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(54) Title: FLUORINATED POLY(ARYLENE ETHERS)

(57) **Abrégé/Abstract:**

Fluorinated poly(arylene ethers) having a repeat unit such as (A) are useful as dielectric materials in multilayer interconnects in integrated circuit chips and multichip modules and as protective materials for chips.



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ABSTRACT OF THE DISCLOSURE

Fluorinated poly(arylene ethers) having a repeat unit such as (A) are useful as dielectric materials in multilayer interconnects in integrated circuit chips and multichip modules and as protective materials for chips.

FLUORINATED POLY(ARYLENE ETHERS)Background of the Invention

5 This invention relates to novel fluorinated aromatic polyethers which are useful as dielectric materials in microelectronic articles.

 Polymer films and coatings are often used in the electronic industry as insulating materials and passivation layers, especially in integrated circuit devices such as multichip
10 modules. Polymers having a low dielectric constant ϵ are preferred, because components insulated with them can be designed with higher circuit densities and can operate at higher speeds and with less signal broadening. The effect of ϵ on the performance of multilayer integrated circuit articles is discussed in "Microelectronics Packaging Handbook," Tummala et al. (eds.), pp. 687-692 (van Nostrand Reinhold); Watari et al., U.S. Pat. 4,744,007 (1988); and
15 Budde et al., U.S. Pat. 4,732,843 (1988).

 Polyimide is an insulator of choice for many electronic applications, because of its superior mechanical and thermal properties and its fabricability into thin films and coatings. However, polyimide has a relatively high ϵ , a limitation accentuated by polyimide's tendency to
20 absorb water (up to 3-4 %) in humid environments. Water absorption causes ϵ to rise, compromising performance. One commercially available polyimide has an ϵ of about 3.2 at 0 % relative humidity (%RH), which rises to about 3.8 at 60 %RH. As noted by Denton et al. in J. Electronic Mater. 14(2), 119 (1985), polyimide moisture absorption can also adversely affect performance through increased insulator conductivity, loss of adhesion, or corrosion. Further,
25 some polyimides are susceptible to hydrolysis and/or attack by solvents (often manifested by crazing or cracking upon exposure to a solvent).

 It has been proposed, in Mercer, U.S. Pat. 4,835,197 (1989), to improve the solvent resistance of polyimide by curing with an acetylene, maleimide, or vinyl terminated curing agent.
30 However, a polyimide so cured would still have the relatively high dielectric constant of polyimides and their tendency to absorb moisture.

 It has also been proposed by one of us to use fluorinated polymers having a binaphthyl moiety as dielectric materials.
35

 Polyquinoxalines, polyquinoxalones, polybenzoxazoles, and copolymers thereof with polyimides have also been proposed as polymers for microelectronic applications by Labadie et al., in SAMPE J. vol. 25, pp. 18-22 (Nov./Dec. 1989).

40 Kellman et al., ACS Symp. Ser. 326, Phase Transfer Catalysis, p. 128 (1987) discloses the preparation of polyethers from diphenols and hexafluorobenzene and decafluorobiphenyl, although no particular utility is disclosed for the polymers so prepared. Similar disclosures are made in Kellman et al., Polym. Prepr. 22(2), 383 (1981) and Gerbi et al., J. Polym. Sci. Polym. Letters Ed. 23, 551 (1985).
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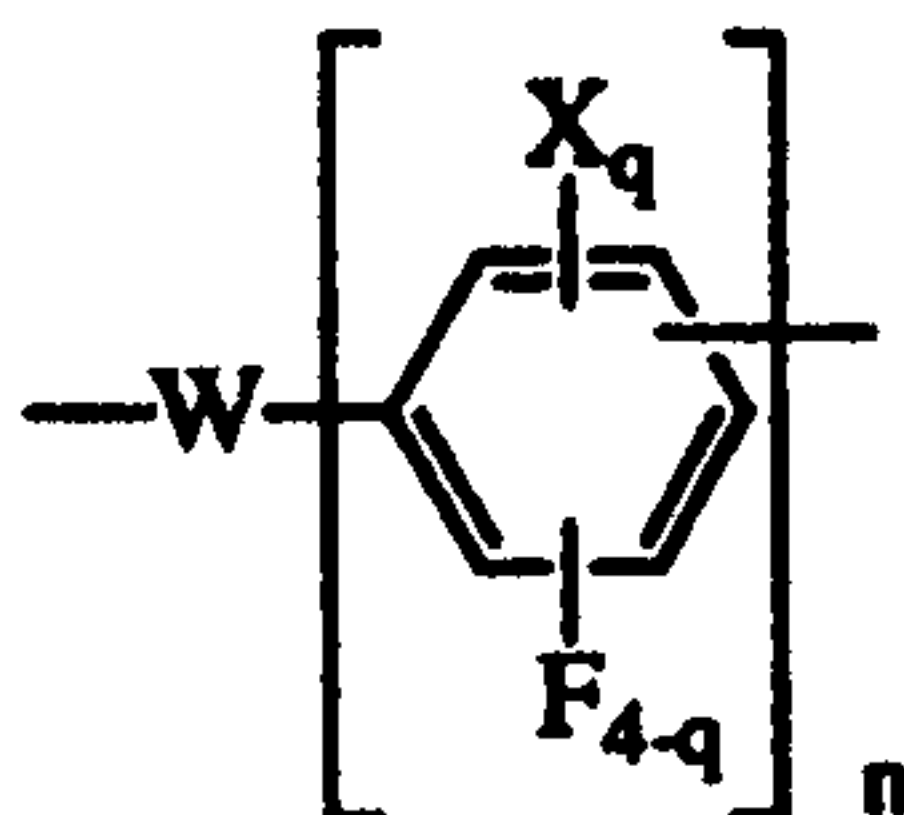
This invention provides a fluorinated poly(arylene ether) which is especially suitable as a dielectric material in electronic articles. The polymers of this invention have low dielectric constants which are little affected by increases in the ambient humidity, can be made solvent resistant, and exhibit excellent adhesion to itself and other adherends.

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Summary of the Invention

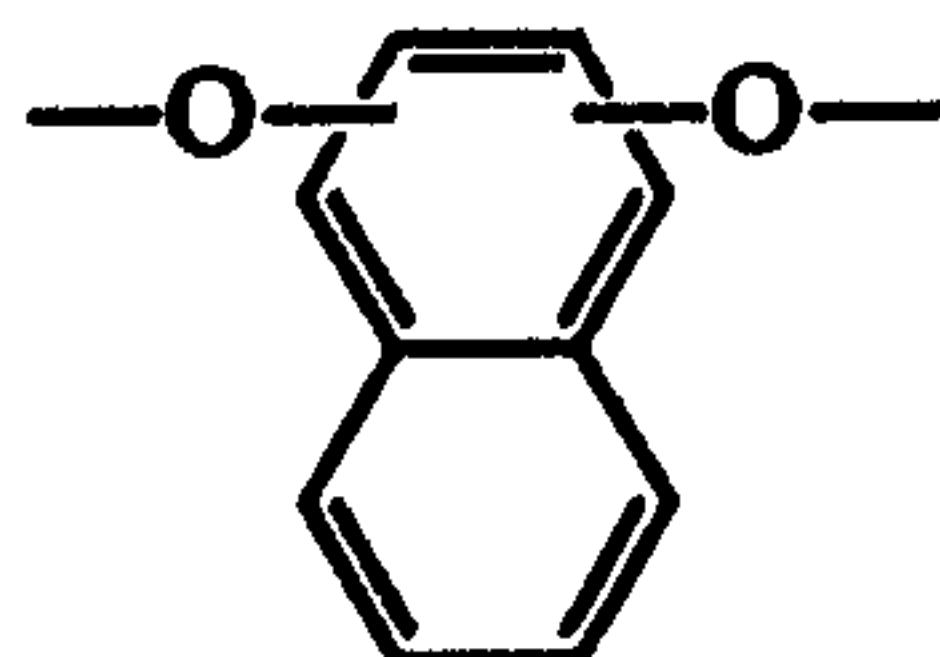
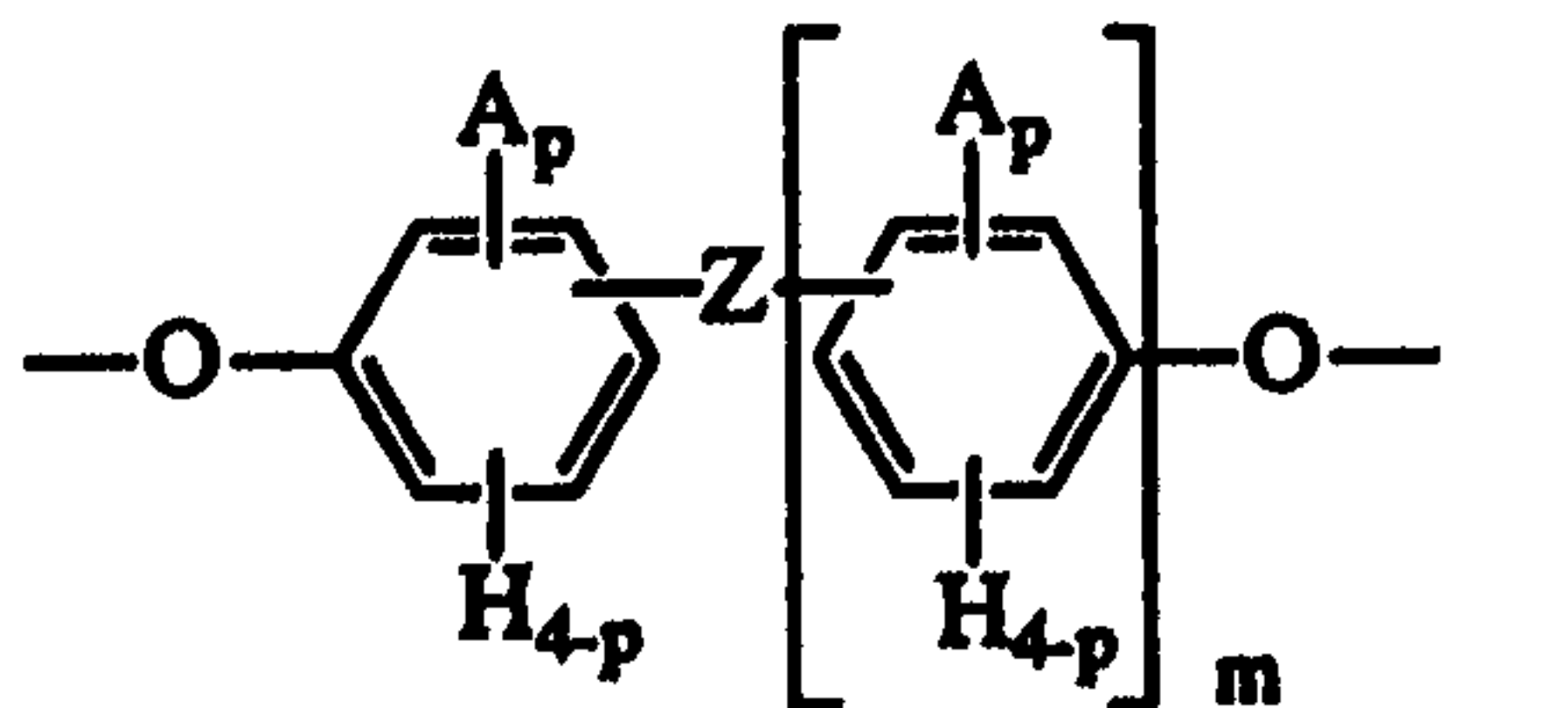
This invention provides a fluorinated poly(arylene ether) comprising a repeat unit of the structure

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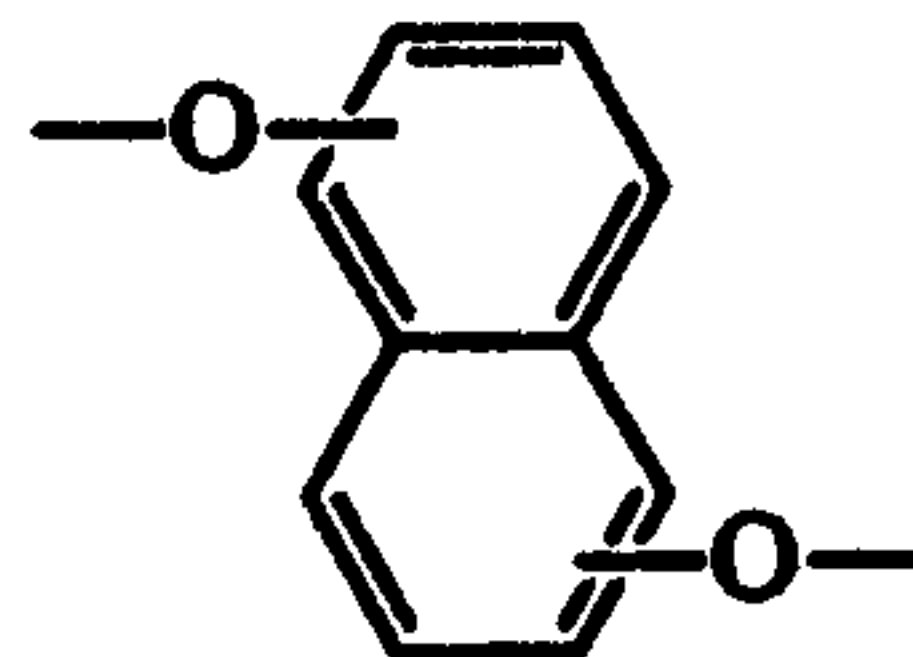


wherein -W- is

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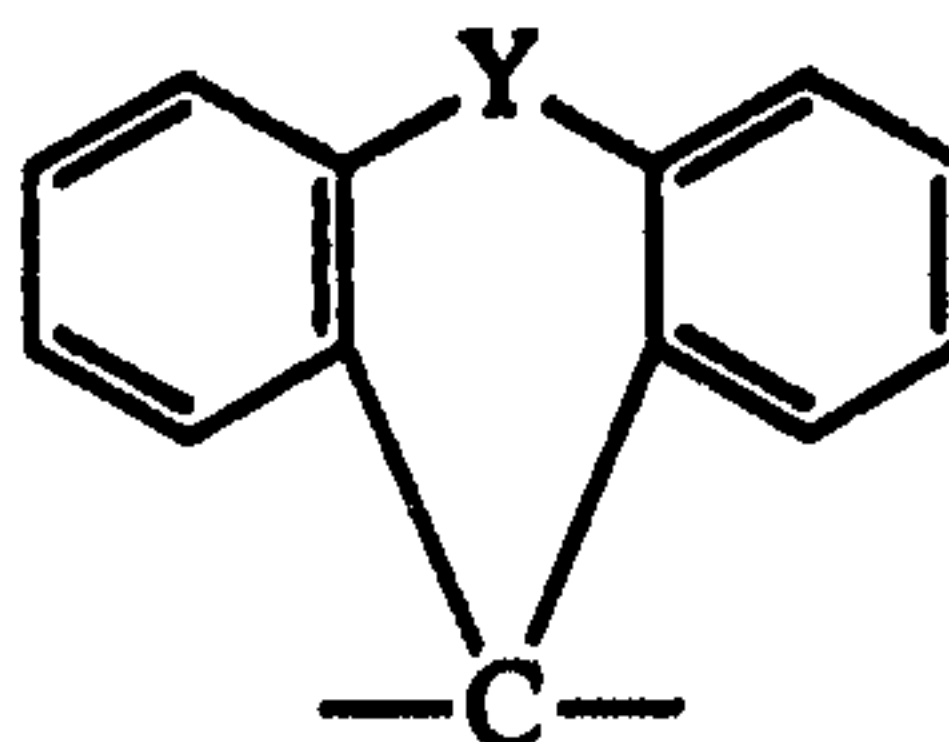


, or



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wherein each -A is independently -F, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; p is 0, 1, or 2; -Z- is a direct bond, -C(CH₃)₂-, -C(CF₃)₂-, -O-, -S-, -SO₂-, -CO-, -P(C₆H₅)-, -C(CH₃)(C₆H₅), -C(C₆H₅)₂-, -(CF₂)₁₋₆-, or



