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(12) **United States Patent**
Chu et al.

(10) **Patent No.:** **US 11,572,438 B2**

(45) **Date of Patent:** **Feb. 7, 2023**

(54) **LIQUID-CRYSTAL POLYMER, LAMINATED MATERIAL, LIQUID-CRYSTAL POLYMER SOLUTION, AND METHOD OF FORMING LIQUID-CRYSTAL POLYMER FILM**

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(73) Assignee: **INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 208 days.

(21) Appl. No.: **16/918,990**

(22) Filed: **Jul. 1, 2020**

(65) **Prior Publication Data**

US 2021/0002555 A1 Jan. 7, 2021

Related U.S. Application Data

(60) Provisional application No. 62/869,669, filed on Jul. 2, 2019.

(51) **Int. Cl.**
G02F 1/1333 (2006.01)
C08G 63/60 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC **C08G 63/605** (2013.01); **B32B 7/12** (2013.01); **B32B 15/20** (2013.01); **B32B 27/285** (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC C09K 19/3809; C09K 19/3814; C09K 19/3804; C09K 19/32; C09K 19/3425;
(Continued)

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Primary Examiner — Geraldina Visconti

(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

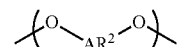
(57) **ABSTRACT**

A liquid-crystal polymer includes at least one repeating unit having a spiro structure, and the repeating unit occupies 1 mol % to 20 mol % of the liquid-crystal polymer. The liquid-crystal polymer is composed of the following repeating units: 1 mol % to 20 mol % of



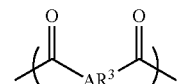
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10 mol % to 35 mol % of



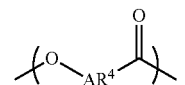
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10 mol % to 35 mol % of



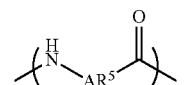
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10 mol % to
50 mol % of



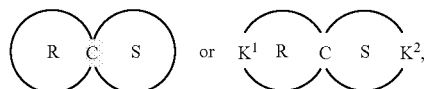
(4)

and 10 mol % to 40 mol % of



(5)

AR¹ is



(Continued)

wherein each of ring R and ring S is independently a C₃₋₂₀ ring, ring R and ring S share a carbon atom, and each of K¹ and K² is independently a C₅₋₂₀ conjugated system. Each of AR², AR³, AR⁴, and AR⁵ is independently AR⁶ or AR⁶—Z—AR⁷.

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18 Claims, No Drawings

- (51) **Int. Cl.**
B32B 7/12 (2006.01)
B32B 15/20 (2006.01)
B32B 27/28 (2006.01)
B32B 27/36 (2006.01)
C09K 19/38 (2006.01)
- (52) **U.S. Cl.**
 CPC *B32B 27/288* (2013.01); *B32B 27/36* (2013.01); *C09K 19/3809* (2013.01); *C09K 19/3814* (2013.01); *B32B 2305/55* (2013.01); *C09K 2219/03* (2013.01)

- (58) **Field of Classification Search**
 CPC C09K 2219/03; B32B 2305/55; G02F 1/1333
 See application file for complete search history.

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LIQUID-CRYSTAL POLYMER, LAMINATED MATERIAL, LIQUID-CRYSTAL POLYMER SOLUTION, AND METHOD OF FORMING LIQUID-CRYSTAL POLYMER FILM

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/869,669 filed on Jul. 2, 2019, the entirety of which is incorporated by reference herein.

TECHNICAL FIELD

The technical field relates to liquid-crystal polymer.

BACKGROUND

In recent years, liquid-crystal polymer (LCP) has been widely utilized in many high-value, high-end applications, especially in LCP films. Such LCP films have low moisture absorption, low dielectric constant, and low dielectric loss. Moreover, the polyimide (PI) films utilized in flexible copper clad laminate (FCCL) in mobile cell phones cannot satisfy the needs of 4G/5G high speed communication, and the PI films may possibly be replaced with LCP films. However, traditional LCP materials have a high-order molecular alignment, which can easily result in a crystallinity difference between MD and TD directions during the processes of film extrusion and film blowing. As such, the LCP film strength in the MD orientation is high, and the LCP film can easily crack in the TD direction. Accordingly, the thermal processes for preparing LCP films need high-threshold equipments and technologies.

Accordingly, a novel soluble LCP composition is called for, in order for solution-type and film-level LCP to be applied in FCCL product.

SUMMARY

One embodiment of the disclosure provides a liquid-crystal polymer, including at least one repeating unit having a spiro structure, and the liquid-crystal polymer includes 1 mol % to 20 mol % of the repeating unit.

One embodiment of the disclosure provides a laminated material, including a support; and a liquid-crystal polymer film disposed on the support, wherein the liquid-crystal polymer film includes the described liquid-crystal polymer.

One embodiment of the disclosure provides a liquid-crystal polymer solution, including 100 parts by weight of solvent; and 0.01 to 100 parts by weight of the described liquid-crystal polymer.

One embodiment of the disclosure provides a method of forming liquid-crystal polymer film, including coating the described liquid-crystal polymer solution onto a support; and removing the solvent to form a liquid-crystal polymer film on the support.

A detailed description is given in the following embodiments.

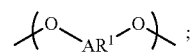
DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed

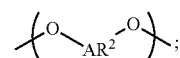
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embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details.

