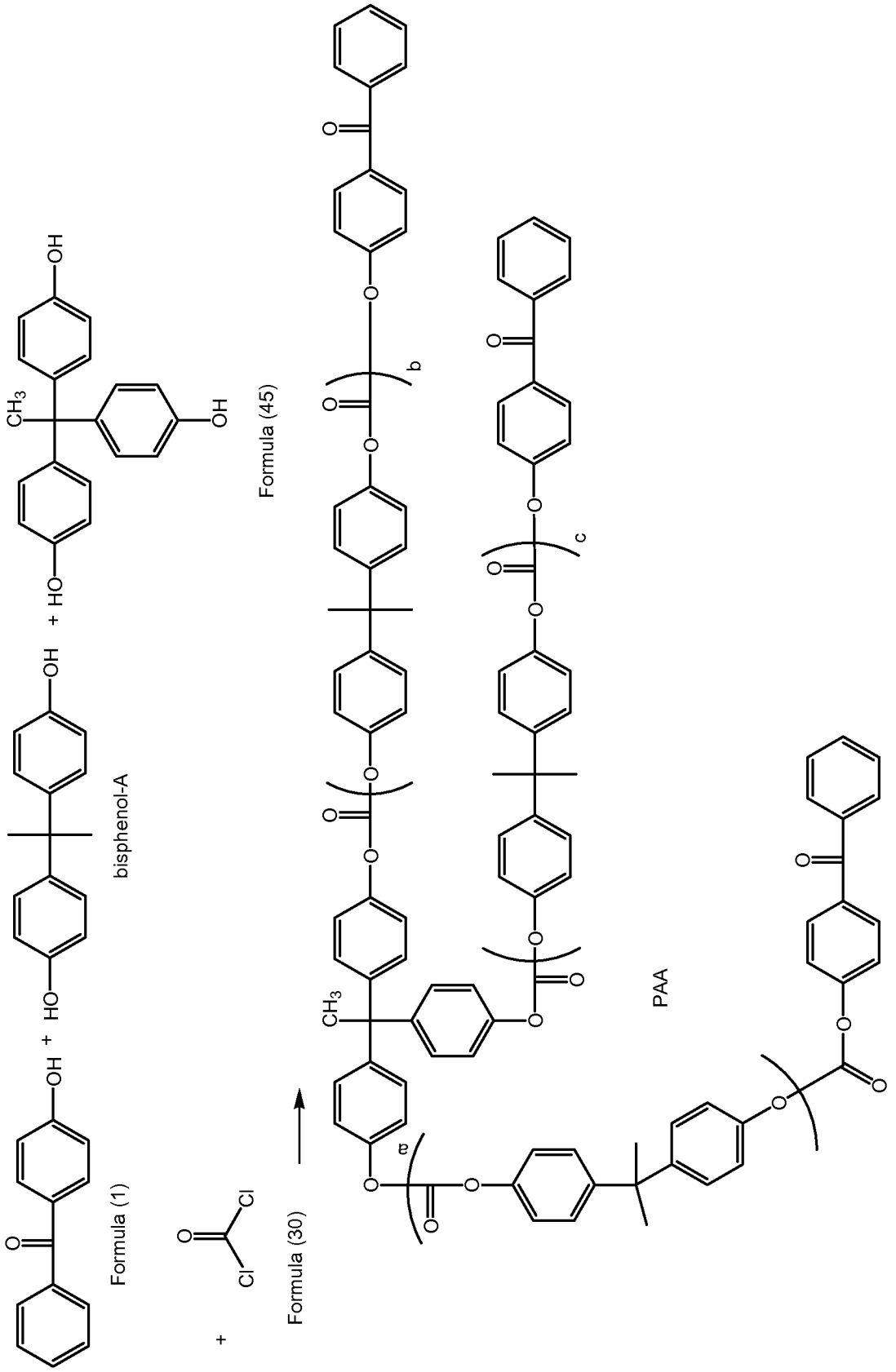


FIG. 5

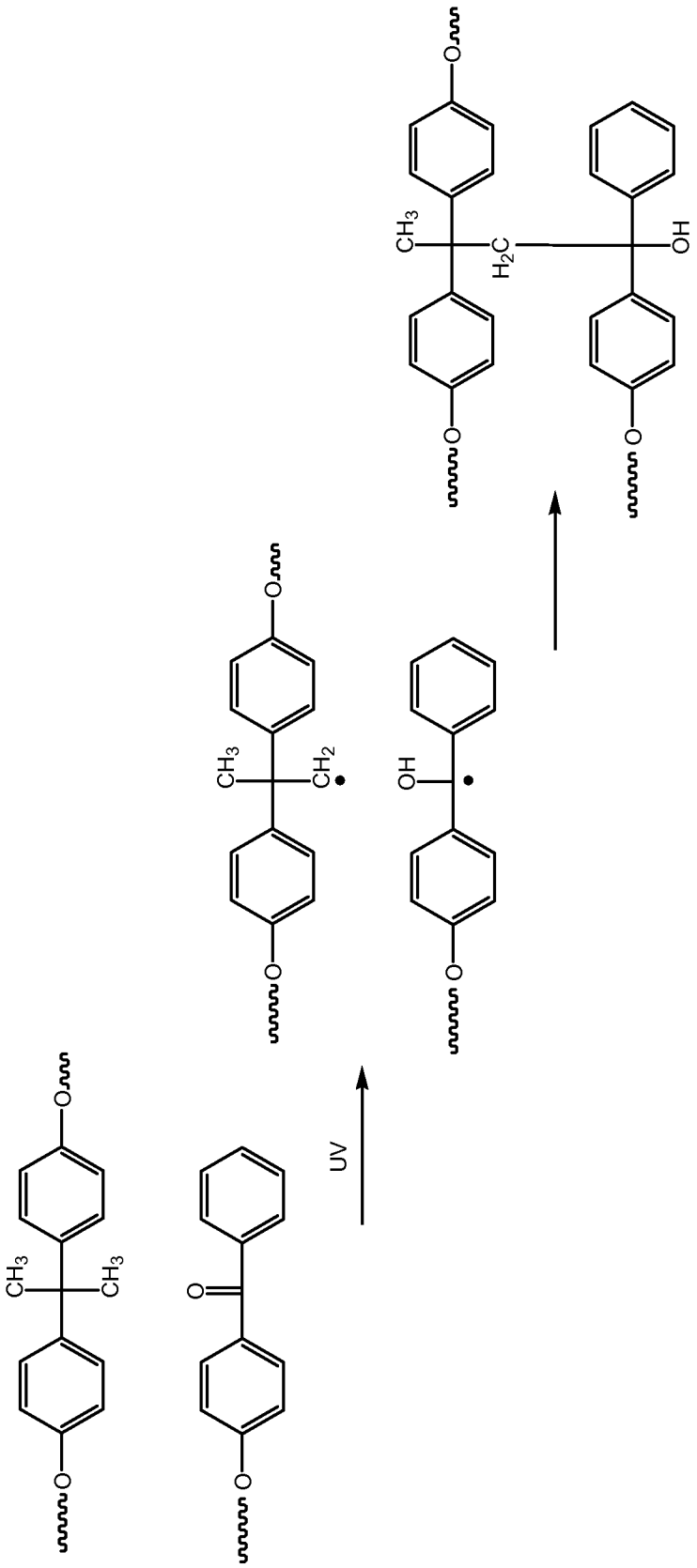


FIG. 6