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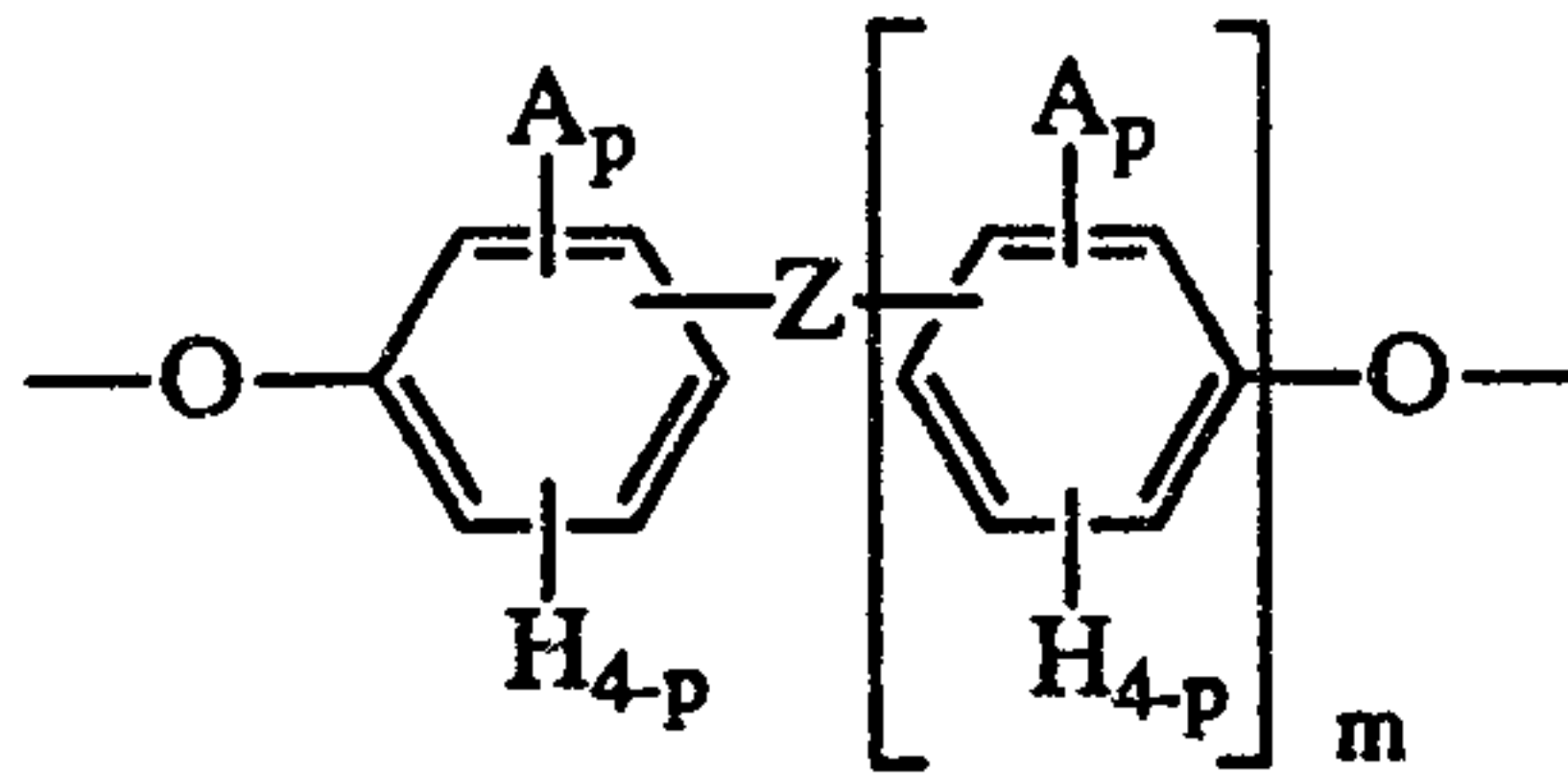
wherein -Y- is -O- or a direct bond;

and m is 0, 1, or 2;

each -X is independently -H, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; q is 0, 1, or 2; and n is 1 or 2;

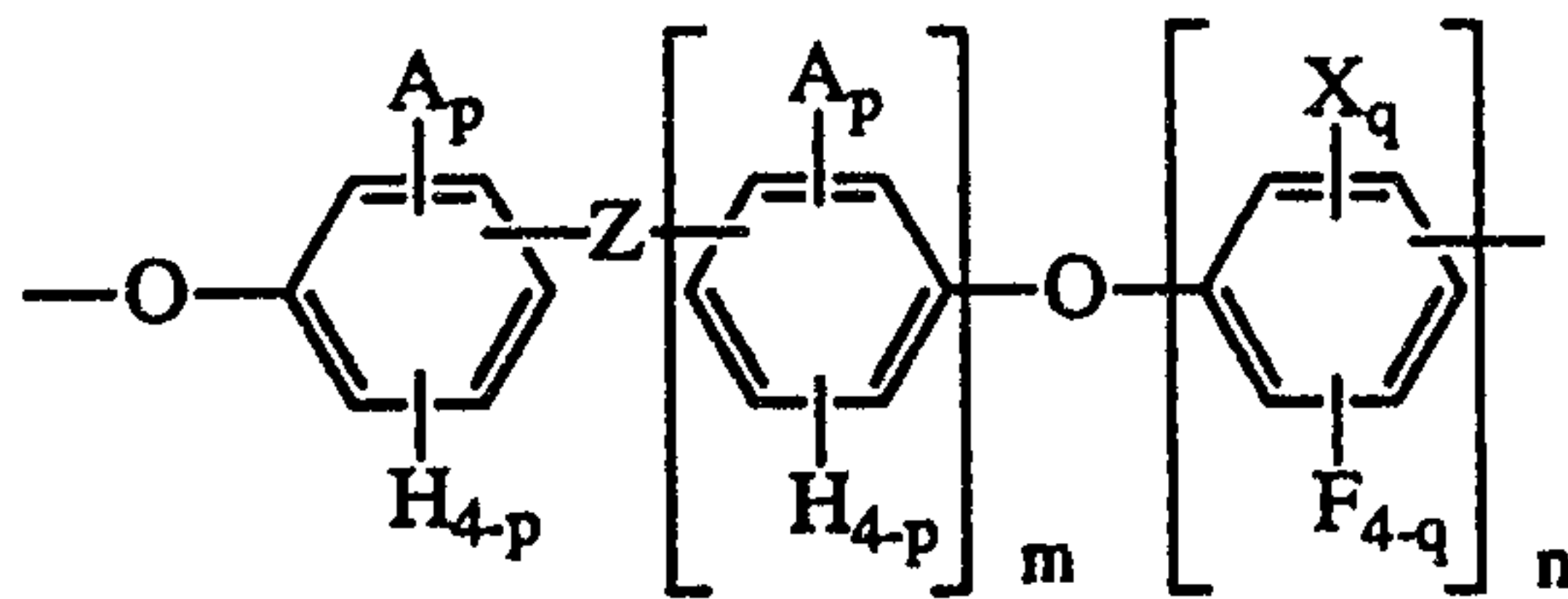
provided that if -Z- is -C(CH₃)₂-, -S-, or -SO₂- and m is 1, then p and q are not both 0.

Preferably, -W- is



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corresponding to a fluorinated poly(arylene ether) having the repeat unit



10 wherein -A, p, -Z-, m, -X, q, and n are as previously defined. Further, the group -Z- is preferably para-bonded to each ether oxygen in the benzene rings.

15 These fluorinated poly(arylene ethers) can be used as dielectric materials in multilayer interconnects, integrated circuit chips, and multichip modules; as protective materials for chips; and as dielectric material for circuit boards.

Brief Description of the Drawings

20 Fig. 1a depicts a multichip module having a multilayer interconnect in which the interlayer dielectric is a fluorinated poly(arylene ether) of this invention. Fig. 1b shows in cross-section the multilayer interconnect.

25 Fig. 2 shows in cross-section an integrated circuit chip having thereon a multilayer interconnect in which the interlayer dielectric is a fluorinated poly(arylene ether) of this invention.

Fig. 3 shows in cross-section an integrated circuit chip protected by a coating of a fluorinated poly(arylene ether) of this invention.

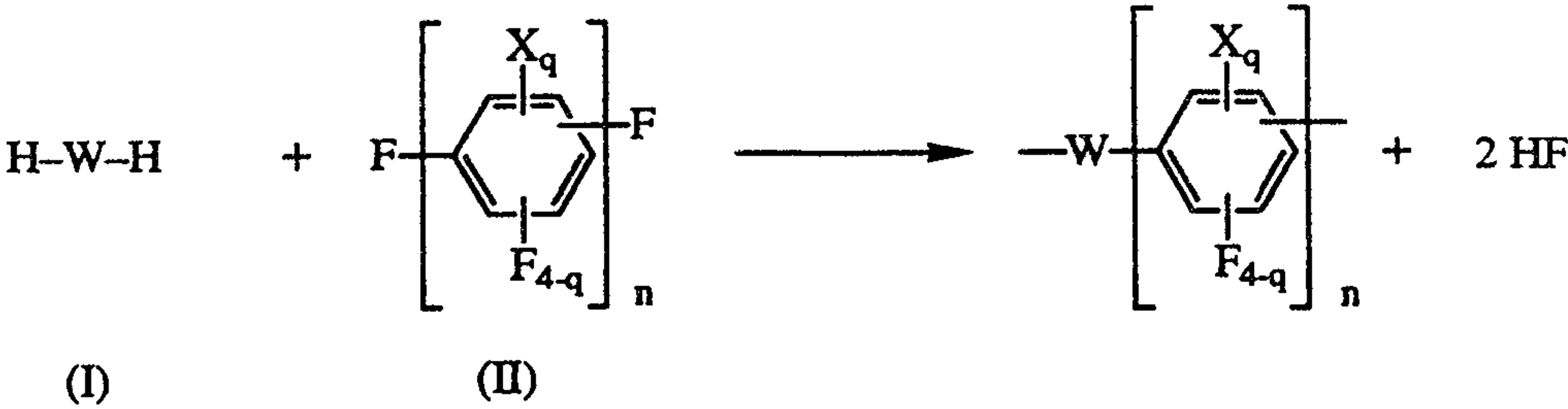
30 Fig. 3a shows in cross-section a circuit board in which the substrated is made from a fluorinated poly(arylene ether).

Fig. 4 compares the dielectric constants of polymers of this invention and of comparison polymers not according to this invention.

Description of the Preferred Embodiments

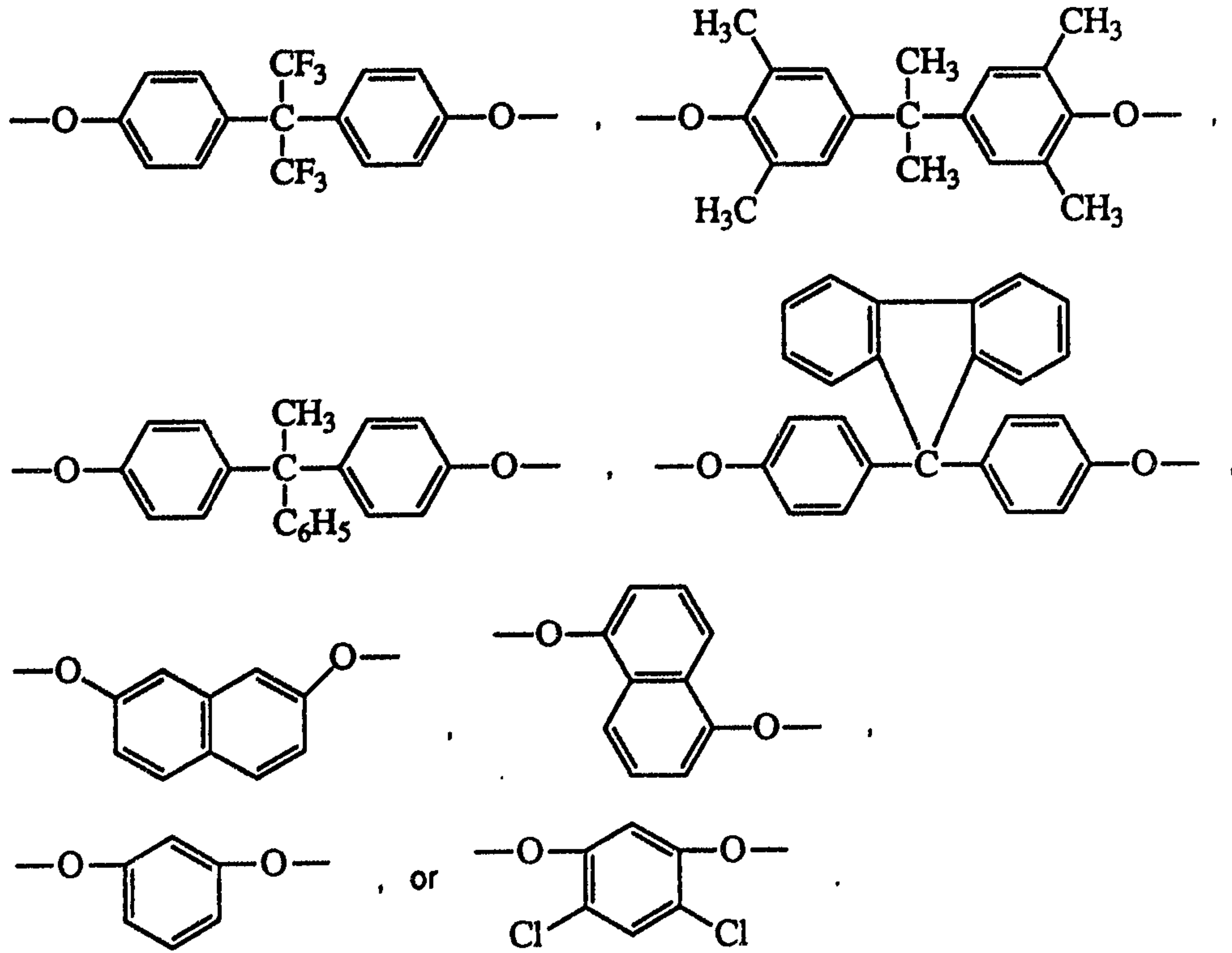
The fluorinated poly(arylene ethers) of this invention can be made by the condensation polymerization of a diphenol (I) with a fluorinated monomer (II):

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In the equation above, -W-, -X, q, and n have the same meaning as defined earlier. Suitable diphenols (I) include 4,4'-(hexafluoroisopropylidene)diphenol, 4,4'-isopropylidene-di(2,6-dimethylphenol), 4,4'-(1-phenylethylidene) bisphenol, 9,9'-bis(4-hydroxyphenyl)fluorene, 1,5-dihydroxynaphthalene, 2,7-dihydroxynaphthalene, resorcinol, and 4,6-dichlororesorcinol, corresponding to fluorinated poly(arylene ether) repeat units in which -W- is:

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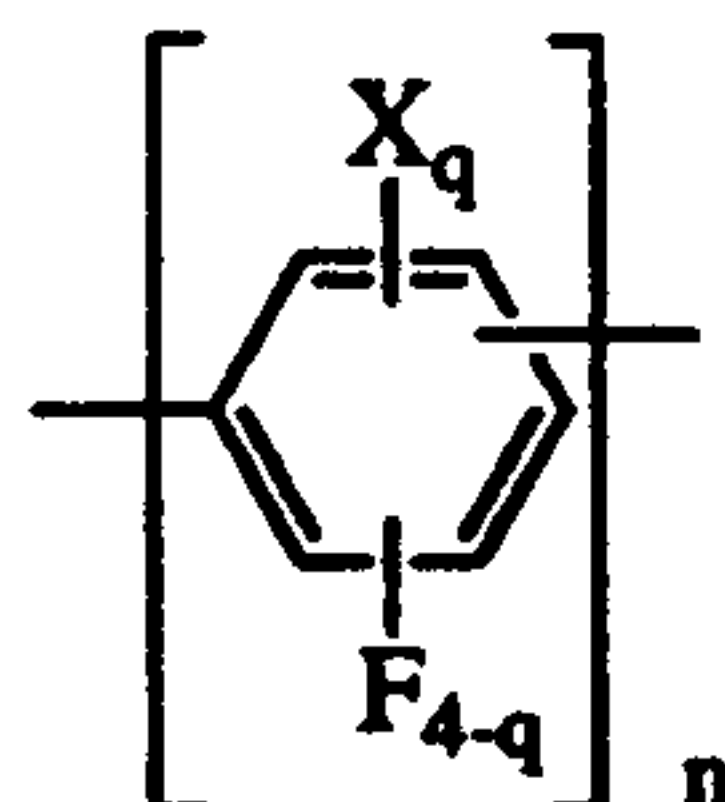
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Preferred diphenols (I) include 4,4'-(hexafluoroisopropylidene)diphenol, 9,9'-bis(4-hydroxyphenyl)fluorene, and 1,5-dihydroxynaphthalene.