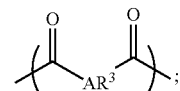
One embodiment of the disclosure provides a liquid-crystal polymer including at least one repeating unit having a spiro structure, and the liquid-crystal polymer includes 1 mol % to 20 mol % of the repeating unit. For example, the liquid-crystal polymer is composed of the following repeating units: 1 mol % to 20 mol % of



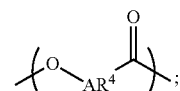
10 mol % to 35 mol % of



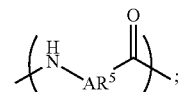
10 mol % to 35 mol % of



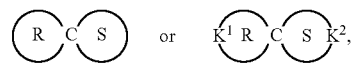
10 mol % to 50 mol % of



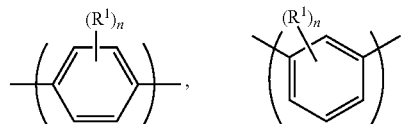
and 10 mol % to 40 mol % of



wherein AR¹ is

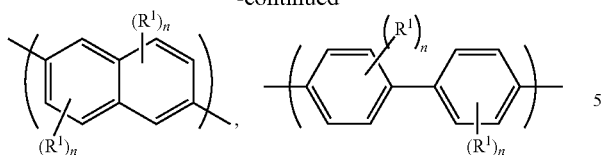


each of ring R and ring S is independently a C₃₋₂₀ ring, ring R and ring S share a carbon atom, and each of K¹ and K² is independently a C₅₋₂₀ conjugated system; wherein each of AR², AR³, AR⁴, and AR⁵ is independently AR⁶ or AR⁶—Z—AR⁷, each of AR⁶ and AR⁷ is independently

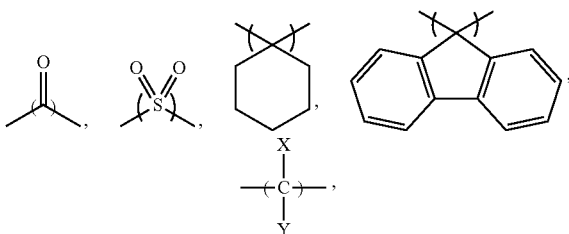


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or a combination thereof, and Z is —O—,



or C₁₋₅ alkylene group; wherein each of X and Y is independently H, C₁₋₅ alkyl group, CF₃, or

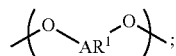


wherein R¹ is H, CH₃, CH(CH₃)₂, C(CH₃)₃, CF₃, OCH₃, or

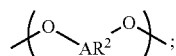


and n=1 to 4.

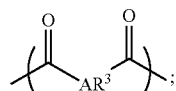
In some embodiments, the liquid-crystal polymer is composed of the following repeating units: 1 mol % to 20 mol % of



10 mol % to 35 mol % of

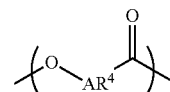


10 mol % to 35 mol % of



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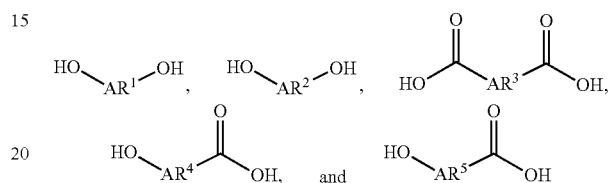
and 10 mol % to 50 mol % of



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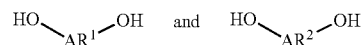
10 Each of AR¹, AR², AR³, and AR⁴ is defined as above, and the related description is not repeated here.

In some embodiments,



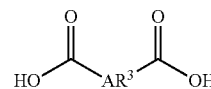
can be reacted to form the liquid-crystal polymer.

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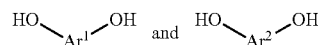
30 (sum of diol) and

35



(diacid) have a molar ratio of 1:1. If

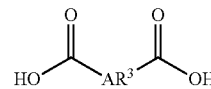
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(sum of diol) and

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(1)

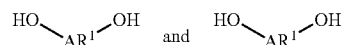


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(diacid) have a molar ratio of greater than or less than 1, excessive

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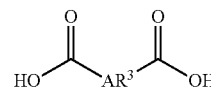
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or excess

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(3)

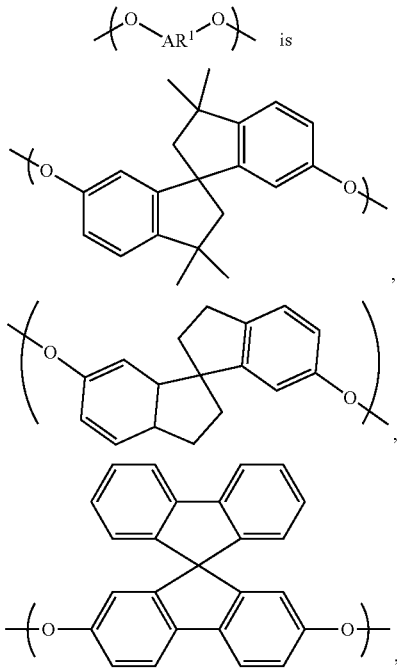


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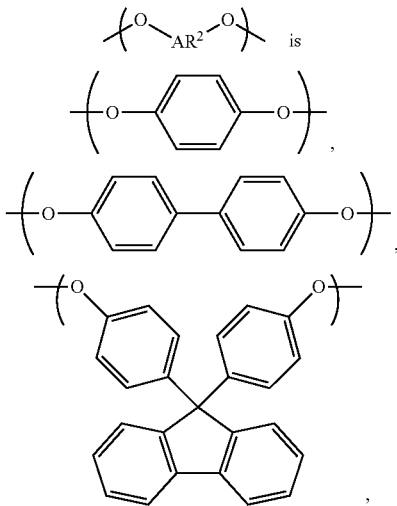
cannot be reacted to copolymerize.