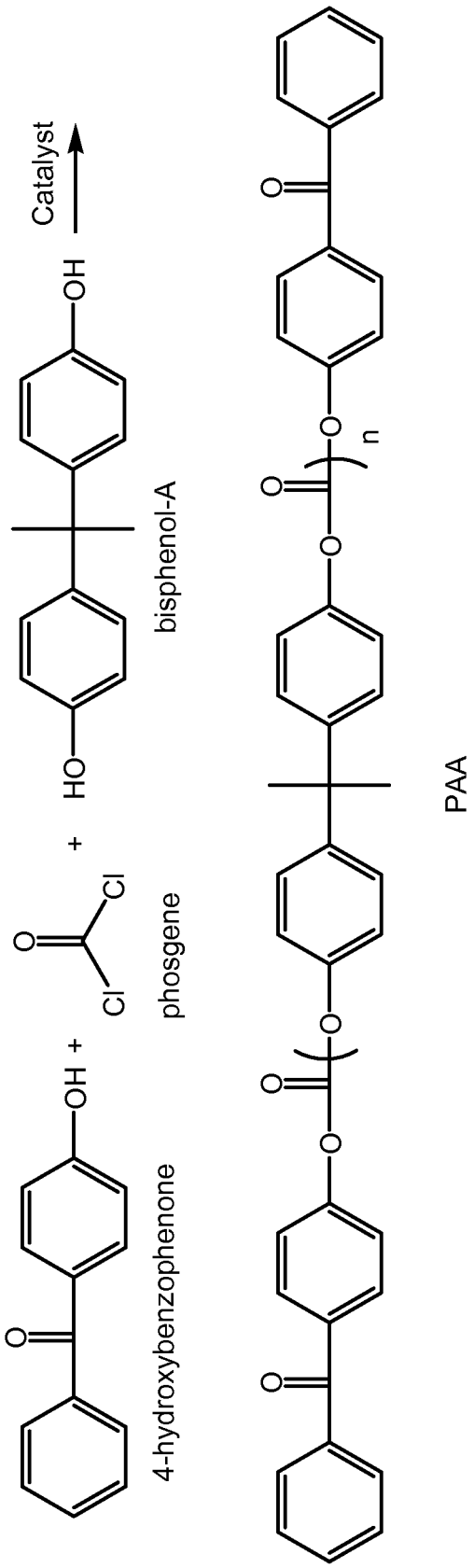

Catalyst
OH
HO
bisphenol-A
+
Cl
Cl
O
phosgene
OH +
O
4-hydroxybenzophenone
O
O
O
O
O
n
PAA