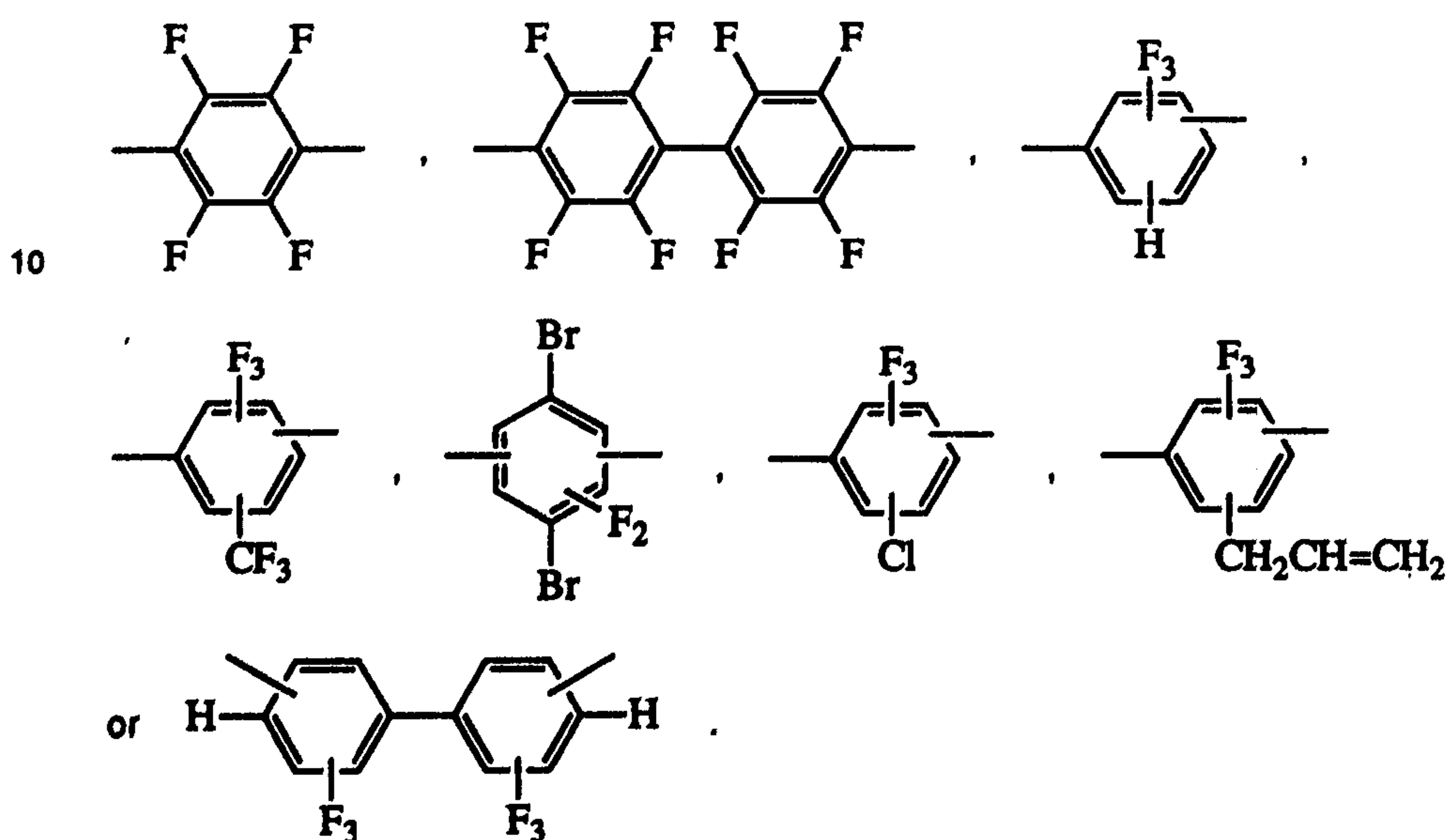
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Suitable fluorinated monomers (II) include hexafluorobenzene, decafluorobiphenyl, pentafluorobenzene, octafluorotoluene, 1,4-dibromotetrafluorobenzene, chloropentafluorobenzene, allylpentafluorobenzene, and 2,2',3,3',5,5',6,6'-octafluorobiphenyl, corresponding to fluorinated poly(arylene ether) repeat units in which

5



is



Preferred fluorinated monomers includes hexafluorobenzene and decafluorobiphenyl.

Contrary to what has been taught in the art, it has been discovered that complete fluorine substitution of the aromatic ring in monomers (II) is not necessary for effective polymerization, monomers such as pentafluorobenzene, octafluorotoluene, 1,4-dibromotetrafluorobenzene, and chloropentafluorobenzene being suitable.

20

Monomers (I) and (II) are used in substantially stoichiometric amounts if high molecular weight polymer is desired. Alternatively, if lower molecular weight material is desired, for example to facilitate the preparation of solutions for spin or other solvent coating operations, a slight stoichiometric excess of either monomer can be used to control the molecular weight.

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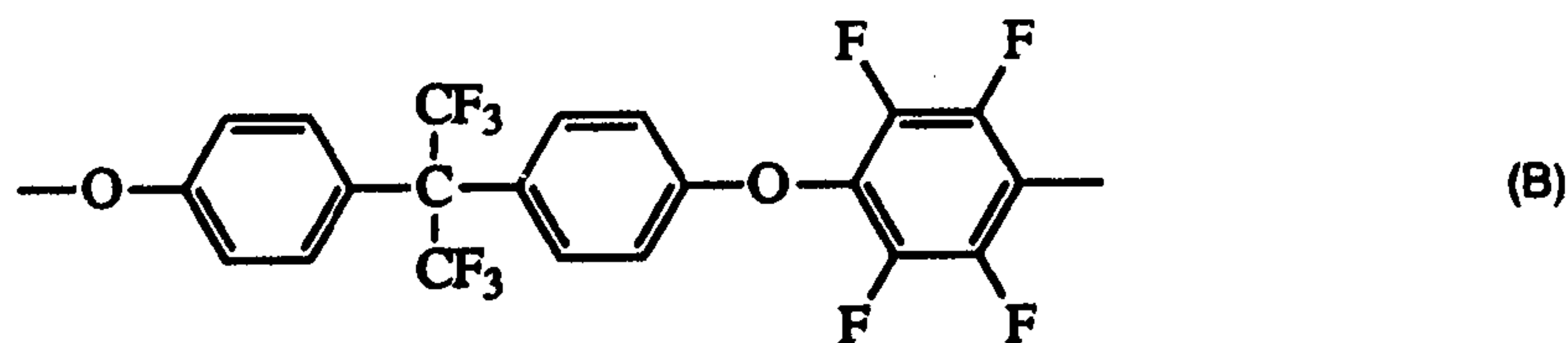
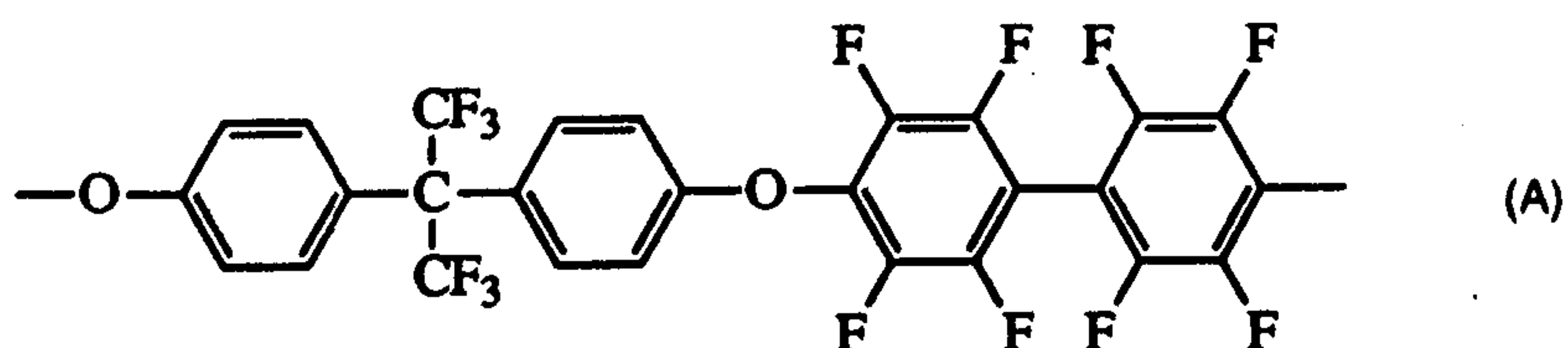
A base such as an alkali metal carbonate, bicarbonate, or hydroxide is added to the polymerization mixture to convert the phenoxy groups to the corresponding phenoxides. Sodium and potassium carbonate are preferred. A polar aprotic solvent, such as N,N-dimethylacetamide,

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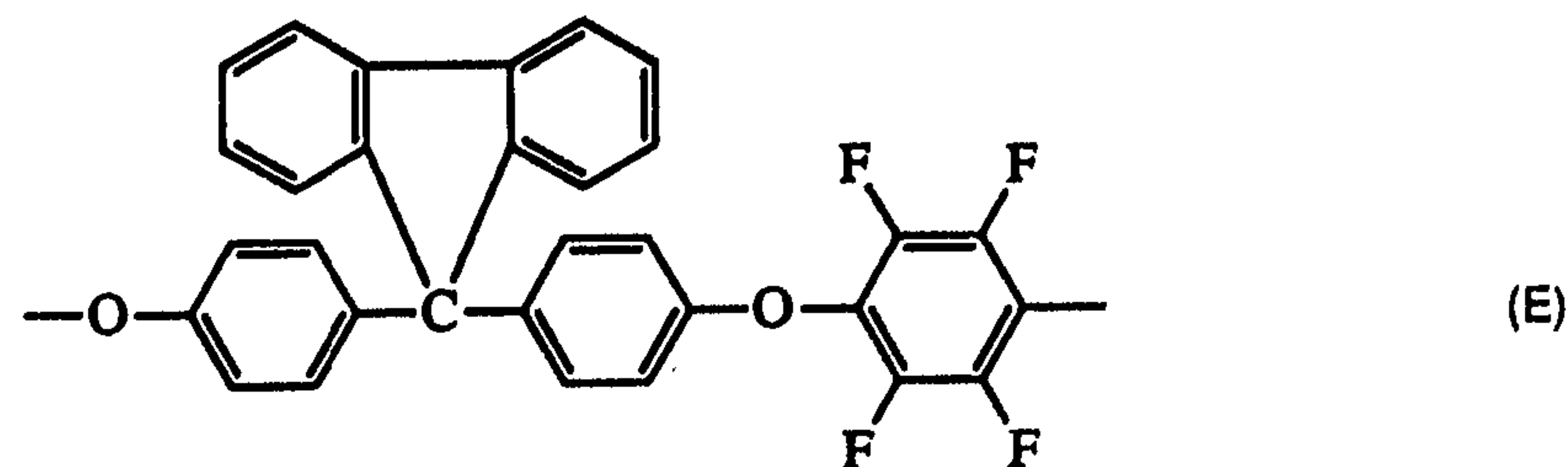
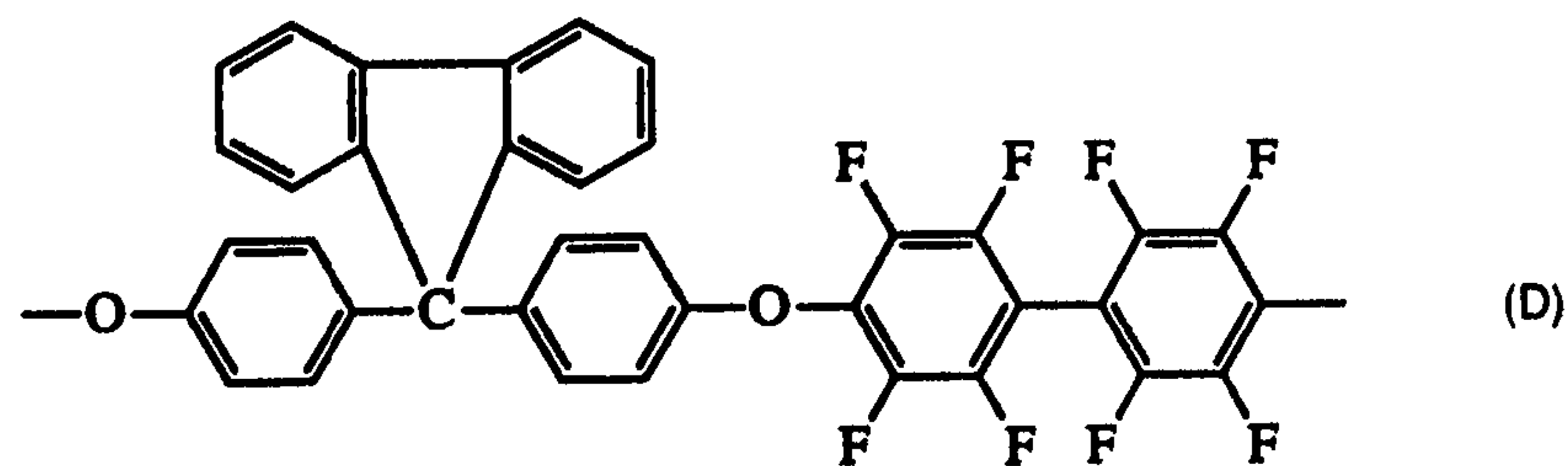
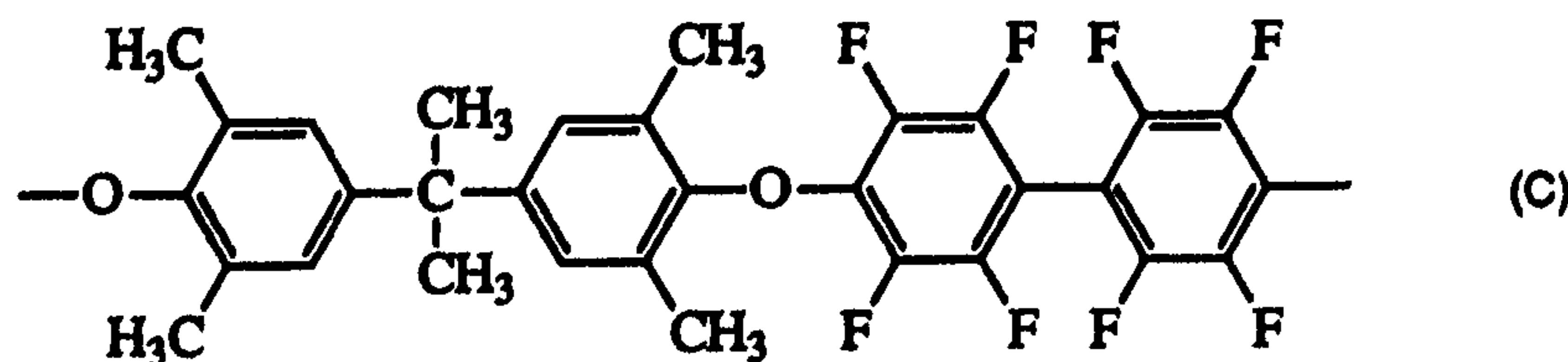
N,N-dimethylformamide, or 1-methyl-2-pyrrolidinone is used. The use of such solvents is advantageous compared to other solvents such as nitrobenzene, which are more toxic and which are not soluble in water, thereby requiring work-up of the polymerization mixture in an organic solvent as opposed to water. The reaction is carried out at an elevated temperature, although such temperature should not be excessively high. A temperature between about 50 °C and about 125 °C is generally suitable, with a temperature between about 60 and about 90 °C being especially preferred. Reaction times are typically between about 10 and about 72 hours.

The following repeat units are preferred:

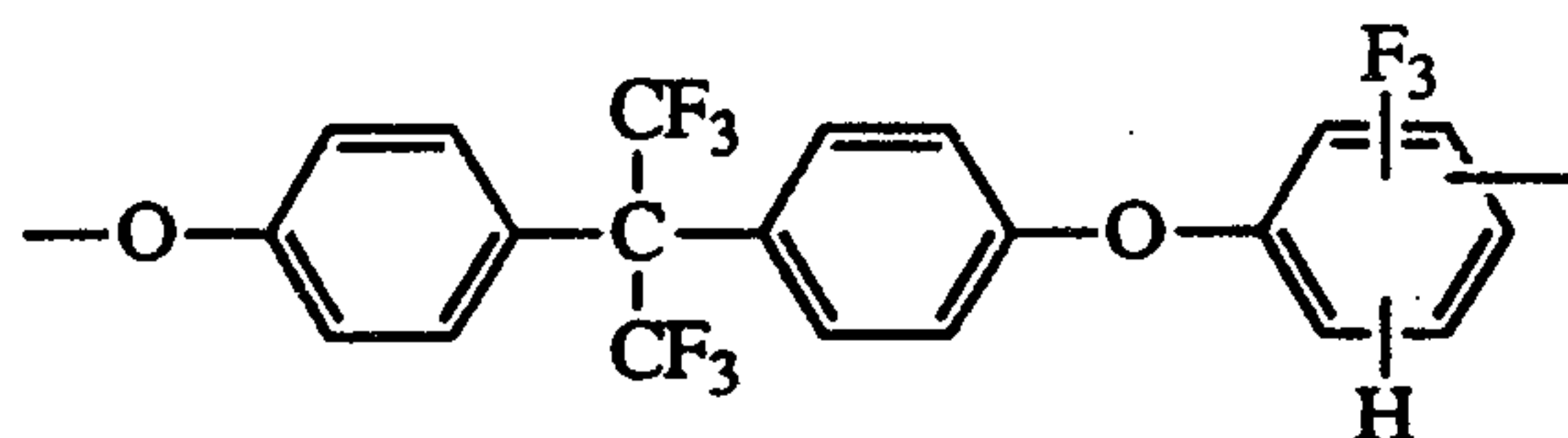
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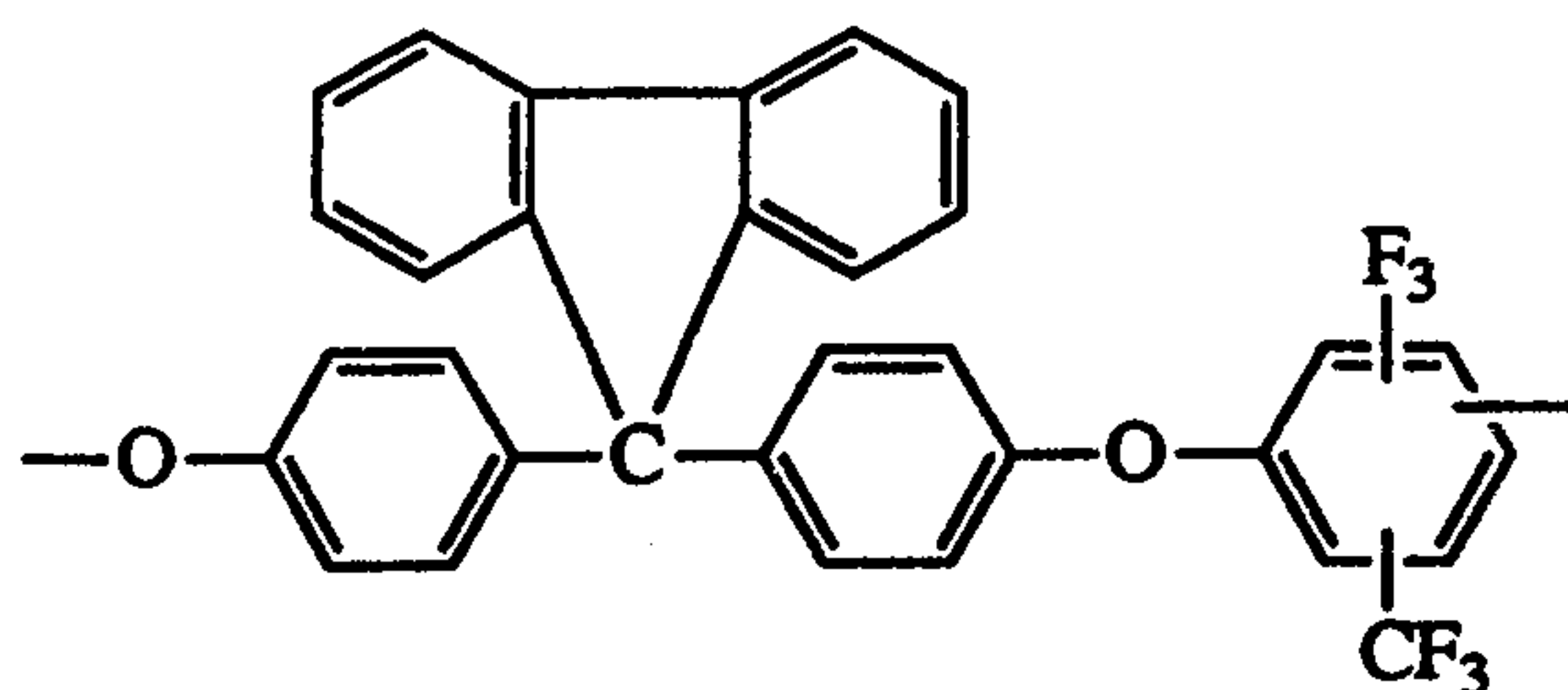
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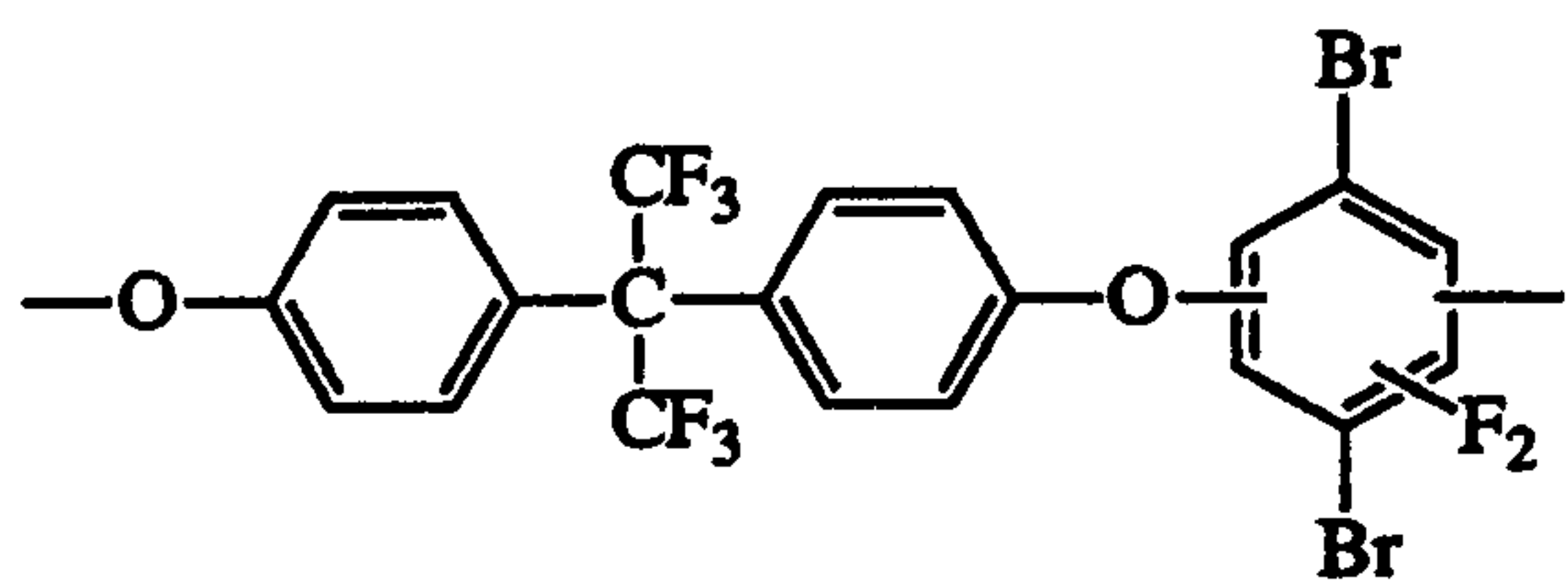
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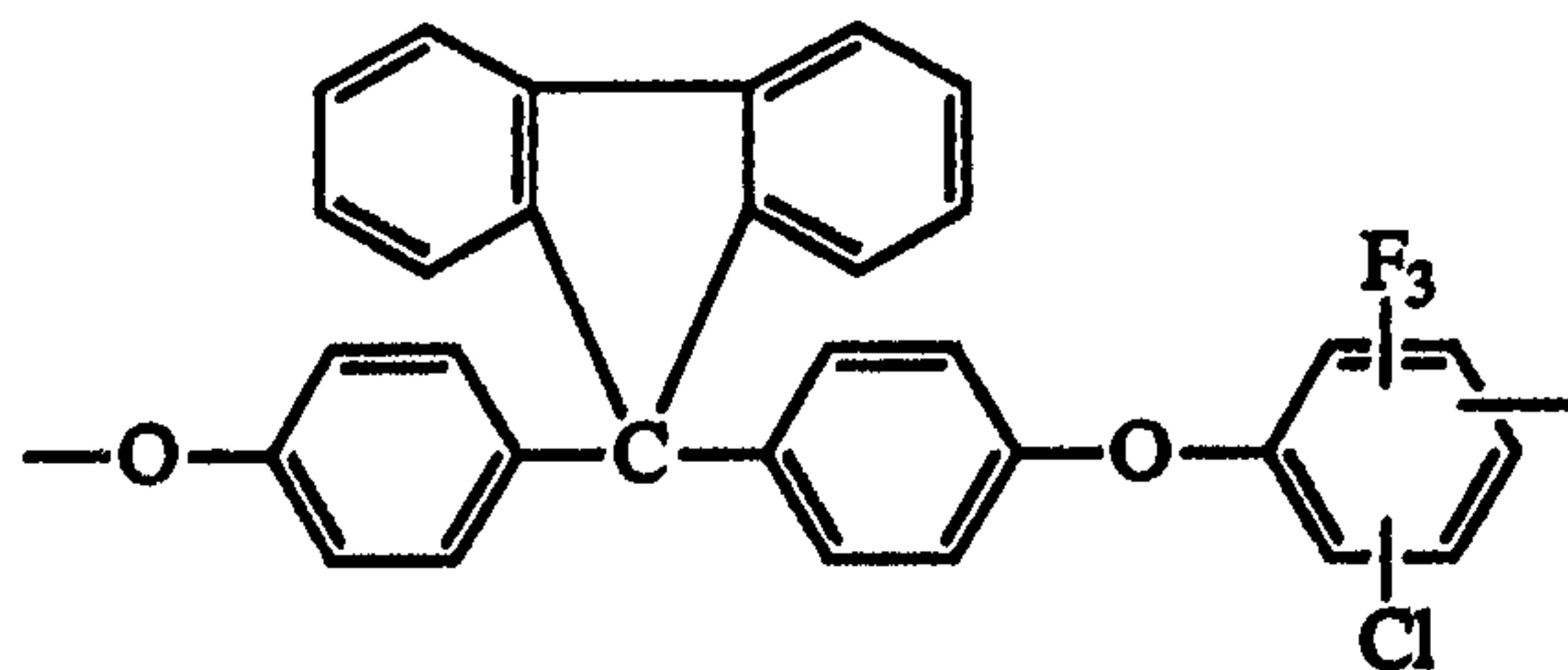


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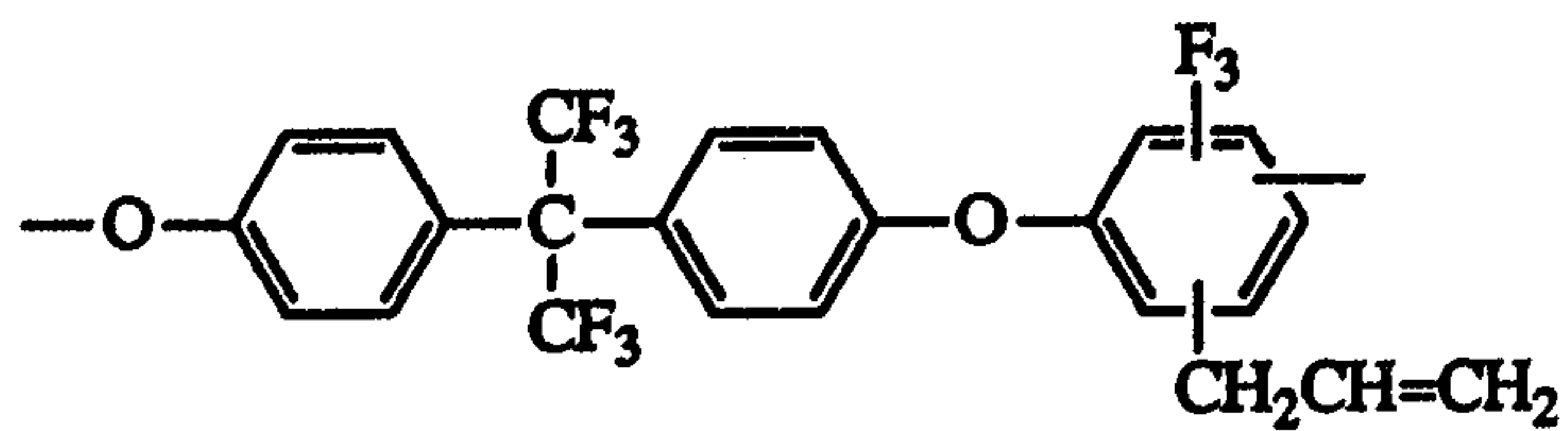


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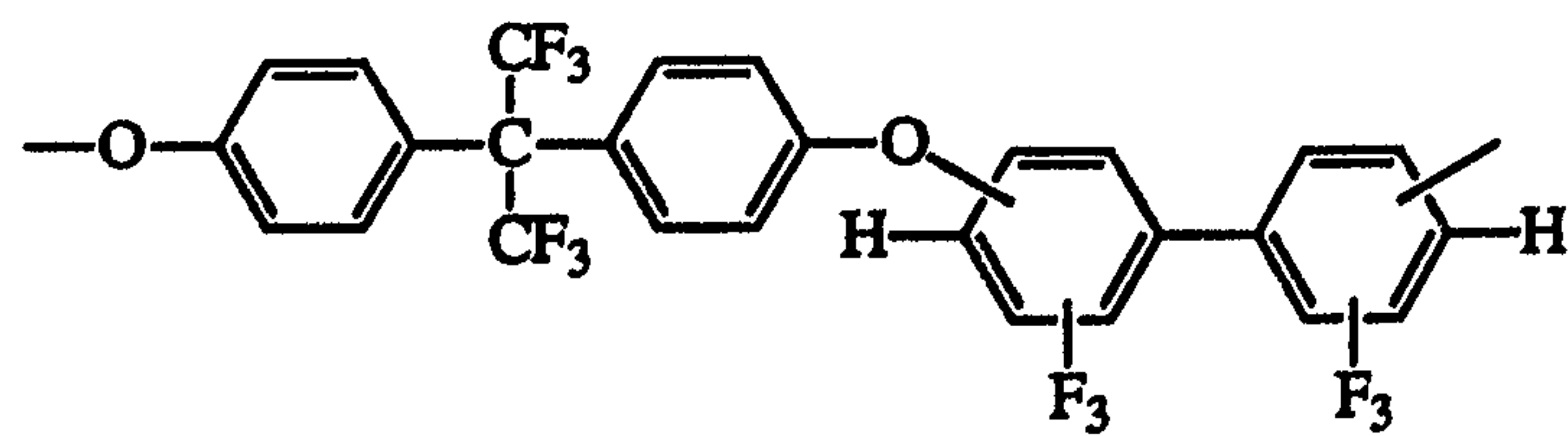


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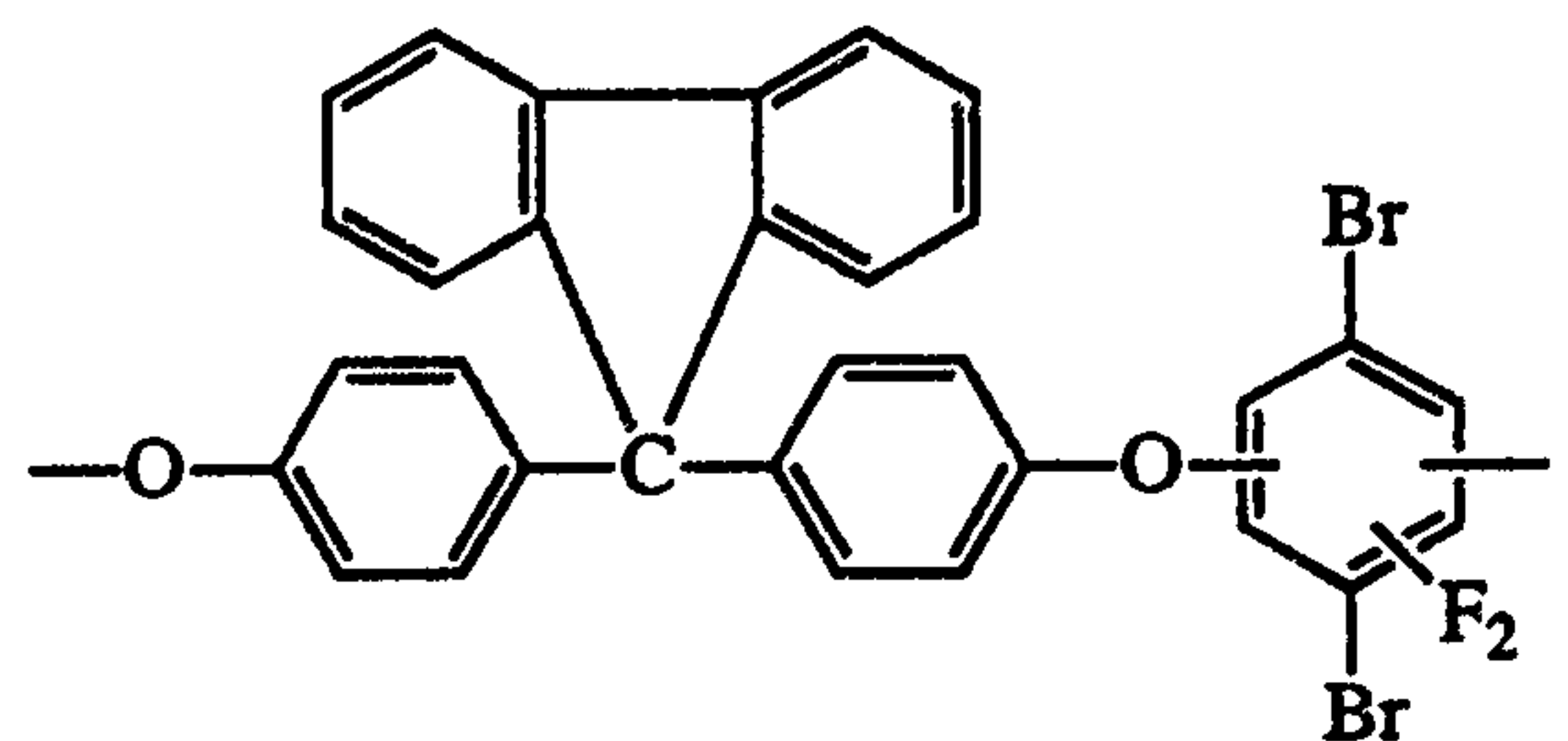