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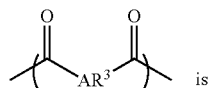
In some embodiments, the repeating unit



or a combination thereof. The repeating unit



or a combination thereof In some embodiments, the repeating unit

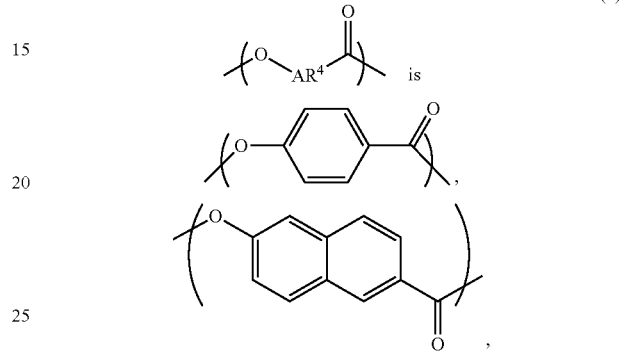


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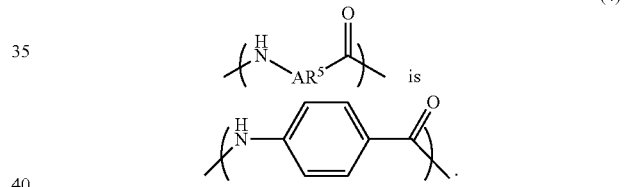
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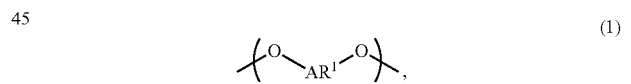
10 In some embodiments, the repeating unit



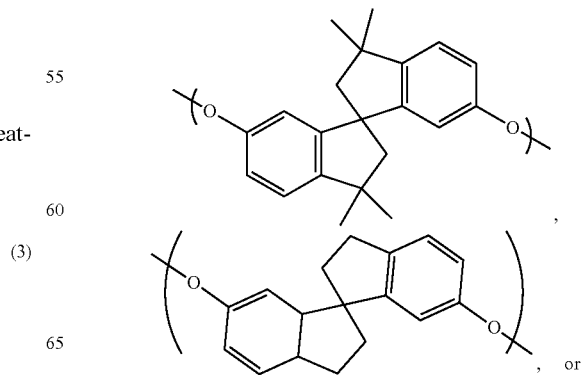
or a combination thereof In some embodiments, the repeating unit



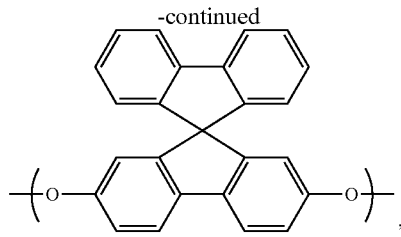
In the liquid crystal polymer, if the content of



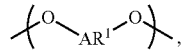
50 such as



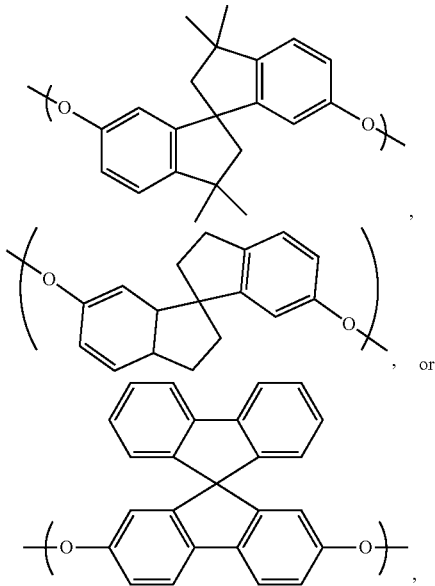
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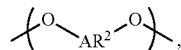
is too low, the solubility enhancement of the liquid-crystal polymer will be limited. If the content of



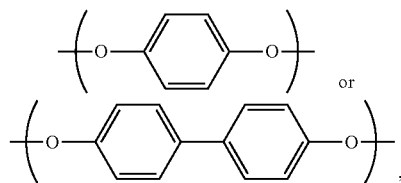
such as



is too high, the crystallinity of the liquid-crystal polymer will be lowered, and the melting point of the liquid crystal polymer will disappear. In the liquid-crystal polymer, if the content of



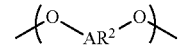
such as



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is too low, the crystallinity of the liquid-crystal polymer will be degraded. If the content of

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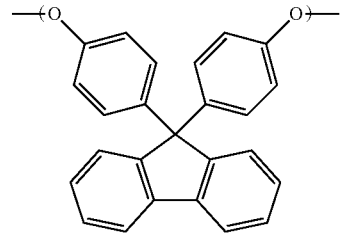


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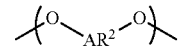
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is too low, the solubility of the liquid-crystal polymer will be degraded. If the content of

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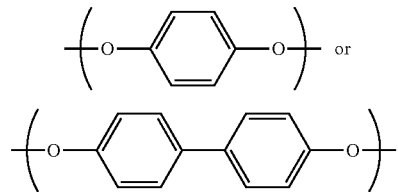