FIG. 7

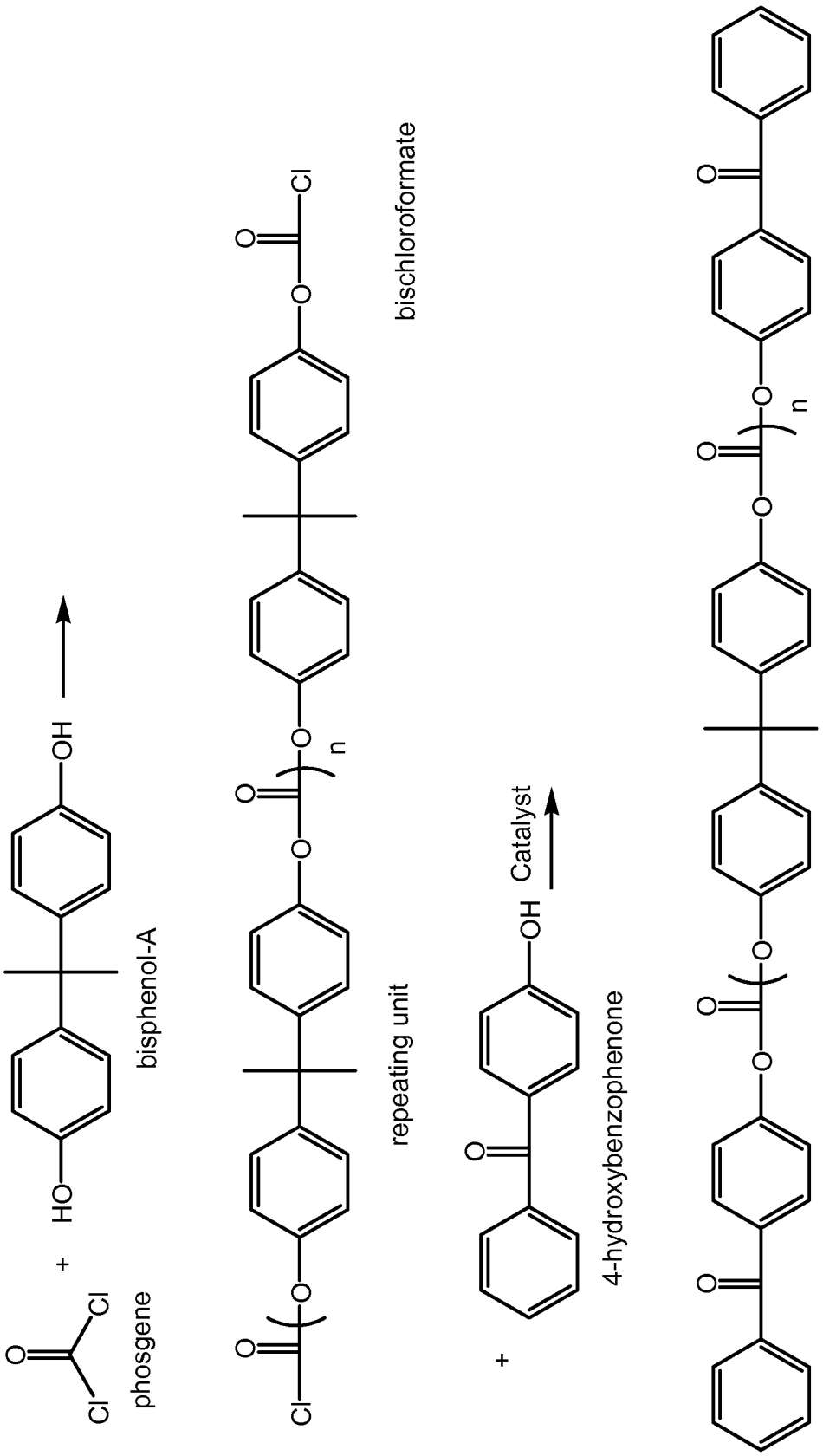

phosgene
bisphenol-A
repeating unit
bischloroformate
Catalyst
4-hydroxybenzophenone
PAA