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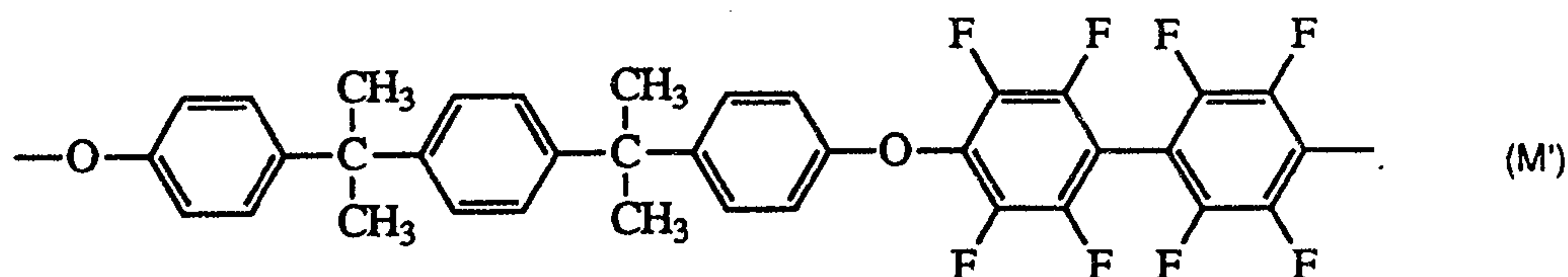
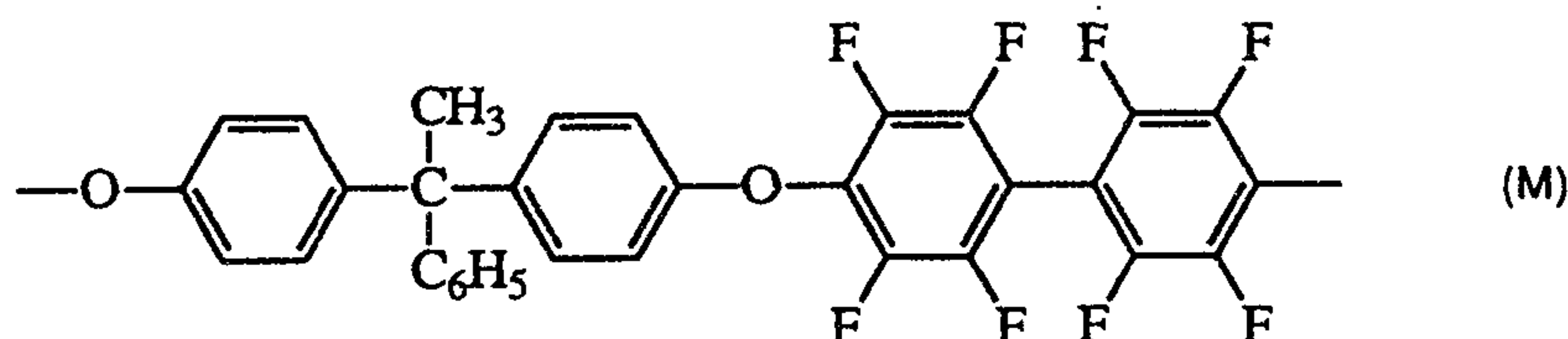
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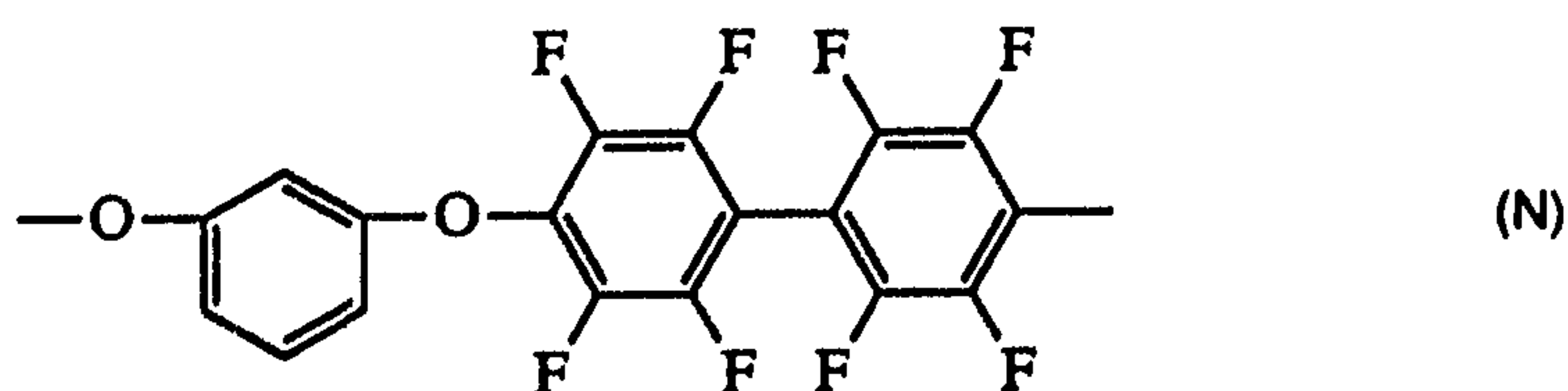
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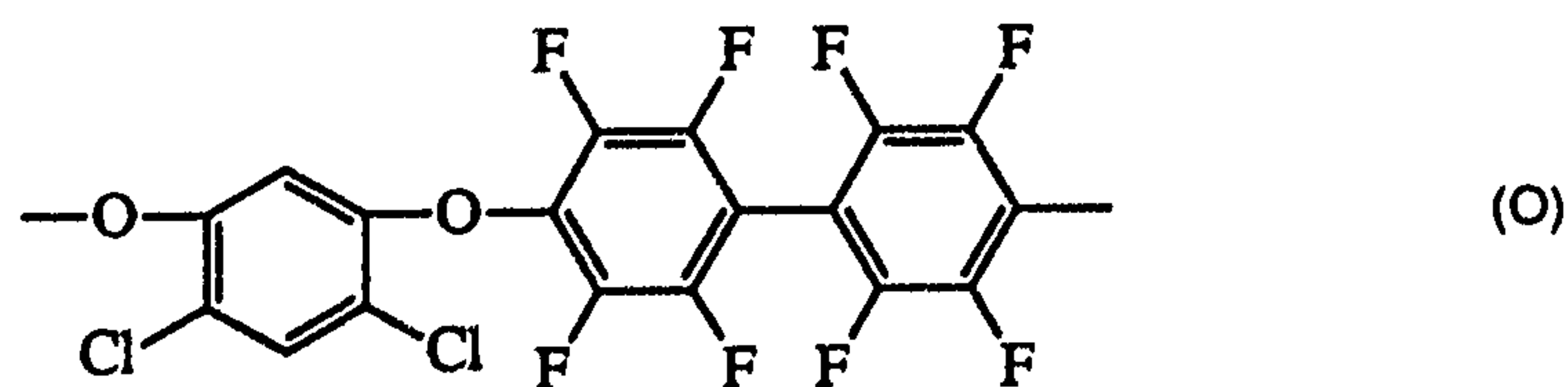
The polymers can be homopolymers, consisting essentially of a single repeat unit such as one of the aforementioned ones. Or, they can be copolymers comprising a repeat unit of this invention in combination with another repeat unit of this invention or with a different type of repeat unit. Fluorinated poly(arylene ether) copolymers can be made for example by using two different

10 diphenols (I) as comonomers, or two different fluorinated monomers (II) as comonomers. A preferred copolymer comprises repeat units (A) and (N):



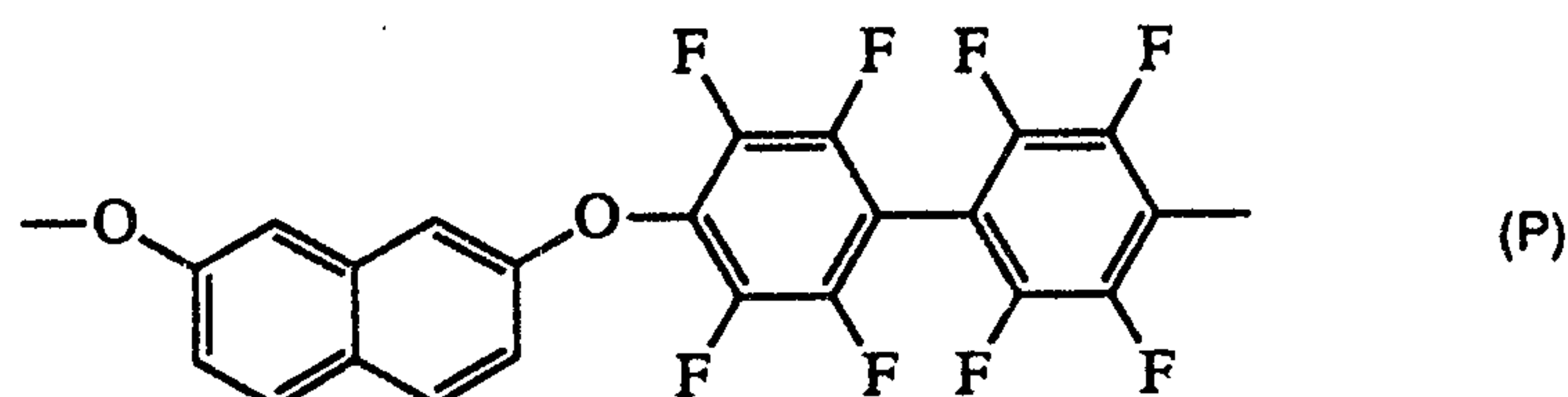
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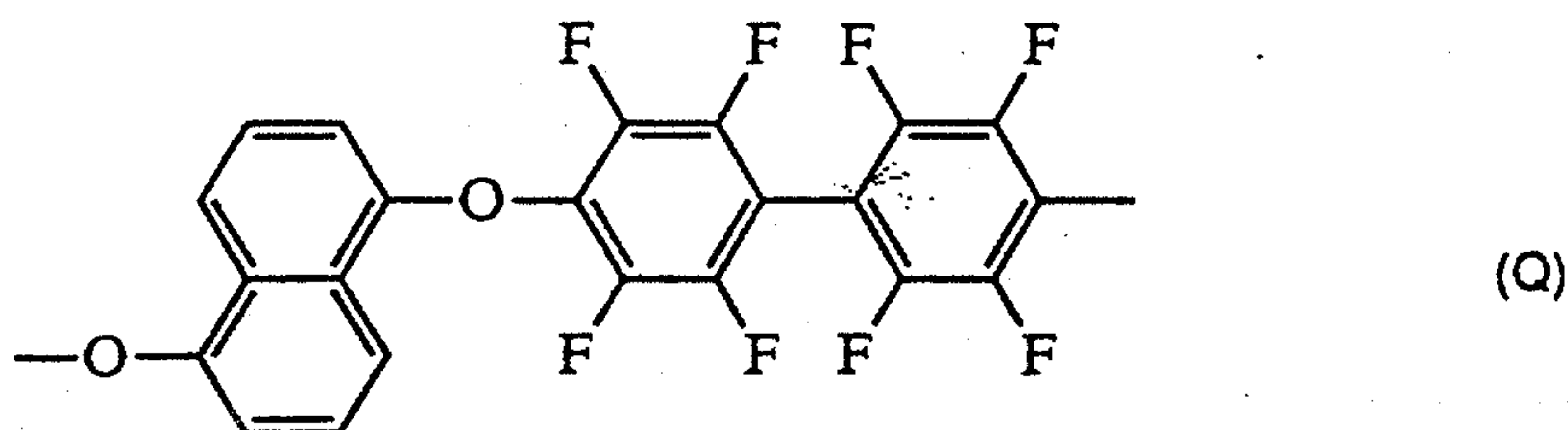
Another preferred copolymer comprises the repeat units (A) and (D). Yet another preferred copolymer comprises repeat units (A) and (O)



20

Still other preferred copolymers comprise repeat unit (A) and either repeat unit (P) or (Q) or repeat unit (D) with repeat unit (Q):





In a copolymer where a repeat unit of this invention is combined with a repeat unit of another type of polymer (that is, a polymer which is not a fluorinated poly(arylene ether), it is preferred that at least 60 mole %, more preferably at least 80 mole %, of the repeat units are a fluorinated aromatic ether repeat unit according to this invention. A copolymer can be alternating, random, or block.

Fig. 1a shows a multichip module 1 employing fluorinated poly(arylene ethers) of this invention. Substrate 2, typically made of silicon, glass, or ceramic, supports high density multilayer interconnect 3 in which the dielectric material providing insulation between the various layers is a fluorinated poly(arylene ether). On interconnect 3 are mounted semiconductor chips 4a-d, which are connected to each other by electrical conductors in interconnect 3. Substrate 1 may also contain electrical conductors, for example for power and ground. Lead frames 5 (only one labeled for simplicity) provide connections to external circuitry.

Fig. 1b shows a partial cross-section of multilayer interconnect 3 supported on substrate 2. Layers of electrical connections 10a-c are separated from each other by a fluorinated poly(arylene ether) dielectric 12. Via 11 provides connections between the various layers as necessary. Interconnect 3 is connected to an integrated circuit chip (not shown) by bond pad 13. Via 11 is shown here in the stacked pillar design, although other designs conventional in the art, such as the stair-stepped or nested via designs, can be used. Other multichip module designs in which the fluorinated poly(arylene ethers) of this invention can be used as interlayer dielectrics is disclosed in Balde, "Overview of Multichip Technology", Electronic Materials Handbook, vol. 1, Packaging ASM International, p. 297-312 (1989).

The fluorinated poly(arylene ethers) can also be used as interlayer dielectrics in an interconnect associated with a single integrated circuit chip. Fig. 2 shows this embodiment in cross-section. Integrated circuit chip 15 has on a surface thereof plural layers 16 of poly(arylene ether) dielectric and multiple layers of metal conductors 17.

The fluorinated poly(arylene ethers) of this invention can further be used as protective coatings on integrated circuit chips, for protection against alpha particles. Semiconductor devices are susceptible to soft errors when alpha particles emitted from radioactive trace contaminants in the packaging or other nearby materials strike the active surface. Fig. 3 shows schematically an integrated circuit having a protective coating of fluorinated poly(arylene ether). Integrated circuit chip 25 is mounted on substrate 26 and held in place with the assistance of adhesive 27. A coating of fluorinated poly(arylene ether) 28 provides an alpha particle protection layer for the active surface of chip 25. Optionally, additional protection is provided by encapsulant 29, made of

for example epoxy or silicone. Conductor 30 provides connections between chip 25 and conductors (not shown) on substrate 26 and thence to external circuitry.

5 The fluorinated poly(arylene ethers) can also be used as a substrate (dielectric material) in circuit boards (also referred to as printed wiring boards or PWB's). Figure 3a shows in cross-section a circuit board 35 made of a substrate 36 having on a surface thereof a pattern of conductors 37. Substrate 36 is made of a fluorinated poly(arylene ether) of this invention. Substrate 36 may be reinforced with woven nonconducting fibers, such as glass cloth. Although in Figure 3a the circuit board is shown as single sided, those skilled in the art will appreciate that 10 other constructions, such as double sided or multilayer, can also be made with a fluorinated poly(arylene ether) substrate.

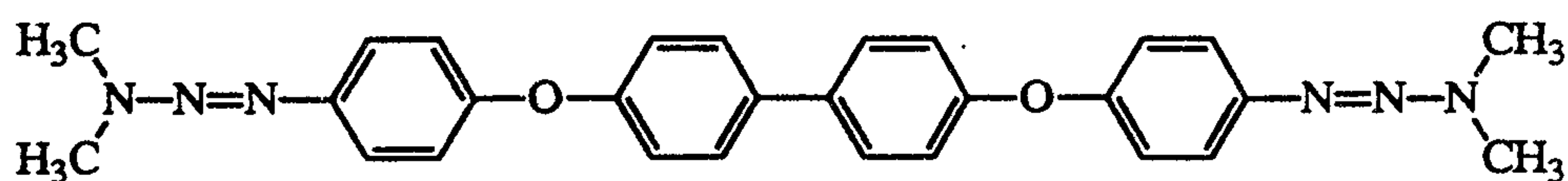
Films or coatings of fluorinated poly(arylene ethers) can be formed by solution techniques such as spraying, spin coating, or casting, with spin coating being preferred. Preferred solvents 15 are 2-ethoxyethyl ether, cyclohexanone, N,N-dimethylformamide, N,N-dimethylacetamide, methyl isobutyl ketone, 2-methoxyethyl ether, 5-methyl-2-hexanone, γ -butyrolactone, and mixtures thereof. Typically the coating thickness is between about 3 to about 15 μ .

Additives can be used to enhance or impart particular target properties, as is 20 conventionally known in the polymer art, including stabilizers, flame retardants, pigments, plasticizers, surfactants, and the like. Compatible or non-compatible polymers can be blended in to give a desired property.

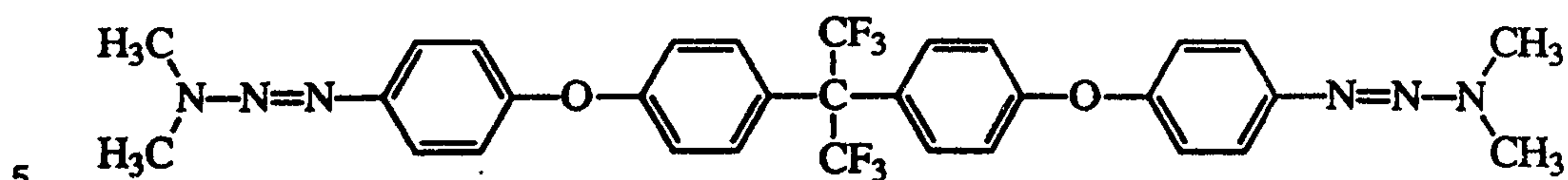
25 Polymers for microelectronic applications desirably contain low levels (generally less than 20 ppm) of ionic impurities. If a polymer is made by a synthetic route which requires the use of a transition metal reagent or catalyst, the effective removal of transition metal residues may be a difficult task. An advantage of the instant polymers is that they can be made by a route which does not involve transition metal species, and the potassium (or sodium) carbonate reagent and potassium (or sodium) fluoride by-product can be easily removed.

30 The fluorinated poly(arylene ethers) show good high temperature stability. For example, polymer (A) shows by TGA an initial weight loss in air at 500 °C. However, they also unexpectedly crosslink when heated in air at temperatures above 300 °C, as shown by the formation of large amounts of gelled material. Preferably, the crosslinking temperature is between about 300 and 35 about 425 °C. It appears that the presence of oxygen is required for the crosslinking reaction to take place, as similar heating cycles in nitrogen do not lead to the formation of gel. This characteristic makes the fluorinated poly(arylene ethers) particularly useful in the hereindescribed microelectronic applications, because they can be readily applied from solution, and then be converted into a solvent resistant coating by heating in air.

40 Fluorinated poly(arylene ethers) can also be crosslinked by bistriazene compounds such as



and



The bistriazene crosslinking agent is used in an amount effective to crosslink the fluorinated poly(arylene ether) (I), preferably between about 10 and about 40, more preferably between about 15 and about 30 weight %, based on the combined weights of the polymer and bistriazene compound. Crosslinking is effected by heating to a temperature between 300 and 400 °C, optionally with a stepped or stagewise heating profile, for between about 15 and 90 minute total time.