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such as

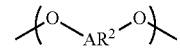
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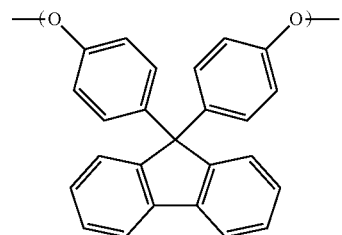
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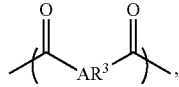
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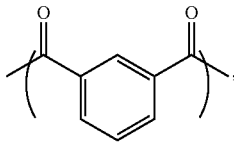


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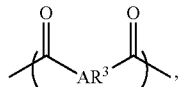
is too high, the crystallinity of the liquid-crystal polymer will be degraded. If the content of



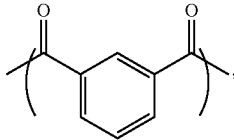
such as



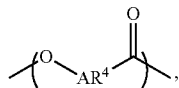
is too low, the solubility of the liquid-crystal polymer will be lowered. If the content of



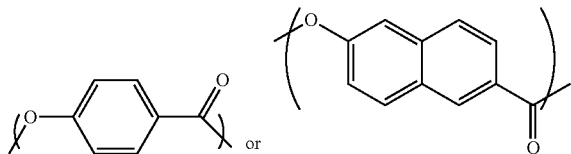
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is too high, the crystallinity of the liquid-crystal polymer will be degraded. If the content of

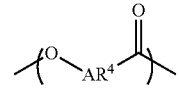


such as

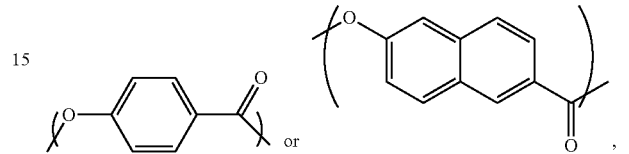


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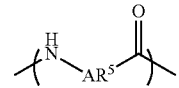
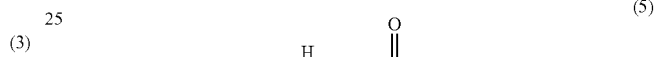
is too low, the crystallinity of the liquid-crystal polymer will be degraded. If the content of



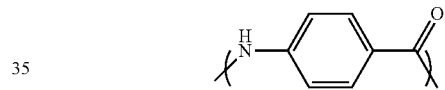
10 such as



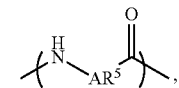
20 is too high, the solubility of the liquid-crystal polymer will be degraded. If the content of



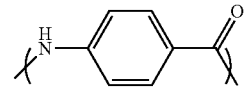
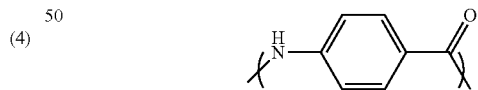
30 such as



is too low, the solubility of the liquid-crystal polymer will be degraded. If the content of

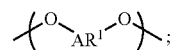
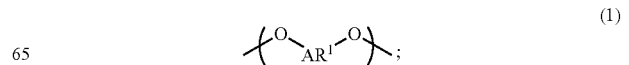


45 such as



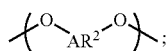
55 is too high, the dielectric property of the liquid-crystal polymer will be degraded, the crystallinity of the liquid-crystal polymer will be degraded, or the liquid-crystal polymer cannot be successfully polymerized.

60 In some embodiments, the liquid-crystal polymer is composed of the following repeating units: 1 mol % to 15 mol % of

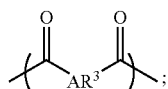


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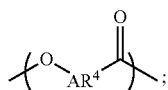
15 mol % to 35 mol % of



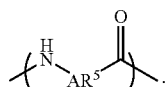
15 mol % to 35 mol % of



15 mol % to 35 mol % of



and 10 mol % to 40 mol % of



Each of AR¹AR², AR³, AR⁴, and AR⁵ is defined as above, and the related description is not repeated here.

In some embodiments, the liquid-crystal polymer has an inherent viscosity of 0.1 dL/g to 5 dL/g. If the inherent viscosity of the liquid-crystal polymer is too low, the film formability of the liquid-crystal polymer will be degraded. If the inherent viscosity of the liquid-crystal polymer is too high, the solubility of the liquid-crystal polymer will be degraded.

The method of manufacturing the liquid-crystal polymer of the disclosure is not specifically limited. For example, the hydroxyl-containing monomer or amine-containing monomer is firstly reacted with excess amount of fatty acid anhydride to perform acylation to form an acylated compound. The acylated compound is reacted with carboxylic acid-containing monomer to perform transesterification to form the liquid-crystal polymer. Alternatively, the acylated compound that is pre-acylated can be reacted with the carboxylic acid-containing monomer to perform the transesterification to form the liquid-crystal polymer.

The fatty acid anhydride content in the acylation can be 1.0 to 1.2 times the total equivalent of the hydroxyl group and amine group. The acylation can be performed at 130° C. to 180° C. for 5 minutes to 10 hours, such as 140° C. to 160° C. for 10 minutes to 3 hours.

The fatty acid anhydride for the acylation in the disclosure is not specifically limited and may include acetic anhydride, propionic anhydride, butanoic anhydride, isobutanoic anhydride, pentanoic acid, trimethylacetic anhydride, 2-ethylhexanoic anhydride, monochloroacetic anhydride, dichloroacetic anhydride, trichloroacetic anhydride, monobromoacetic anhydride, dibromoacetic anhydride, tribromoacetic anhydride, monofluoroacetic anhydride, difluoroacetic anhydride, trifluoroacetic anhydride, glutaric anhy-

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dride, maleic anhydride, succinic anhydride, β-bromopropionic anhydride, the like, or a combination thereof. In some embodiments, the fatty acid anhydride can be acetic anhydride, propionic anhydride, butanoic anhydride, or isobutanoic anhydride.