FIG. 8

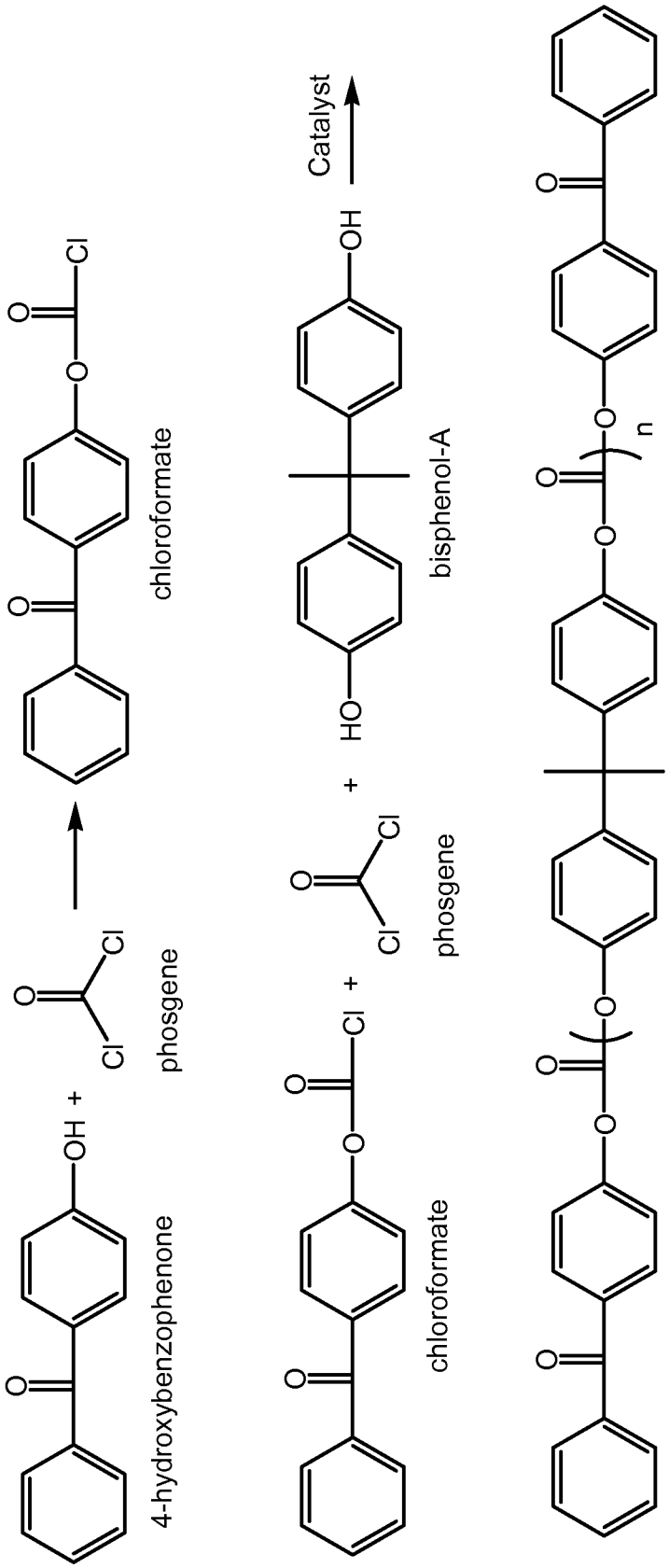

4-hydroxybenzophenone
phosgene
chloroformate
bisphenol-A
Catalyst
PAA

FIG. 9

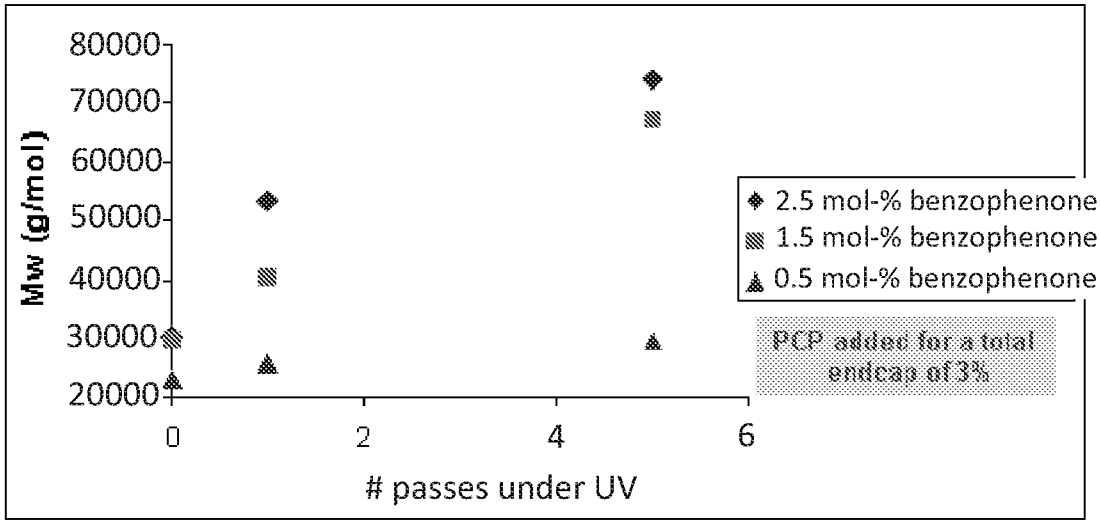

80000
70000
60000
50000
40000
30000
20000
Mw (g/mol)
0
2
4
6