Another method of crosslinking fluorinated poly(arylene ethers) is with a peroxydic compound, such as dicumyl peroxide, cumene hydroperoxide, or benzoyl peroxide. An intimate mixture of the polymer and the peroxydic compound is heated to a temperature of between about 350 °C and about 425 °C, preferably about 400 °C, under nitrogen. Typically, the peroxydic compound is used in an amount of between about 5 and about 20 % by weight, based on the combined amounts of polymer and peroxydic compound, with about 10 wt. % being preferred. In some fluorinated poly(arylene ethers), peroxide crosslinking may be facilitated by their possessing reactive side chains, such as the allyl groups in polymer (J), although the presence of such functionalities is not required for effective peroxide crosslinking.

Fluorinated poly(arylene ethers) are also useful as adhesives and matrix resins for composite applications. Further, they are also useful as solvent resistant, crosslinked films for a variety of applications, such as wires having a wrapped insulation, especially after crosslinking.

The practice of our invention can be further understood by reference to the following examples, which are provided by means of illustration, not limitation.

Example 1

This example describes the preparation of a polymer having repeat unit (A): To a 500 mL round bottom flask was added 15.01 g (0.0447 mole) of 4,4'-(hexafluoroisopropylidene)diphenol ("6F-diphenol"), 15.29 g (0.0458 mole) of decafluorobiphenyl, 240 g of dimethylacetamide ("DMAc"), and 16.85 g (0.125 mole) of potassium carbonate. The mixture was heated with stirring under nitrogen at about 80 °C for 23 hours. The mixture was filtered hot to remove the unreacted potassium carbonate and potassium fluoride by-product. About 75 mL of DMAc was removed by rotary evaporation. The solution was cooled to room temperature and poured into water to precipitate the polymer. The polymer was filtered, washed three times with water, suspended in 200 mL of ethanol for 2 hours, filtered, and dried at 100 °C for 2 hours to yield a white powder. A

solution of 2 grams of polymer in 8 grams of a 50/50 mixture of 2-ethoxy ethyl ether and cyclohexanone was spin coated onto a ceramic substrate and dried 15 minutes at 100 °C, 20 minutes at 180 °C, and 45 minutes at 400 °C. The resulting polymer film was tough and flexible, insoluble in 2-ethoxy ethyl ether, and had a T_g of 189 °C by DSC (192 °C by TMA).

5

Example 2

This example describes the preparation of a polymer having repeat unit (B): To a 100 mL round bottom flask was added 2.20 g (0.0118 mole) of hexafluorobenzene, 3.90 g (0.0116 mole) of 6F-diphenol, 4.0 g (0.030 mole) of potassium carbonate, and 50 g of DMAc. The mixture was heated with stirring under nitrogen at about 70 °C for 48 hours. The mixture was then worked up as described in Example 1 to yield a white powder. A film of the polymer obtained was tough and flexible, insoluble in 2-ethoxy ethyl ether, and had a T_g of about 185 °C by DSC.

15

Example 3

This example describes the preparation of a polymer having repeat unit (C): The reaction of Example 1 was repeated except that 12.7 g of 4,4-isopropylidene bis(2,6-dimethylphenol) ("tetramethyl Bisphenol A") was used in place of the 6F-diphenol and the reaction was heated to 80 °C for 72 hours. 22.3 g of polymer was obtained. A film of the polymer had a moisture absorption of 0.15% after immersion in 50 °C water for 16 hours.

Example 4

25 This example describes the preparation of the copolymer having repeat units (A) and (N): The reaction of Example 1 was repeated except that a mixture of 7.51 g of 6F-diphenol and 2.458 g of resorcinol was used in place of the 6F-diphenol. 19.8 g of polymer was obtained. A film of the polymer had a moisture absorption of 0.10% after immersion in 50 °C water for 16 hours.

30

Example 5

The polymer having the repeat unit (D) was prepared as follows: To a 250 mL round bottom flask was added 10.15 g (0.029 mole) of 9,9-bis(4-hydroxyphenyl)fluorene, 9.97 g (0.0298 mole) of decafluorobiphenyl, 115 g of DMAc, and 10.0 g (0.074 mole) of potassium carbonate. 35 The mixture was heated with stirring under nitrogen at 75 °C for 16 hours. The mixture was cooled to room temperature, poured into rapidly stirring water to precipitate the polymer, filtered, washed twice with water, filtered and dried. A white fluffy powder was obtained. Two grams of the white polymer powder were dissolved in 8 grams of a 50/50 mixture of cyclohexanone and 2-ethoxy ethyl ether. About 1.5 mL of the polymer solution was spin coated onto a glass substrate and dried 10 min at 100 °C, 15 min at 200 °C, and 30 min at 400 °C. The resulting polymer film 40 was released from the glass substrate by immersion in water to yield a tough, flexible, transparent film. The film had a dielectric constant of 2.62 at 0 % RH and a dielectric constant of 2.68 at 58 % RH. The polymer had a T_g of about 258 °C by DSC.

Example 6

This example describes the preparation of the polymer having the repeat unit (E): The procedure of Example 5 was repeated, except that 5.54 g (0.0298 mole) of hexafluorobenzene was used in place of the decafluorobiphenyl and the reaction was allowed to run for 42 hours. The resulting polymer film had a dielectric constant of 2.65 at 0% RH and of 2.73 at 58 % RH.

Example 7

This example describes the preparation of the copolymer having repeat units (A) and (D): To a 250 mL round bottom flask was added 5.07 g (0.0145 mole) of 9,9-bis(4-hydroxyphenyl)fluorene, 4.87 g (0.0145 mole) of 6F-diphenol, 9.97 g (0.0298 mole) of decafluorobiphenyl, 115 g of DMAc, and 10.0 g (0.074 mole) of potassium carbonate. The mixture was heated with stirring under nitrogen at 75 °C for 16 hours. The mixture was cooled to room temperature, poured into rapidly stirring water to precipitate the polymer, filtered, washed twice in 300 mL of water, filtered and dried. A white fluffy powder was obtained. Two grams of the white polymer powder were dissolved in 8 grams of a 50/50 mixture of cyclohexanone and 2-ethoxy ethyl ether. About 1.5 mL of the polymer solution was spin coated onto a glass substrate and dried 10 min. at 100 °C, 15 min. at 200 °C, and 30 min. at 400 °C. The resulting polymer film was released from the glass substrate by immersion in water to yield a tough, flexible, transparent film. The film had a dielectric constant of 2.60 at 0 % RH and 2.66 at 58 % RH.

Example 8

This Example describes the preparation of a polymer having repeat unit (F). To a 100 mL round bottom flask was added 3.50 g (0.0208 mol) of pentafluorobenzene, 7.00 g (0.0208 mol) of 6F-diphenol, 4.2 g of potassium carbonate, and 50 g of DMAc. The mixture was heated to 80 °C for 24 hours under nitrogen with stirring, then heated to 120 °C for an additional 36 hours. The mixture was allowed to cool to room temperature and poured into water to precipitate the polymer as a lightly colored powder. The polymer was washed three times with water and dried at room temperature for 18 hours and at 100 °C for 4 hours. One gram of polymer was dissolved in 4 grams of a 1:1:1 mixture of DMAc, 2-ethoxy ethyl ether, and cyclohexanone. The mixture was spin coated on to a glass substrate and cured 15 min at 100 °C, 15 min at 200 °C, and 15 min at 400 °C to yield an amber film. The polymer had a moisture absorption of 0.15%. Based on model studies with similar fluorinated benzenes, discussed in more detail below, and the expected mechanism for the polymerization reaction, it is believed that in the pentafluorobenzene two fluorines are displaced, with the hydrogen being retained. Polymer (F) had a Tg of 120 °C by DSC.

Example 9

This example describes the preparation of a polymer having repeat unit (G). The procedure in Example 8 was repeated except that 4.99 g (0.0211 mol) of octafluorotoluene was used in place of pentafluorobenzene and 7.38 g (0.0211 mol) of 9,9-bis(4-hydroxyphenyl)fluorene was used instead of the 6F-diphenol. The reaction was run at 80 °C for 24 hours and then at 120

°C for an additional 24 hours. A white powder was obtained. Again, it is believed that two ring fluorines are displaced, with the trifluoromethyl group remaining intact. The polymer had a T_g of 260 °C by DSC.

5 **Example 10**

 This Example describes the preparation of a polymer having repeat unit (H). The procedure in Example 9 was repeated except that 6.40 g (0.0208 mol) of 1,4-dibromotetrafluorobenzene was used in place of octafluorotoluene. A white powder was obtained.
10 One gram of the powder was dissolved in 4 grams of DMAc and spin coated on to glass substrate and cured as described in Example 8 to yield an amber film. The polymer had a dielectric constant of 2.6 and a moisture absorption of 0.15%. Its T_g was 199 °C as measured by DSC.

 GC-MS analysis of the products from the model reaction between phenol (2 equivalents)
15 and 1,4-dibromotetrafluorobenzene showed that two fluorines were displaced, with the two bromines being retained and a mixture of isomeric products being obtained. Thus, it is believed that in polymer (H), the two bromines were also retained.

20 **Example 11**

 This Example describes the preparation of a polymer with repeat unit (I). To a 100 mL round bottom flask was added 5.05 g (0.0249 mol) of chloropentafluorobenzene, 9.10 g (0.0260 mol) of 9,9-bis(4-hydroxyphenyl)fluorene, 65 g of DMAc, and 11.5 g of potassium carbonate. The mixture was heated to 100 °C for 27 hours under nitrogen with stirring. The mixture was allowed
25 to cool to room temperature and poured into water with stirring to precipitate the polymer. The polymer was washed with three times with water and dried at room temperature for 18 hours and at 100 °C for 5 hours to yield a white powder. Two grams of the polymer were dissolved in 8 mL of a 1:1 mixture of 2-ethoxy ethyl ether and cyclohexanone, spin coated onto a glass substrate, and dried as described in Example 8. An amber film was obtained. The polymer had a moisture
30 absorption of 0.1%.

 GC-MS analysis of the product from the model reaction between phenol (2 equivalents) and chloropentafluorobenzene showed that two fluorines were displaced, with the chlorine being retained and a mixture of isomeric products being obtained. Thus, it is believed that, in polymer
35 (I), the chlorine was also retained.

Example 12

 This Example describes the preparation of a polymer with repeat unit (J). To a 100 mL round bottom flask was added 4.20 g (0.0202 mol) of allylpentafluorobenzene, 6.85 g (0.0204 mol) of 6F-diphenol, 45 mL of DMAc, and 8.0 g of potassium carbonate. The mixture was heated
40 to 110 °C under nitrogen with stirring for 72 hours. The mixture was allowed to cool to room temperature and was poured into water to precipitate the polymer. The polymer was washed with 100 mL of deionized water and 100 mL of denatured ethanol and dried in air for 3 days to yield a
45 light yellow powder. Three grams of the powder and 0.15 g of t-butyl peroxybenzoate were

dissolved in 8.5 mL of DMAc and spin coated onto a glass substrate and dried 10 min at 110 °C and 20 min at 200 °C to yield an amber film that was insoluble in DMAc.

GC-MS analysis of the product from the reaction between phenol (2 equivalents) and allylpentafluorobenzene showed that two fluorines were displaced, with the allyl group being retained and a mixture of isomeric products being obtained. Thus, it is believed that, in the polymer described above, the allyl group was also retained.

Example 13

10

This example describes the preparation of a polymer with repeat unit (K): To a 100 ml round bottom flask was added 1.25 g (0.0042 mol) 2,2',3,3',5,5',6,6'-octafluorobiphenyl ("OFB"), 1.41 g (0.0042 mol) of 6F-diphenol, 19 g of DMAc, and 2 g of potassium carbonate. The mixture was heated to 120 °C for 72 hours under nitrogen with stirring. The mixture was allowed to cool to room temperature and poured into water to precipitate the polymer. The polymer was collected by filtration, washed with 75 ml of a 50/50 mixture of ethanol and water, and dried over night at room temperature, followed by 1 hour at 100 °C to yield a white powder. The polymer had a T_g of 147 °C by DSC.

20

GC/MS analysis of the product from the reaction between 4-methoxyphenol (2 equivalents) and OFB showed that two fluorines were displaced, with retention of the two hydrogens, and a mixture of isomeric products being obtained. Thus, it is believed that, in the polymer described above, the two hydrogens were also retained.

Example 14

25

This example describes the preparation of a polymer with repeat unit (L). The procedure of Example 12 was repeated with the exception that 6.22 g (0.0202 mol) of 1,4-dibromotetrafluorobenzene, 7.07 g (0.0202 mol) of 9,9-bis(4-hydroxyphenyl)fluorene, 10 g potassium carbonate, and 55 mL of DMAc were used. The polymer was obtained as a white powder, T_g 291 °C by DSC.

30

Example 15

35

This example describes the preparation of a polymer with repeat unit (M). To a 250 ml round bottom flask was added 10.2 g (0.0354 mol) of 4,4'-(1-phenylethylidene) bisphenol, 11.6 g (0.0347 mol) of decafluorobiphenyl, 12 g of potassium carbonate, and 135 g of DMAc. The mixture was heated to 80 °C under nitrogen with stirring for 16 hours. The mixture was allowed to cool to room temperature and poured into water to precipitate the polymer. The polymer was filtered, washed with water, and dried. Two grams of the polymer were dissolved in 8 g of a mixture of 2-ethoxy ethyl ether and cyclohexanone (ratio 8 : 2, respectively) and spin coated onto a glass substrate, and dried 15 min at 100 °C, 15 min at 200 °C, and 15 min at 400 °C to yield a flexible, transparent film. The polymer had a T_g of 208 °C by DSC and a dielectric constant of 2.64 at 0 %RH.

45

Example 16

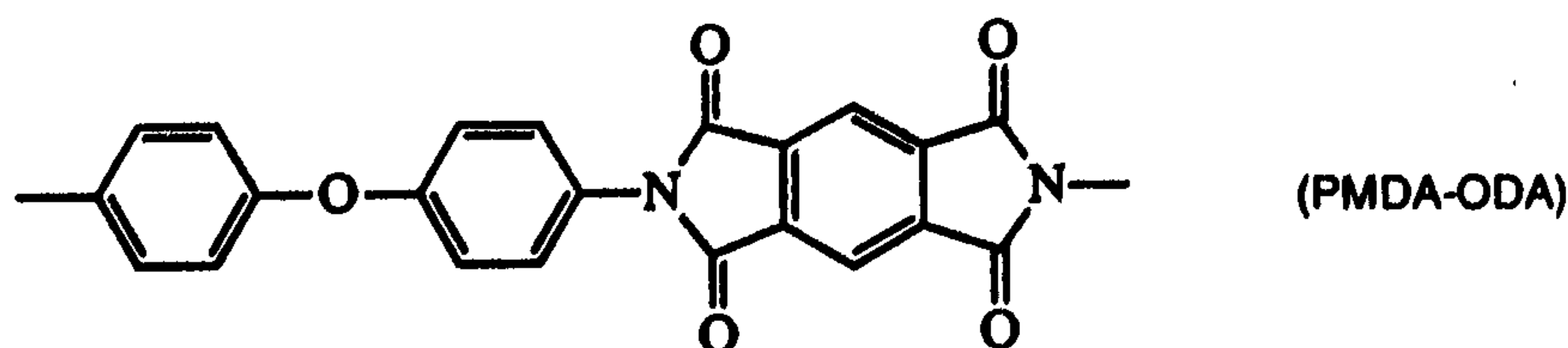
This example describes the preparation of a copolymer having repeat units (A) and (O), in a molar ratio of 1:4. To a 100 mL round bottom flask was added 3.75 g (0.021 mol) of 4,6-dichlororesorcinol, 1.76g (0.0053 mol) of 6F-diphenol, 8.80 g (0.026 mol) of decafluorobiphenyl, 62 g of DMAc, and 10 g of potassium carbonate. The mixture was heated under nitrogen for 8 hours at 110 °C. The mixture was poured without cooling into water to precipitate the polymer. The polymer was collected by filtration, washed with water, and dried to yield a light pink powder. The polymer had a T_g of 149 °C by DSC.

Example 17

This example describes the preparation of a polymer (referred to hereinafter as BPA-DFB) from 4,4'-isopropylidenediphenol and decafluorobiphenyl: The reaction of Example 1 was repeated except that 10.20 g of 4,4'-isopropylidenediphenol ("Bisphenol A") was used in place of the 6F-diphenol. 21.5 g of polymer was obtained from the reaction. A film of the polymer had a bulk moisture absorption of 0.2 % after immersion in 50 °C water for 16 hours.

Example 18

This is a comparative example in which a polymer not according to this invention, having the repeat unit



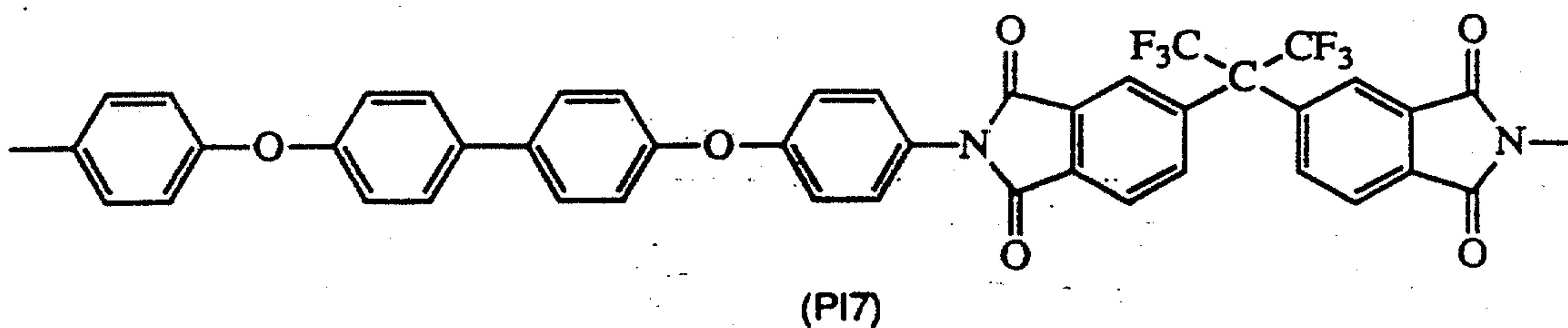
is prepared and compared against the polymers of this invention.