- (2) A catalyst can be added into the acylation and the transesterification. The catalyst can be a known catalyst for polymerization of polyester, such as metal salt catalyst (e.g. magnesium acetate, tin acetate, tetrabutyl titanate, lead acetate, potassium acetate, antimony trioxide, or the like), or organic catalyst such as heterocyclic compound having at least two nitrogen atoms (e.g. N,N'-dimethylaminopyridine, N-methylimidazole, pyrazole, or the like).

- (3) An additive can be added into the acylation reaction and the transesterification reaction, and the specific additive those are known in the art includes binding agent, anti-precipitation agent, UV absorber, thermal stabilizer, antioxidant, or a combination thereof.

- (4) The aromatic liquid-crystal polymer can be manufactured by batch-type equipment, continuous-type equipment, or the like.

- (5) The liquid-crystal polymer can be dissolved in a solvent to form a liquid-crystal polymer solution. The solvent and the liquid-crystal polymer may have a weight ratio of 100:0.01 to 100:100. For example, the liquid-crystal polymer solution may contain 100 parts by weight of the solvent and 0.01 to 100 parts by weight of the liquid-crystal polymer. In one embodiment, the crystal liquid solution contains 100 parts by weight of the solvent and 1 to 40 parts by weight of the liquid-crystal polymer. Alternatively, the liquid-crystal polymer solution contains 100 parts by weight of the solvent and 1 to 20 parts by weight of the liquid-crystal polymer. If the amount of the liquid-crystal polymer is too low, the coated film cannot easily achieve the desired thickness. If the amount of the liquid-crystal polymer is too high, the solution viscosity will be too high to be coated. The liquid-crystal polymer is similar to that described above, and the related description is not repeated here. For example, the solvent can be halogen-containing solvent (such as 1-chlorobutane, chlorobenzene, 1,1-dichloroethane, chloroform, or 1,1,2,2-tetrachloroethane), ether solvent (such as diethyl ether, tetrahydrofuran, or 1,4-dioxolane), ketone solvent (such as acetone or cyclohexanone), ester solvent (such as ethyl acetate), lactone solvent (such as butyl acrylate), carbonate solvent (such as vinyl carbonate or acrylic carbonate), amine solvent (such as triethylamine or pyridine), nitrile solvent (such as acetonitrile), amide solvent (such as N,N'-dimethylformamide, N,N'-dimethylacetamide, tetramethylurea, or N-methylpyrrolidone), nitro solvent (such as nitromethane or nitrobenzene), sulfide solvent (such as dimethyl sulfoxide or butane disulfone), phosphide solvent (hexamethyl phosphoric triamide or tri-n-butyl phosphide), paraffin, olefin, alcohol, aldehyde, aromatic hydrocarbon, terpene, hydrogenated hydrocarbon, heterocyclic compound, or a combination thereof.

- (5) The liquid-crystal polymer solution may further include another resin. For example, at least one resin that is not the liquid-crystal polymer can be added to the liquid-state composition. The resin may include thermoplastic resin or thermosetting resin. The thermoplastic resin can be polypropylene, polyamide, polyester (such as non-liquid-crystal polyallylate), polyphenylene sulfide, polyetherketone, polycarbonate, polyether sulfone, polyphenylene ether, polyetherimide, fluororesin, an elastomer (typically, copolymer of glycidyl methacrylate and polyethylene), or a modified product thereof. The thermosetting resin can be novolac resin, epoxy resin, polyimide resin, or cyanate resin.

- (5) The liquid-crystal polymer solution may further include another resin. For example, at least one resin that is not the liquid-crystal polymer can be added to the liquid-state composition. The resin may include thermoplastic resin or thermosetting resin. The thermoplastic resin can be polypropylene, polyamide, polyester (such as non-liquid-crystal polyallylate), polyphenylene sulfide, polyetherketone, polycarbonate, polyether sulfone, polyphenylene ether, polyetherimide, fluororesin, an elastomer (typically, copolymer of glycidyl methacrylate and polyethylene), or a modified product thereof. The thermosetting resin can be novolac resin, epoxy resin, polyimide resin, or cyanate resin.

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In addition, the other resin can be dissolved in the solvent for the liquid-crystal polymer when the other resin is adopted.

In addition, the liquid-crystal polymer solution may further include another additive to enhance the size stability, mechanical properties, thermal conductivity, dielectric properties, thermal stability, light stability, anti-aging properties, coatability, and film formability. The additive may include inorganic filler (e.g. silica, alumina, titania, zirconia, hydrous aluminum silicate, calcium carbonate, calcium phosphate, barium titanate, strontium titanate, or aluminum hydroxide), organic filler (e.g. epoxy resin powder, melamine resin powder, polyurea resin powder, benzomelamine formaldehyde resin powder, styrene resin powder, fluororesin powder, or fluororesin dispersion), anti-oxidant, thermal stabilizer, UV absorber, light stabilizer, anti-aging agent, toughening agent, chain extender, plasticizer, cross-linking agent, additives for coating inks (e.g. defoamer, leveling agent, wetting and dispersing agent, thickener, thixotropy controller, adhesion promoter, or coupling agent), or a combination thereof.