passes under UV
2.5 mol-% benzophenone
1.5 mol-% benzophenone
0.5 mol-% benzophenone
PCP added for a total endcap of 3%

FIG. 10

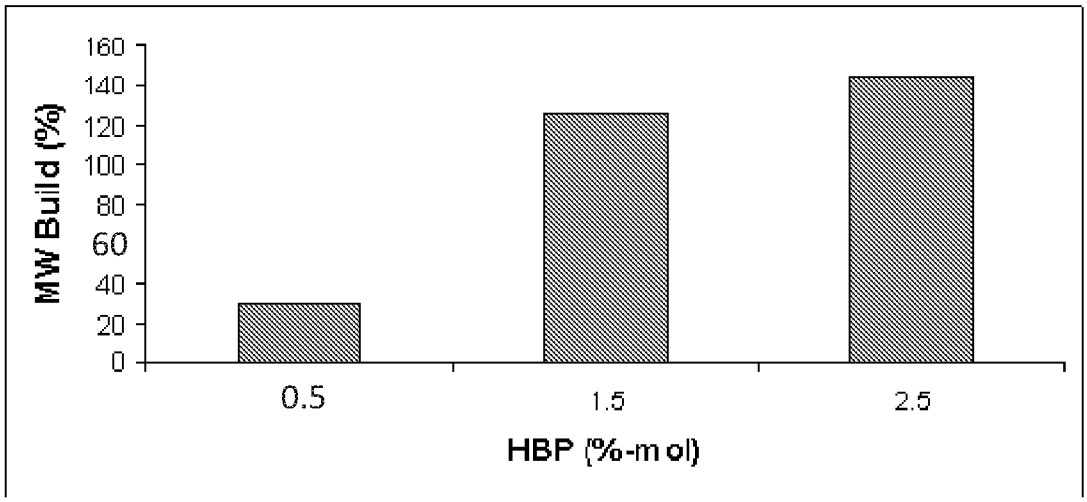

160
140
120
100
80
60
40
20
0
MW Build (%)
0.5
1.5
2.5
HBP (%-mol)