To a 100 mL round bottom flask was added 1.80 (0.009 moles) g of 4,4'-oxydianiline ("ODA") and 30 mL of dry 1-methyl-2-pyrrolidinone ("NMP"). The solution was cooled in an ice bath and 2.006 g (0.0092 moles) of pyromellitic dianhydride (PMDA) was added with stirring under nitrogen. A viscous, amber solution resulted. The polymer solution was spin coated onto a 4 by 4 inch (ca. 10 by 10 cm) glass substrate and dried for 10 min at 100 °C, 15 min at 200 °C, and 30 min at 350 °C to yield an amber film. The film showed a bulk moisture absorption of 2.55% after immersion in 50 °C water for 16 hours.

Example 19

This is another comparative example in which another prior art polyimide, referred to herein as PI7, is prepared and compared against the polymers of this invention.

17



To a 100 mL round bottom flask was added 3.35 g (0.009 mole) of 4,4'-bis(4-aminophenoxy)biphenyl and 17 g of NMP. After stirring at room temperature under nitrogen for 45 minutes, a solution of 4.00 g (0.009 mole) of 2,2-bis(3,4-dicarboxyphenyl)hexafluoropropane dianhydride ("6FDA") in 14 g of NMP was added dropwise with stirring over 10 minutes. After stirring an additional 24 hours at room temperature a viscous solution (2650 cps) resulted. The solution was spin coated on to a 4 by 4 inch (ca. 10 by 10 cm) glass substrate at 2000 rpm and dried 30 min at 100 °C, 20 min at 200 °C, and 30 min at 350 °C to yield an amber film. This polyimide film showed a bulk moisture absorption of 0.85% after immersion in 50 °C water for 16 hours. The properties of PI7 are compared against those of polymers of this invention in Table I, below.

Table I compares the dielectric properties of the polymers of this invention against the properties of the comparative polymers. The dielectric constants were measured at 25 °C and 10 KHz by the method described in U.S. Patent No. 5,108,840 of Mercer.

It can be seen from Table I that the polymers of this invention have significantly lower dielectric constants (ϵ), below 2.80 at 0 %RH and as low as 2.50, compared to ϵ 's above 2.80, up to 3.16, for the comparison polymers. Further, the ϵ 's of our polymers are less sensitive to variations in the ambient humidity. At about 60 %RH, their ϵ 's increase only slightly, as evidenced by a small slope of between about 10 and about 30, while the comparison polymers have a slope of between about 60 and about 100. In a microelectronic article, it is very important that the dielectric material have a low ϵ , preferably below 3 in both dry and wet environments. These differences between my polymers and the comparison polymers are shown graphically in Figure 4.

TABLE I Dielectric Constant of Polymers				
Ex.	Polymer	Dielectric Constant (ε) at 25 °C and 10 KHz		Slope *
		ε _{dry} (@ 0% RH)	ε _{wet} (%RH)	
1	A	2.504	2.62 (65.3)	17.8
2	B	2.50	2.63 (72.3)	18.0
3	C	2.78	2.89 (65.1)	16.9
4	A/N copolymer	2.62	2.68 (54.1)	11.1
5	D	2.62	2.68 (58)	10.3
6	E	2.65	2.73 (58)	13.8
7	A/D copolymer	2.60	2.66 (58)	10.3
8	BPA-DFB	2.617	2.787 (65.3)	26.1
9	PMDA-ODA	3.16	3.76 (58.2)	103.2
10	PI-7	2.85	3.223 (59.4)	63.0

* Slope = $\frac{\epsilon_{wet} - \epsilon_{dry}}{\%RH (wet)} \times 10,000$

Example 20

5 This example describes the preparation of a multilayer high density interconnect article suitable for use in a multichip module or in combination with a single integrated circuit chip.

10 A solution of 22.5 g of polymer (A) in 77.5 g of a 50/50 mixture of 2-ethoxy ethyl ether and cyclohexanone was prepared. A polymeric insulating layer was applied to a ceramic substrate in the following manner: (1) a 5 mL aliquot of the polymer solution was spin coated onto a clean 125 mm diameter ceramic substrate. (2) The coating was dried at 100 °C for 15 min and at 200 °C for another 15 min. (3) A second 5 mL aliquot was applied and cured as above with an additional cure for 60 min at 400 °C. A conductive material was formed by blanket sputtering 200 Å of chromium followed by 5 microns of copper, and finally another 500 Å of chromium. The metal was
15 photolithographically patterned.

20 A second polymeric insulating layer was applied over the patterned metal layer by the three-step process described above. An aluminum metal layer was blanket sputtered onto the dielectric, photolithographically patterned, and vias were generated in the second dielectric layer so that electrical contact could be made with the first metal layer. The aluminum layer was removed. A second metal layer of chromium-copper-chromium was applied as described above and electrical contact was made with the first layer by means of the vias. The second metal layer was then also photolithographically patterned.

25 All metal layers in the device showed excellent adhesion to the fluoropolymer and there was no observable delamination of metal to polymer or polymer to polymer.

Example 21

A sample of polymer (A) was crosslinked by curing in air, for the times and at the temperatures indicated in Table II, below, to produce the indicated gel contents (determined by
5 Soxhlet extraction with DMAc for 24 hrs):

Table II Crosslinking of Polymer (A)		
Cure Temperature (°C)	Cure Time (min)	Gel (%)
300	30	55
400	15	79
400	30	80
400	60	86
400	105	92

However, when polymer (A) was cured in nitrogen for 13 min at 300 °C and then 27 min
10 at 400 °C, no gel was detected.

Example 22

This comparative example demonstrates the preference for fluorination in the bisphenol
moiety for the preparation of fluorinated poly(arylene ethers) having enhanced thermal stability.
15 The thermal stability of polymer (A) (derived from 6F-diphenol and having two -CF₃ groups) was
compared to that of the polymer BPA-DFB (derived from Bisphenol-A and consequently having
two -CH₃'s in the corresponding position) by thermogravimetric analysis (TGA), under isothermal
conditions in air. The results are provided in Table III.

Table III Comparison of Thermal Stability		
After 3 hr at temperature (°C)	Weight loss (%) by TMA	
	Polymer (A)	Polymer BPA-DFB
@ 400 °C	2.5	3.0
@ 425 °C	5.0	20.0
@ 450 °C	19.8	55.0

20

In another comparative study, films of polymer (A) and BPA-DFB were cured at 100 °C
for 15 min, 200 °C for another 15 min, and finally at 425 °C for 60 min. At the end of this
treatment cycle, the film of BPA-DFB had carbonized to such an extent that it was jet black, had
delaminated from the substrate, and had fractured into small pieces. In contrast, the polymer (A)
25 film was only slightly colored, remained transparent, and was still tough and flexible.

Example 23

In this example, fluorinated poly(arylene ether) D is crosslinked with a peroxydic compound. Samples of polymer D containing 10% of dicumyl peroxide or cumene hydroperoxide were heated at 300 °C for 6.5 min and then at 400 °C for 13.5 min under nitrogen in an infra-red oven to produce crosslinked polymer having gel content of 94.0% and 81.4%, respectively. In comparison, a sample of polymer D similarly heated in the absence of any peroxide had a gel content of only 3.3%. The crosslinked polymers retained their low moisture absorption and dielectric constant characteristics. The sample crosslinked with dicumyl peroxide had a moisture absorption of 0.2% and a dielectric constant of 2.6 at 0% RH.

In additional peroxide crosslinking experiments, polymers (A) and (D) were each crosslinked with 10 wt. % benzoyl peroxide to produce crosslinked polymers having gel content of about 51 and 49 %, respectively. Polymer (A) was also crosslinked with 10 wt. % dicumyl peroxide to a gel content of 69%. In comparison, a control sample of polymer (A), similarly heated in the absence of any peroxide, had a gel content of about 0.8 %.

Example 24

This example describes the preparation of a polymer with the repeat unit (M'). To a 100 mL round bottom flask was added 3.21 g (0.0093 mol) Bisphenol P, 3.12 g (0.00934 mol) decafluorobiphenyl, 4.2 g of potassium carbonate, and 22 g DMAc. The reaction mixture was heated at 100 °C for 6 hours under nitrogen with stirring. The polymer was isolated as described in Example 5 to yield a white powder. The polymer had a T_g of 162 °C by DSC. A film of the polymer had a dielectric constant of 2.58 at 0% RH and 2.71 at 66.45% RH.

Example 25

This example describes the preparation of the copolymer having repeat units (A) and (O). To a 100 mL round bottom flask was added 3.75 g (0.026 mol) of 4,6-dichlororesorcinol, 1.76 g (0.0052 mol) of 6F-diphenol, 10.45 g (0.031 mol) of decafluorobiphenyl, 12 g potassium carbonate, and 39 g of DMAc. The reaction mixture was heated to 110 °C for 8 hours under nitrogen with stirring. The gelled reaction mixture was allowed to cool to room temperature and added to water and digested in a blender to isolate an off-white powder. The powder was washed with water and dried. The polymer had a T_g of 149 °C by DSC.

Example 26

This example describes the preparation of the copolymer having repeat units (A) and (P). To a 100 mL round bottom flask was added 5.70 g (0.017 mol) of decafluorobiphenyl, 1.34 g (0.0083 mol) of 2,7-dihydroxynaphthalene, 2.82 g (0.0083 mol) of 6F-diphenol. The reaction mixture was heated to 90 °C for 18 hours under nitrogen with stirring and allowed to cool to room temperature. The polymer was isolated by the procedure described in Example 5 to yield a white powder. The polymer had a T_g of 190 °C by DSC. A film of the polymer had a dielectric constant of 2.54 at 0% RH and 2.64 at 65.4% RH.

Example 27

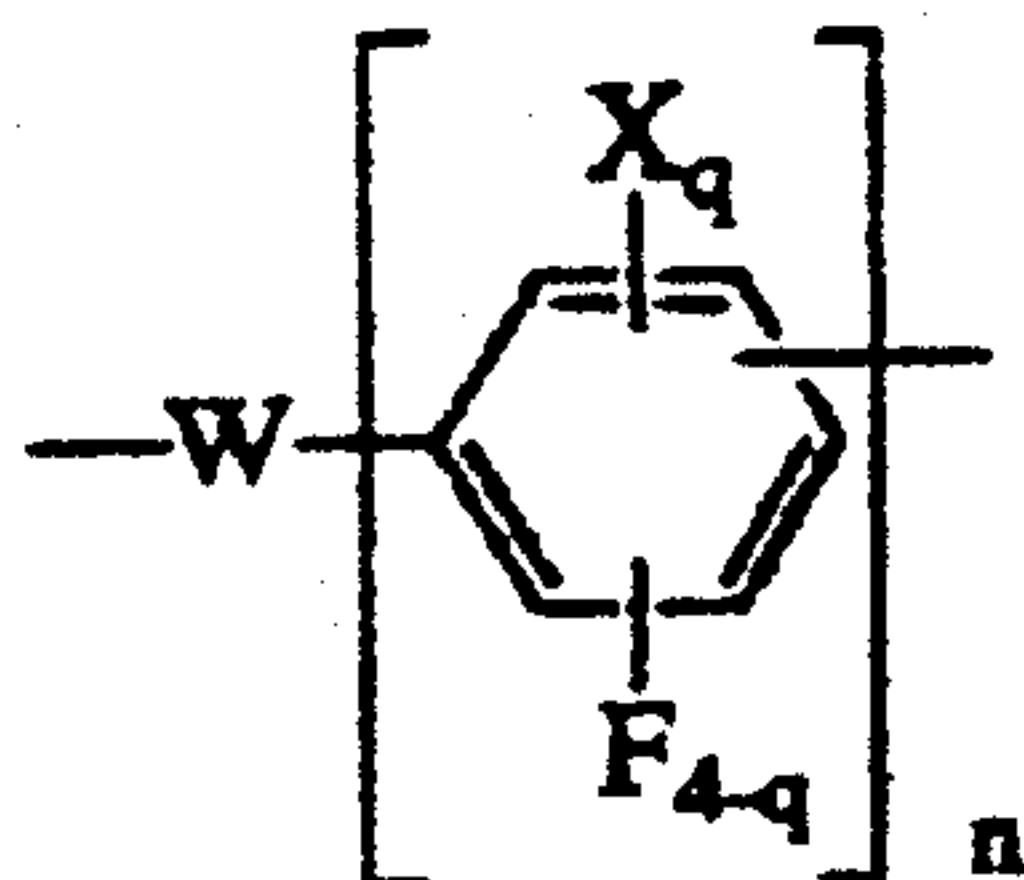
- This example describes the preparation of the copolymer having repeat units (A) and (Q).
- 5 The procedure described in the Example immediately above was repeated except that 1.34 g (0.0083 mol) of 1,5-dihydroxynaphthalene was used instead of 2,7-dihydroxynaphthalene. An off white powder was obtained. The polymer had a T_g of 203 °C by DSC.

Example 28

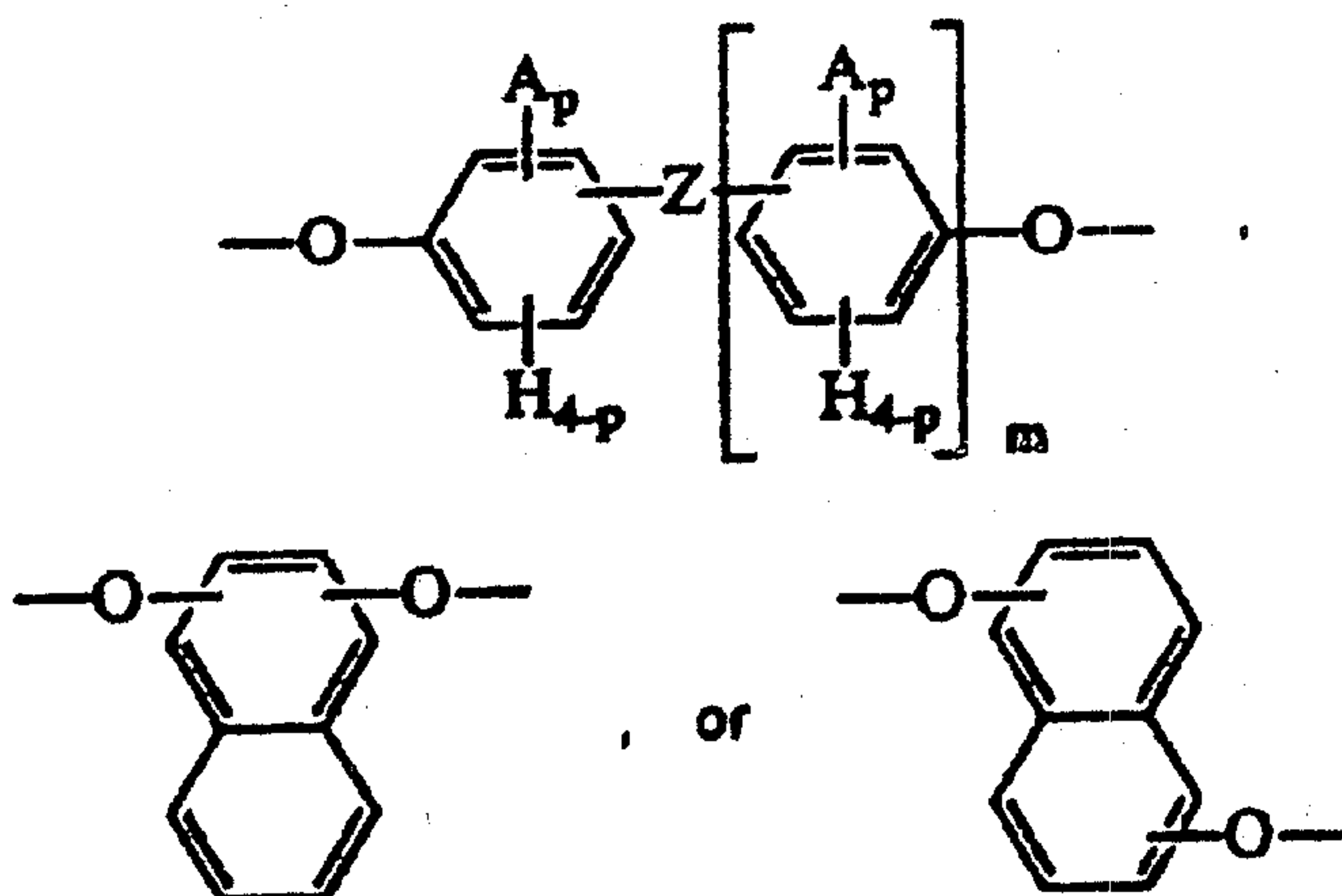
- 10 This example describes the preparation of a copolymer having repeat units (D) and (Q) and its subsequent crosslinking with a peroxide. To a 250 mL round bottom flask was added 3.32 g (0.0207 mol) of 1,5-dihydroxynaphthalene, 7.26 g (0.0207 mol) of 9,9-bis(4-hydroxyphenyl)fluorene, 14.22 g (0.0427 mol) of decafluorobiphenyl, 17 g of potassium
- 15 carbonate, and 127 g of DMAc. The mixture was heated to 85 °C for 16 hr under nitrogen with stirring and then poured while still hot into a blender containing 300 mL of water to precipitate the polymer. The polymer was collected by filtration and washed twice more with 300 mL of water and dried. Two grams of polymer and 0.22 g of dicumyl peroxide were dissolved in 8.5 g of a 1:1 mixture of γ -butyrolactone and cyclohexanone. The solution was spin coated onto a ceramic
- 20 substrate and cured as follows: 30 min at 130 °C, heat to 400 °C at a rate of 5 °C/min, hold at 400 °C for 15 min, and cool to room temperature at a rate of 3 °C/min. A amber film was obtained, which did not stress crack or dissolve when exposed to the aforementioned γ -butyrolactone-cyclohexanone mixture. A control film of the copolymer, similarly heated under nitrogen but without the added of dicumyl peroxide, showed solvent induced stress cracking when exposed to
- 25 the same solvent mixture.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