The liquid-crystal polymer film can be prepared by the following method. First, the described liquid-crystal polymer solution is coated onto a support to make the coated layer flat and uniform. The coating method can be any suitable method such as roll coating, dip coating, spray coating, spin-on coating, curtain coating, slot coating, or screen coating. The support can be copper foil, glass, aluminum foil, or another suitable support. After coating the liquid-crystal polymer solution, the solvent is removed to form the liquid-crystal polymer film on the support. The support can be then optionally removed (depending on the application requirement) by the method such as etching or peeling.

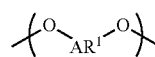
The method of removing the solvent is not specifically limited, which can be evaporation. The solvent can be evaporated by heating, reducing pressure, ventilation, or the like. In the above methods, the heating evaporation is beneficial in high yield and easy to operate. On the other hand, the coating can be heated in ventilation to evaporate the solvent. For example, the coating can be pre-heated in ventilation drying at 60° C. to 200° C. for about 10 minutes to 2 hours, and then heated in ventilation at 200° C. to 400° C. for about 30 minutes to 10 hours.

The thickness of the liquid-crystal polymer film prepared by the above method is not limited, which can be 1 micrometer to 100 micrometers.

One embodiment of the disclosure provides a laminated material, including the support and the liquid-crystal polymer film on the support. The support can be copper foil, glass, aluminum foil, or another suitable support. In some embodiments, the laminated material includes the copper foil and the liquid-crystal polymer film on the copper foil. An adhesive layer can be further disposed between the support (e.g. copper foil) and the liquid-crystal polymer film to enhance the adhesion between the support (e.g. copper foil) and the liquid-crystal polymer film. When the laminated material is applied to the printed circuit board, some adhesive having excellent electric properties (e.g. fluororesin) can be introduced to reduce the transmission loss of the printed circuit board. The laminated material can be further manufactured as a laminated material with double-sided copper foils. For example, the laminated materials with single-sided copper foil can be attached to each other and heat pressed to form the laminated material with double-sided copper foils, in which a middle layer of the liquid-crystal polymer film is interposed between a top layer of the copper foil and a bottom layer of the copper foil.

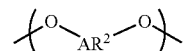
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An appropriate content ratio of

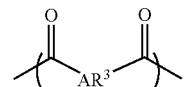


(1)

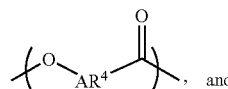
is introduced into the liquid-crystal polymer to combine with appropriate content ratios of



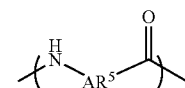
(2)



(3)



(4)



(5)

to efficiently enhance the solubility of the liquid-crystal polymer.

Below, exemplary embodiments will be described in detail so as to be easily realized by a person having ordinary knowledge in the art. The inventive concept may be embodied in various forms without being limited to the exemplary embodiments set forth herein. Descriptions of well-known parts are omitted for clarity.

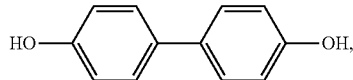
EXAMPLES

Example 1

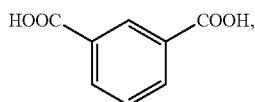
130.2 g of 4,4'-biphenol (0.7 mole), 116.2 g of isophthalic acid (0.7 mole), 131.6 g of 6-hydroxy-2-naphthalene carboxylic acid (0.7 mole), 95.9 g of 4-aminobenzoic acid (0.7 mole), and 286 g of acetic anhydride (2.8 mole) were mixed, then heated to 150° C. to be reacted at 150° C. for 3 hours under nitrogen, and then heated to 320° C. to be reacted at 320° C. for 1 hour. Thereafter, the temperature was kept at 320° C. and the pressure was gradually vacuumed until the reaction achieved ideal viscosity. The vacuum was then broken by using of nitrogen, and the product was extruded out by the nitrogen pressure. The product had an inherent viscosity of 0.81 dL/g, which was measured with an Ostwald viscometer. The product was completely dissolved in N-methyl-2-pyrrolidone (NMP) at 140° C. to obtain a solution with a concentration of 0.3 g/dL. The inherent viscosity of the solution at room temperature (25° C.) was measured by the Ostwald viscometer. The product had thermal decomposition temperature (Td) of 453° C. (measured by thermogravimetric analysis, TGA). The product had melting point (Tm) of 286° C. and glass transition temperature (Tg) of 169° C., which were measured by differential scanning calorimetry (DSC). The product was dissolved in NMP to form a solution with a solid content of 8 wt % (maximum solubility). The solution was coated onto a copper foil and dried, and then heat treated at 200° C. to 300° C. to obtain a liquid-crystal polymer film (with a thickness of 25

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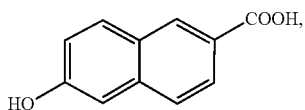
micrometers) attached to the copper foil. The copper foil was then removed by etchant to obtain the liquid-crystal polymer film alone. In the above reaction, the chemical structure of 4,4'-biphenol is