FIG. 11

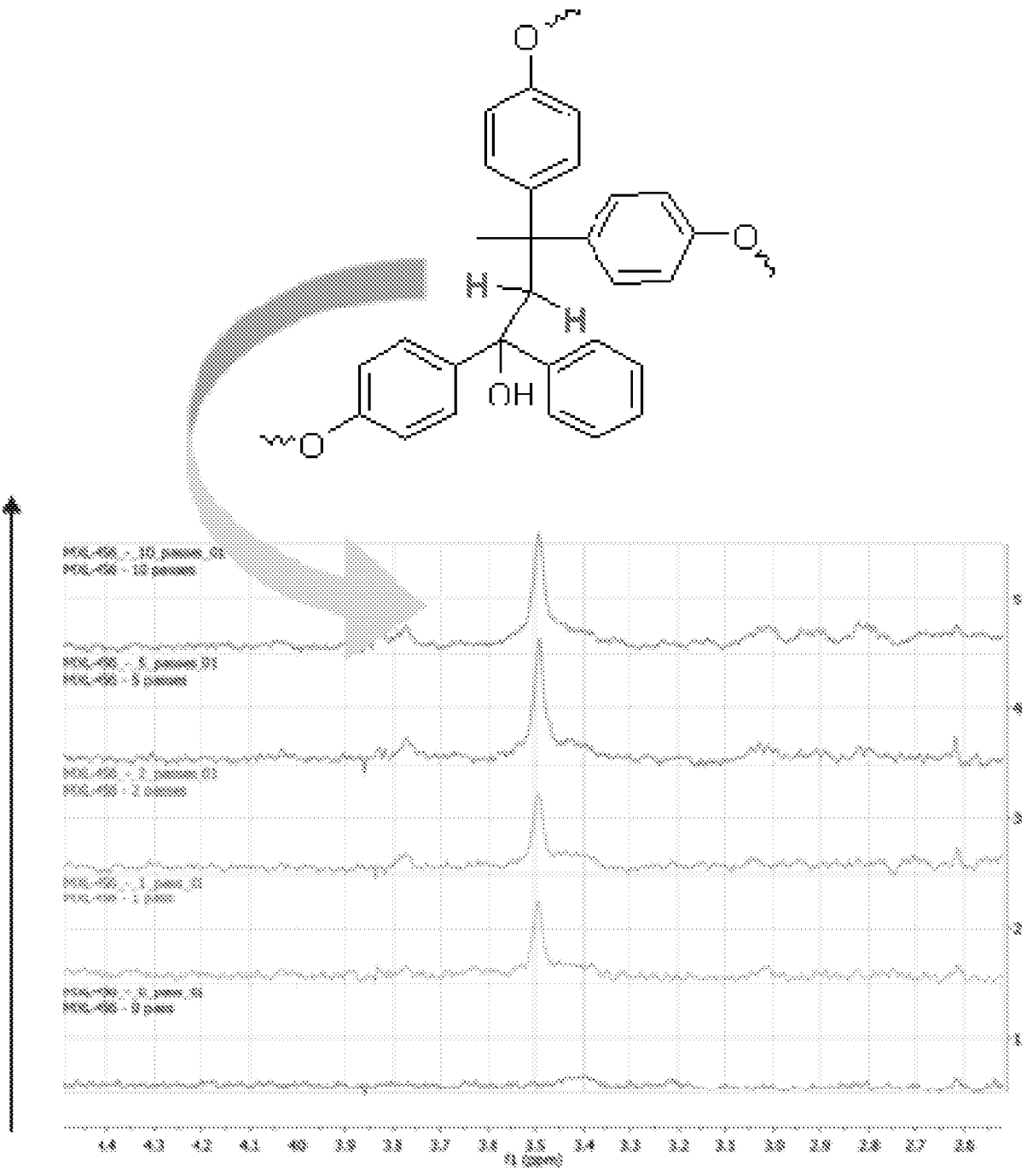


FIG. 12

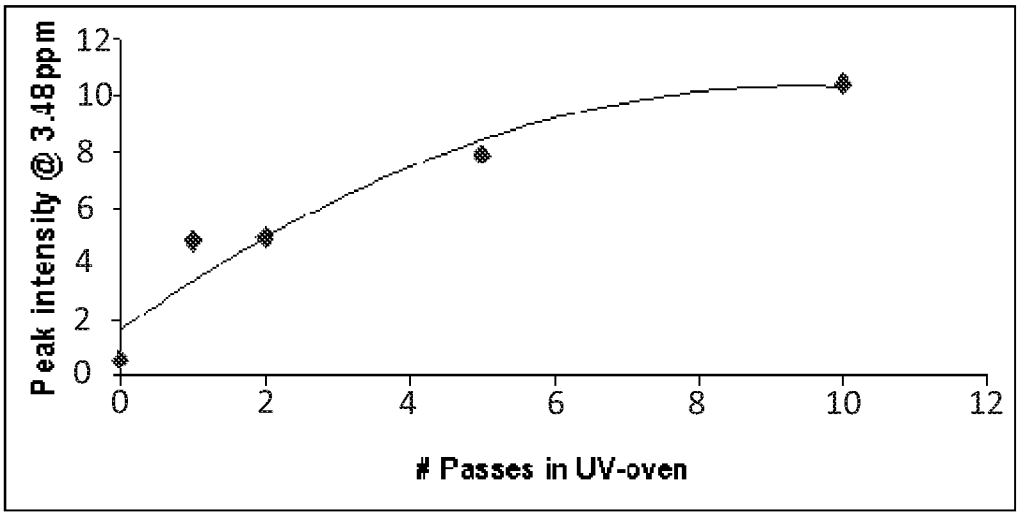

Peak intensity @ 3.48ppm
0
2
4
6
8
10
12
0
2
4
6
8
10
12
Passes in UV-oven

FIG. 13