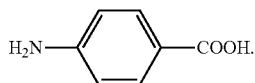
the chemical structure of isophthalic acid is



the chemical structure of 6-hydroxy-2-naphthalene carboxylic acid is



and the chemical structure of 4-aminobenzoic acid is

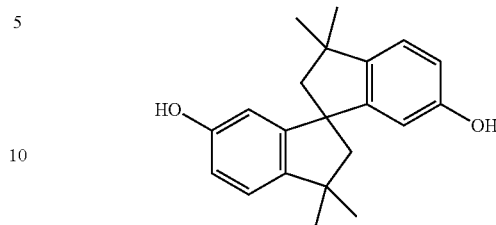


Example 2

86.3 g of spirobiphenol (0.28 mole), 78.2 g of 4,4'-biphenol (0.42 mole), 116.2 g of isophthalic acid (0.7 mole), 131.6 g of 6-hydroxy-2-naphthalene carboxylic acid (0.7 mole), 95.9 g of 4-aminobenzoic acid (0.7 mole), and 286 g of acetic anhydride (2.8 mole) were mixed, then heated to 150° C. to be reacted at 150° C. for 3 hours under nitrogen, and then heated to 320° C. to be reacted at 320° C. for 1 hour. Thereafter, the temperature was kept at 320° C. and the pressure was gradually vacuumed until the reaction achieved ideal viscosity. The vacuum was then broken by nitrogen, and the product was extruded out by the nitrogen pressure. The product had an inherent viscosity of 0.71 dL/g, which was measured with an Ostwald viscometer. The product was completely dissolved in NMP at 140° C. to obtain a solution with a concentration of 0.3 g/dL. The inherent viscosity of the solution at room temperature (25° C.) was measured by the Ostwald viscometer. The product had Td of 450° C. (measured by TGA). The product had Tm of 243° C. and Tg of 165° C., which were measured by DSC. The product was dissolved in NMP to form a solution with a solid content of 16 wt % (maximum solubility). The solution was coated onto a copper foil and dried, and then heat treated at 200° C. to 300° C. to obtain a liquid-crystal polymer film (with a thickness of 40 micrometers) attached to the copper foil. The copper foil was then removed by etchant to obtain the liquid-crystal polymer film alone.

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In the above reaction, the chemical structure of spirobiphenol is



Example 3

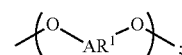
215.6 g of spirobiphenol (0.7 mole), 116.2 g of isophthalic acid (0.7 mole), 131.6 g of 6-hydroxy-2-naphthalene carboxylic acid (0.7 mole), 95.9 g of 4-aminobenzoic acid (0.7 mole), and 286 g of acetic anhydride (2.8 mole) were mixed, then heated to 150° C. to be reacted at 150° C. for 3 hours under nitrogen, and then heated to 320° C. to be reacted at 320° C. for 1 hour. Thereafter, the temperature was kept at 320° C. and the pressure was gradually vacuumed until the reaction achieved ideal viscosity. The vacuum was then broken by nitrogen, and the product was extruded out by the nitrogen pressure. The product had an inherent viscosity of 0.2 dL/g, which was measured with an Ostwald viscometer. The product was completely dissolved in NMP at 140° C. to obtain a solution with a concentration of 0.3 g/dL. The inherent viscosity of the solution at room temperature (25° C.) was measured by the Ostwald viscometer. The product had Td of 413° C. (measured by TGA). The product had no Tm and Tg of 231° C., which were measured by DSC. The product was dissolved in NMP to form a solution with a solid content of 8 wt % (maximum solubility).

As shown in the comparison of Examples 1 and 2, appropriate amount of the spirobiphenol could efficiently increase the solubility of the liquid-crystal polymer, thereby increasing the thickness of the liquid-crystal polymer film. As shown in the comparison of Examples 2 and 3, an overly high ratio of the spirobiphenol resulted in the liquid-crystal polymer without melting point, and reduced the crystallinity of the liquid-crystal polymer.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed methods and materials. It is intended that the specification and examples be considered as exemplary only, with the true scope of the disclosure being indicated by the following claims and their equivalents.

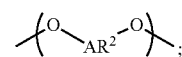
What is claimed is:

1. A liquid-crystal polymer, being composed of the following repeating units:
1 mol % to 20 mol % of



(1)

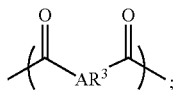
- 10 mol % to 35 mol % of



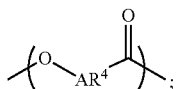
(2)

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10 mol % to 35 mol % of

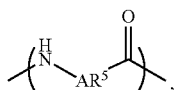


10 mol % to 50 mol % of

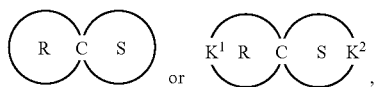


and

10 mol % to 40 mol % of

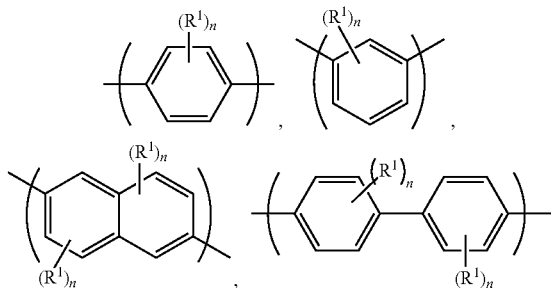


wherein AR¹ is

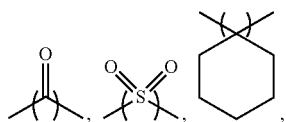


wherein each of ring R and ring S is independently a C₃₋₂₀ ring, ring R and ring S share a carbon atom, and each of K¹ and K² is independently a C₅₋₂₀ conjugated system,

each of AR², AR³, AR⁴, and AR⁵ is independently AR⁶ or AR⁶-Z-AR⁷, each of AR⁶ and AR⁷ is independently



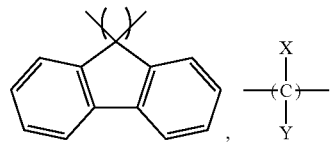
or a combination thereof, and Z is -O-



18

-continued

(3) 5



10 or C₁₋₅ alkylene group; wherein each of X and Y is independently H, C₁₋₅ alkyl group, CF₃, or

(4) 15



20 wherein R¹ is H, CH₃, CH(CH₃)₂, C(CH₃)₃, CF₃, OCH₃, or

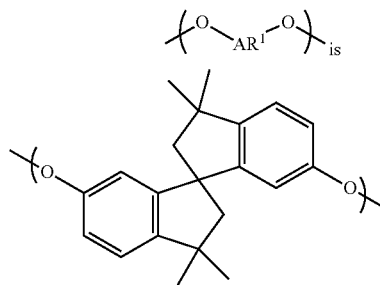
(5) 25



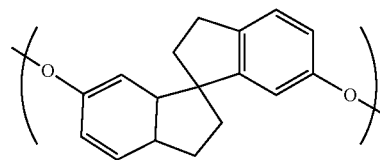
and n=1 to 4.

30 2. The liquid-crystal polymer as claimed in claim 1, wherein

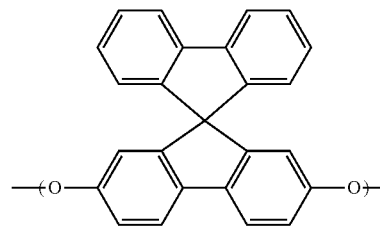
35 (1)



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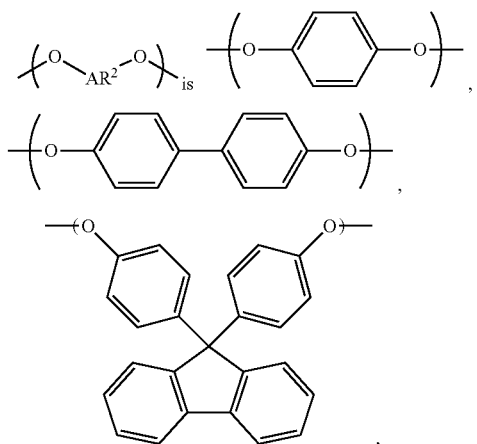
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or a combination thereof.

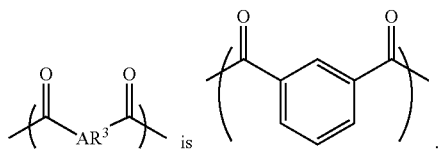
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3. The liquid-crystal polymer as claimed in claim 1, wherein

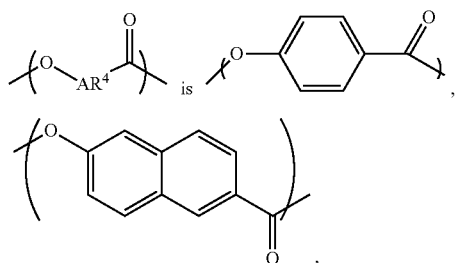


or a combination thereof.

4. The liquid-crystal polymer as claimed in claim 1, wherein



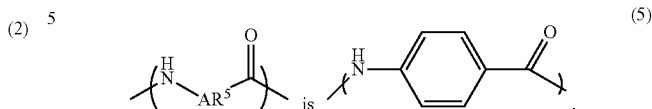
5. The liquid-crystal polymer as claimed in claim 1, wherein



or a combination thereof.

20

6. The liquid-crystal polymer as claimed in claim 1, wherein



7. The liquid-crystal polymer as claimed in claim 1, having an inherent viscosity of 0.1 dL/g to 5 dL/g.

8. A laminated material, comprising:
a support; and
a liquid-crystal polymer film disposed on the support, wherein the liquid-crystal polymer film includes the liquid-crystal polymer as claimed in claim 1.

9. The laminated material as claimed in claim 8, wherein the liquid-crystal polymer film has a thickness of 1 micrometer to 100 micrometers.

10. The laminated material as claimed in claim 8, wherein the support comprises copper foil, glass, or aluminum foil.

11. The laminated material as claimed in claim 8, further comprising an adhesive layer disposed between the support and the liquid-crystal polymer film.

12. A liquid-crystal polymer solution, comprising:
100 parts by weight of solvent; and
0.01 to 100 parts by weight of the liquid-crystal polymer as claimed in claim 1.

13. The liquid-crystal polymer solution as claimed in claim 12, wherein the solvent comprises halogen-containing solvent, ether solvent, ketone solvent, ester solvent, carbonate solvent, amine solvent, nitrile solvent, amide solvent, nitro solvent, sulfide solvent, phosphide solvent, paraffin, olefin, alcohol, aldehyde, aromatic hydrocarbon, terpene, hydrogenated hydrocarbon, heterocyclic compound, or a combination thereof.

14. The liquid-crystal polymer solution as claimed in claim 12, further comprising another resin, and the other resin comprises thermoplastic resin or thermosetting resin.

15. The liquid-crystal polymer solution as claimed in claim 12, further comprising an additive, and the additive comprises inorganic filler, organic filler, anti-oxidant, UV absorber, thermal stabilizer, light stabilizer, anti-aging agent, toughening agent, chain extender, plasticizer, crosslinking agent, additives for coating inks, or a combination thereof.

16. A method of forming liquid-crystal polymer film, comprising:
coating the liquid-crystal polymer solution as claimed in claim 13 onto a support; and
removing the solvent to form a liquid-crystal polymer film on the support.

17. The method as claimed in claim 16, wherein the support comprises copper foil, glass, or aluminum foil.

18. The method as claimed in claim 16, further comprising removing the support after forming the liquid-crystal polymer film on the support.

* * * * *