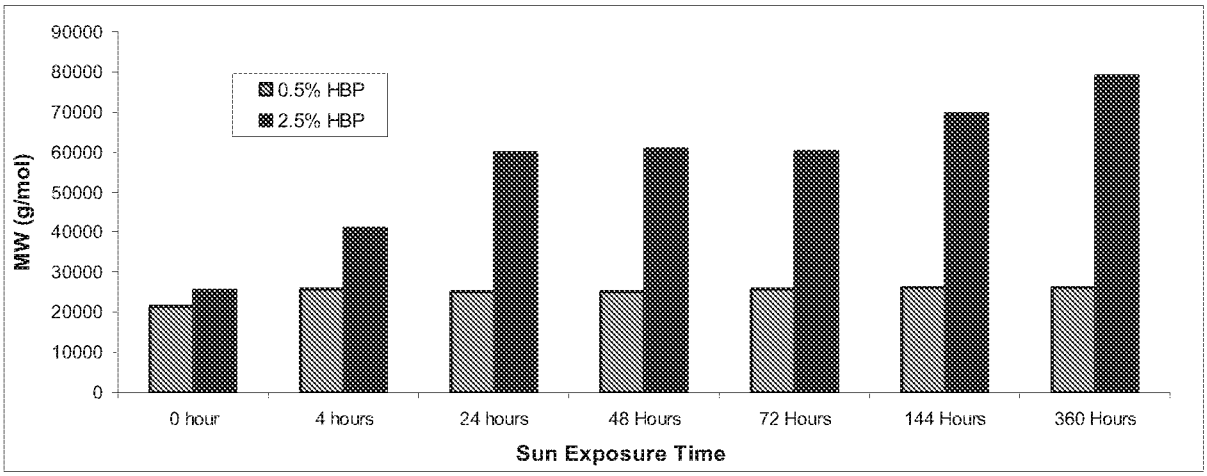

MW (g/mol)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0.5% HBP
2.5% HBP
0 hour
4 hours
24 hours
48 Hours
72 Hours
144 Hours
360 Hours
Sun Exposure Time

FIG. 14

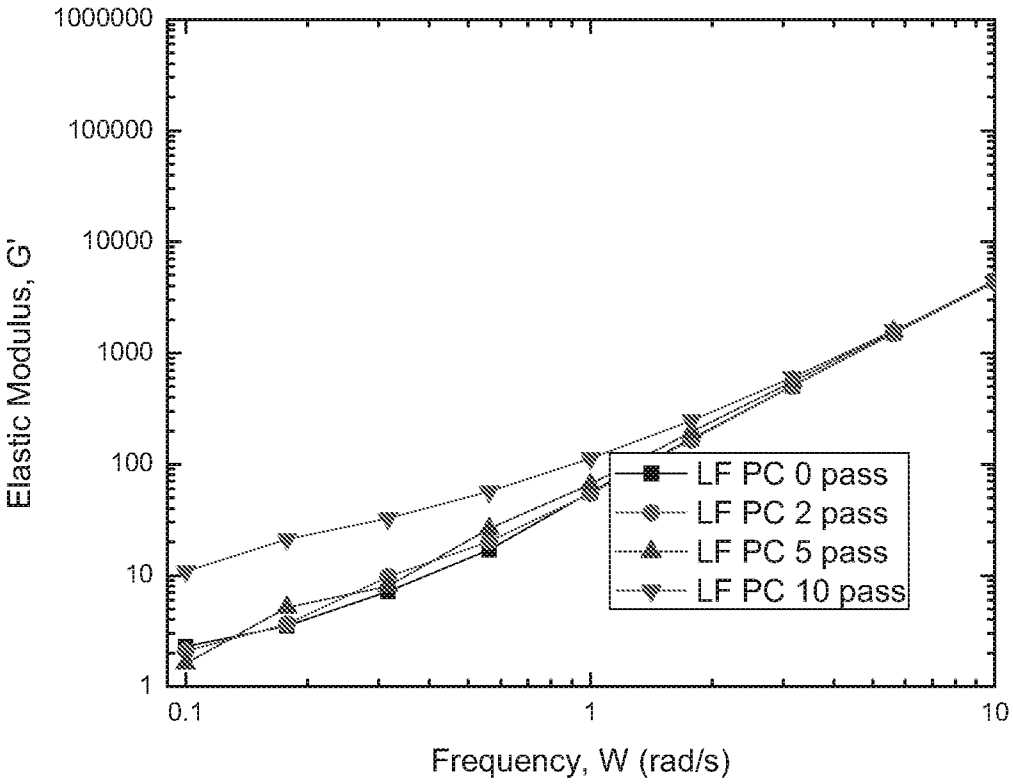

1000000
100000
10000
1000
100
10
1
Elastic Modulus, G'
0.1
1
10
Frequency, W (rad/s)
LF PC 0 pass
LF PC 2 pass
LF PC 5 pass
LF PC 10 pass

FIG. 15

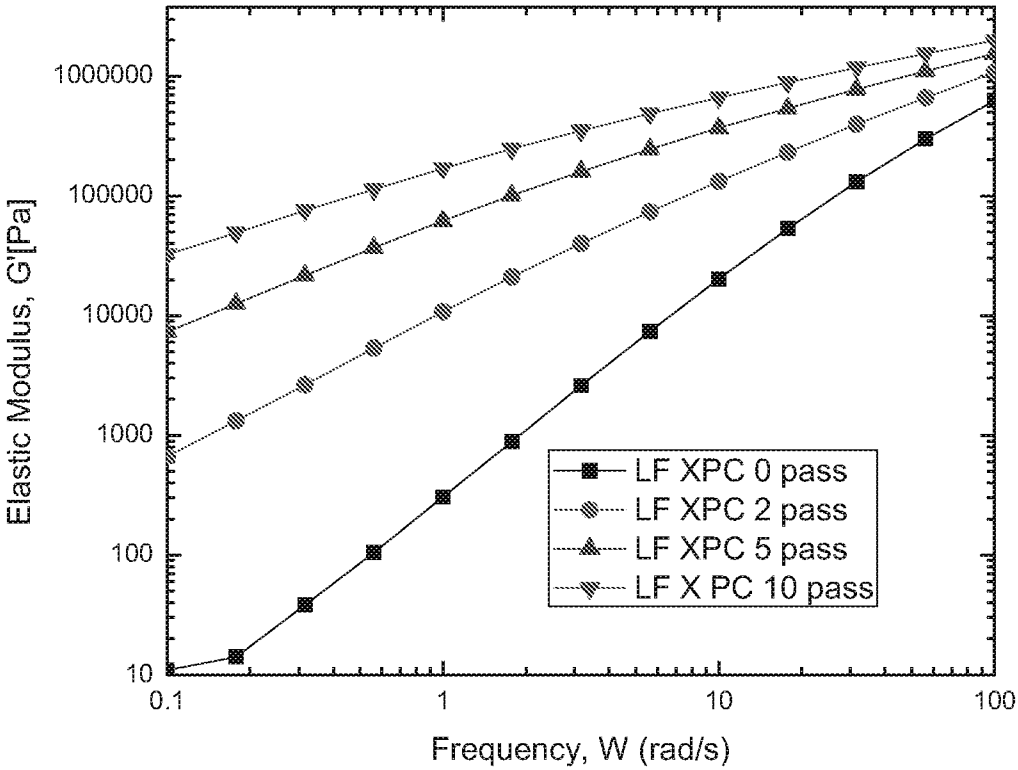

Elastic Modulus, G'[Pa]
1000000
100000
10000
1000
100
10
0.1
1
10
100
Frequency, W (rad/s)
LF XPC 0 pass
LF XPC 2 pass
LF XPC 5 pass
LF X PC 10 pass

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/077024

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08G64/14 C08G64/24
ADD.

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 C08L

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 153 780 A (NARITA YOSHIHIRO ET AL) 8 May 1979 (1979-05-08) example 7 -----	1-53
A	EP 1 359 176 A2 (BAYER AG) 5 November 2003 (2003-11-05) the whole document -----	1-53

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 March 2014	13/03/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Scheunemann, Sven

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/077024

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