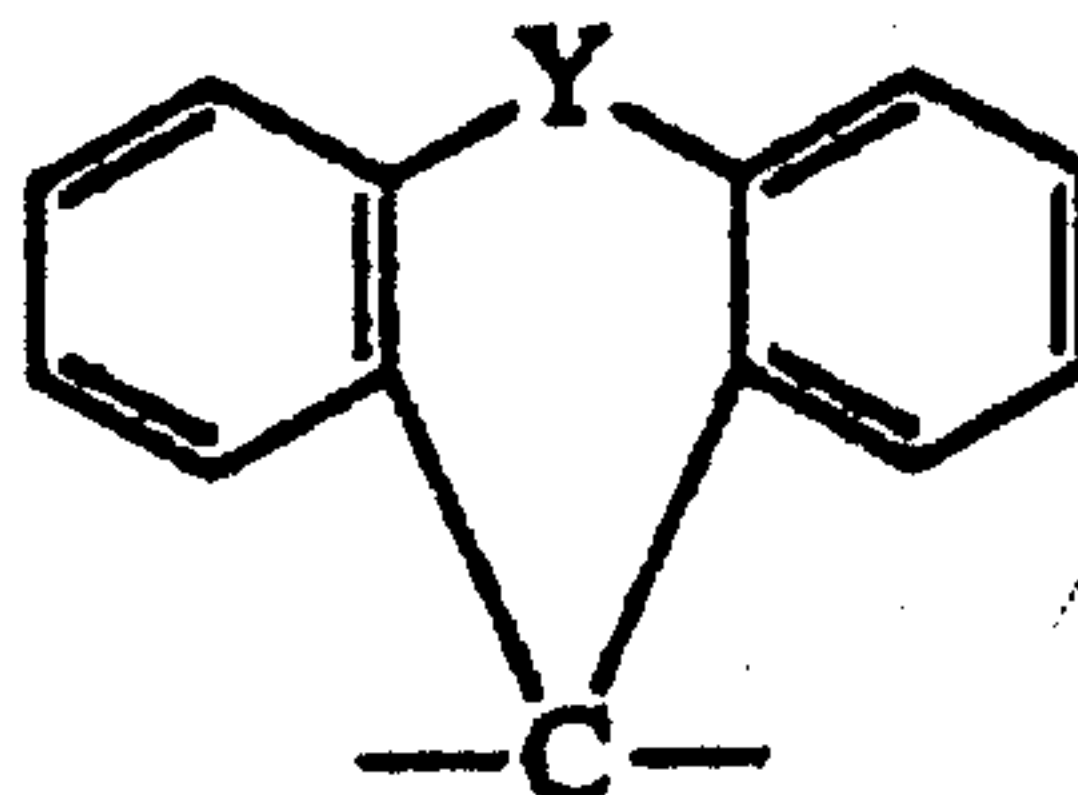
1. A fluorinated poly(arylene ether) comprising a repeat unit of the structure



wherein -W- is



wherein each -A is independently -F, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; p is 0, 1, or 2; -Z- is a direct bond, -C(CH₃)₂-, -C(CF₃)₂-, -O-, -S-, -SO₂-, -CO-, -P(C₆H₅)-, -C(CH₃)(C₆H₅)-, -C(C₆H₅)₂-, -(CF₂)₁₋₆-, or



wherein -Y- is -O- or a direct bond;

and m is 0, 1, or 2;

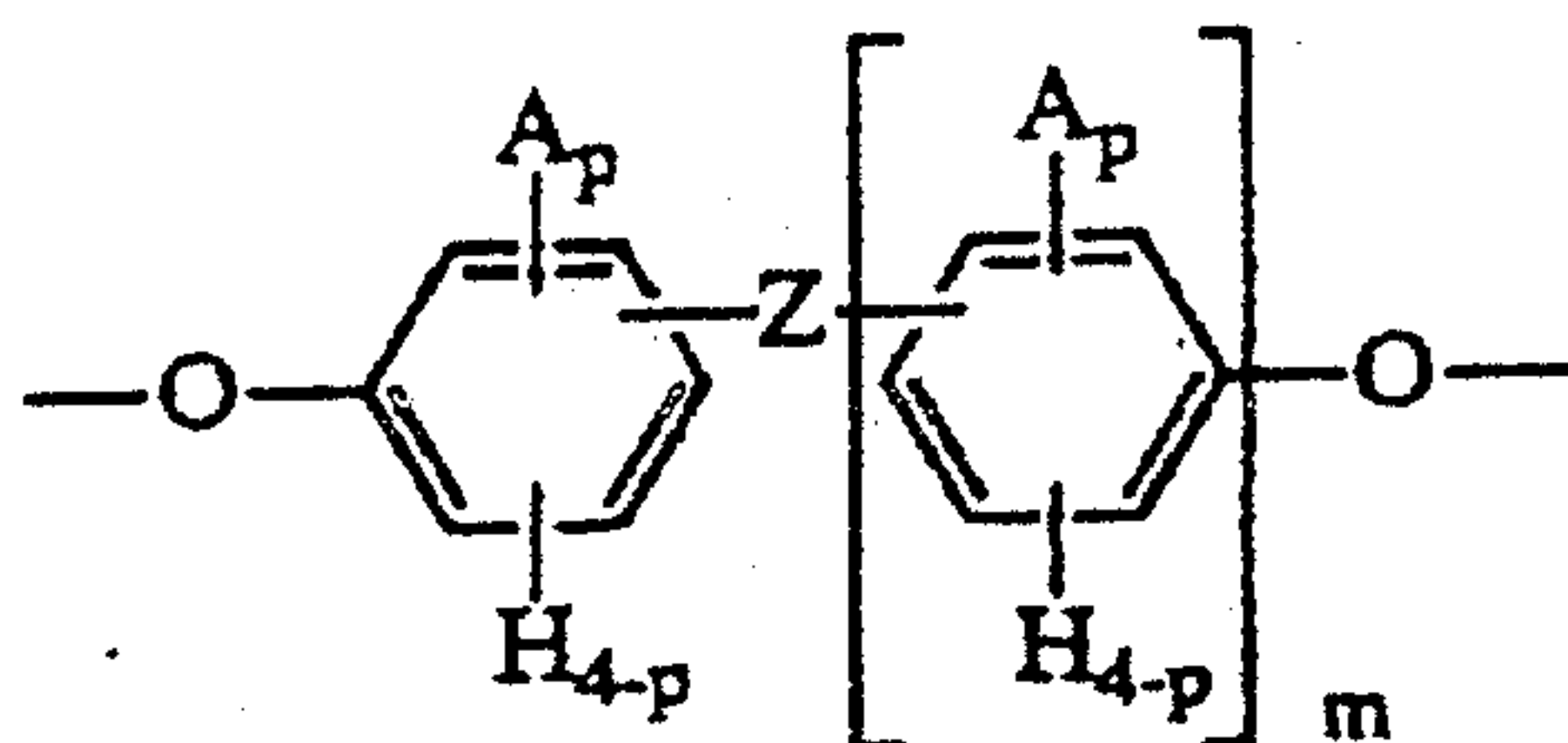
each -X is independently -H, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; q is 0, 1, or 2; and n is 1 or 2;

provided that if -Z- is -C(CH₃)₂-, -S-, or -SO₂- and m is 1, then p and q are not both 0.

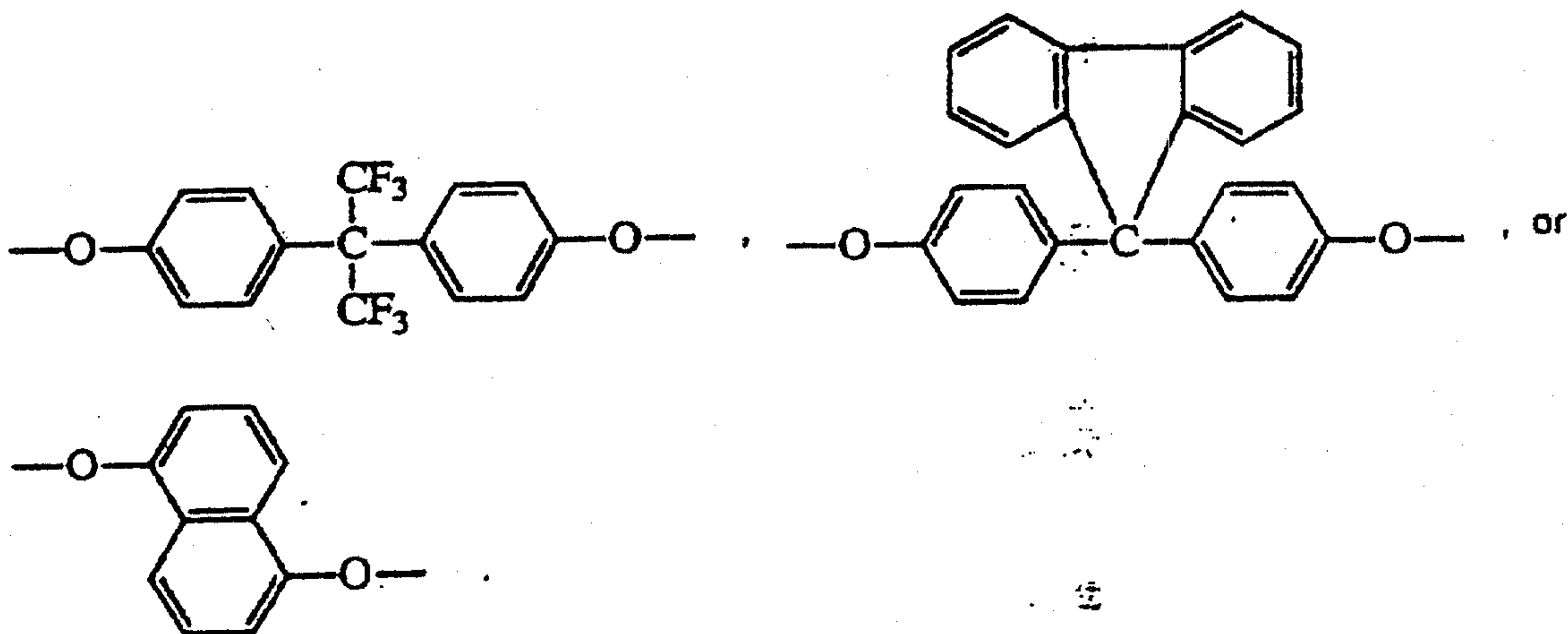
2. A fluorinated poly(arylene ether) according to claim 1, wherein -W- is

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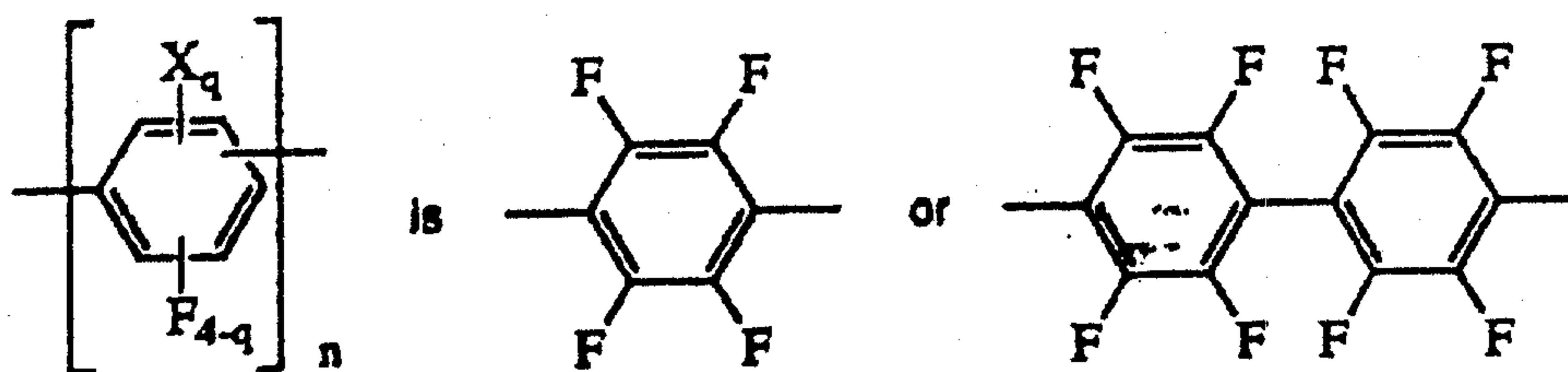
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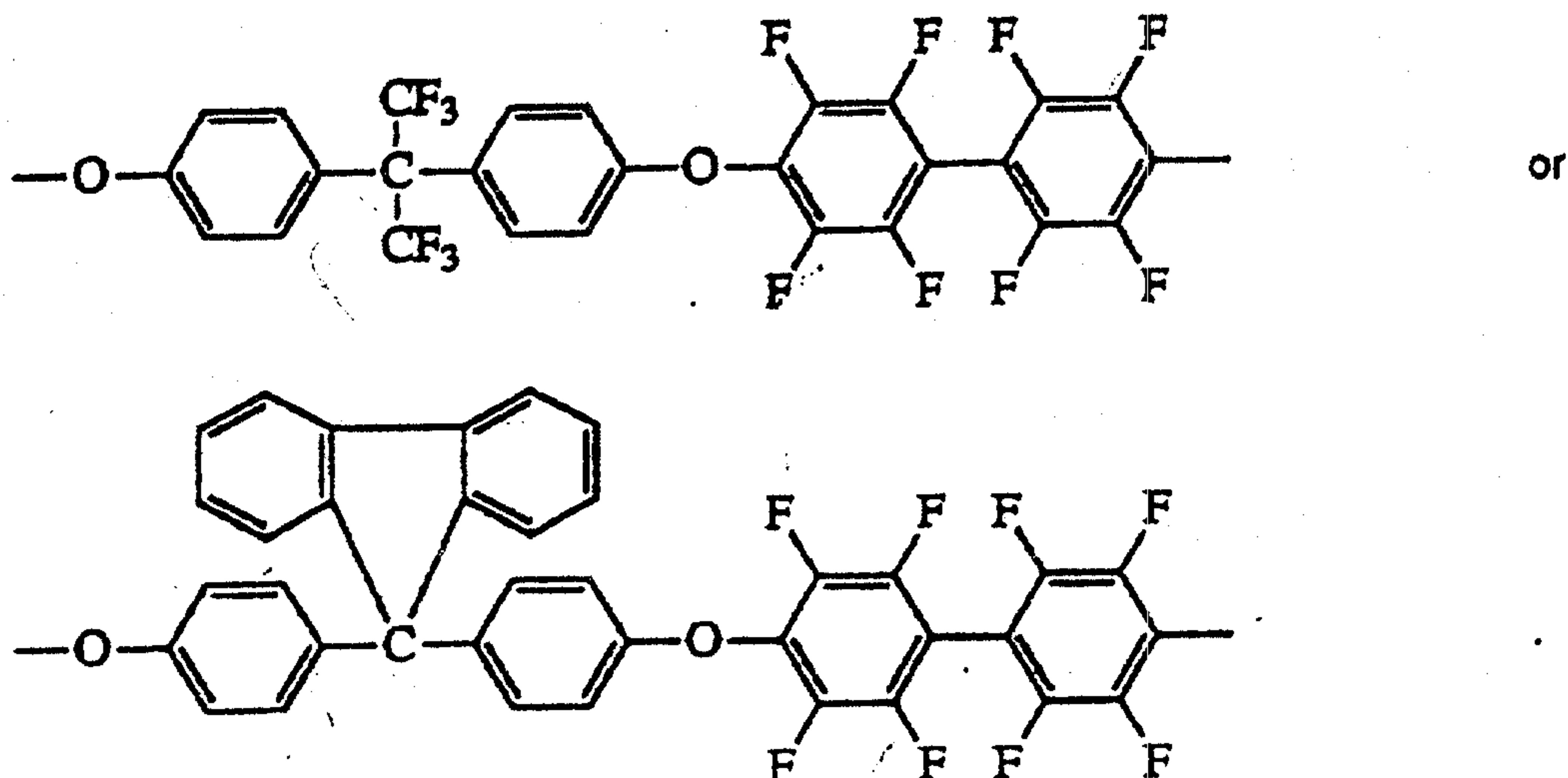
3. A fluorinated poly(arylene ether) according to claim 1, wherein -W- is



4. A fluorinated poly(arylene ether) according to claim 1, wherein



5. A fluorinated poly(arylene ether) according to claim 1, comprising a repeat unit of the structure



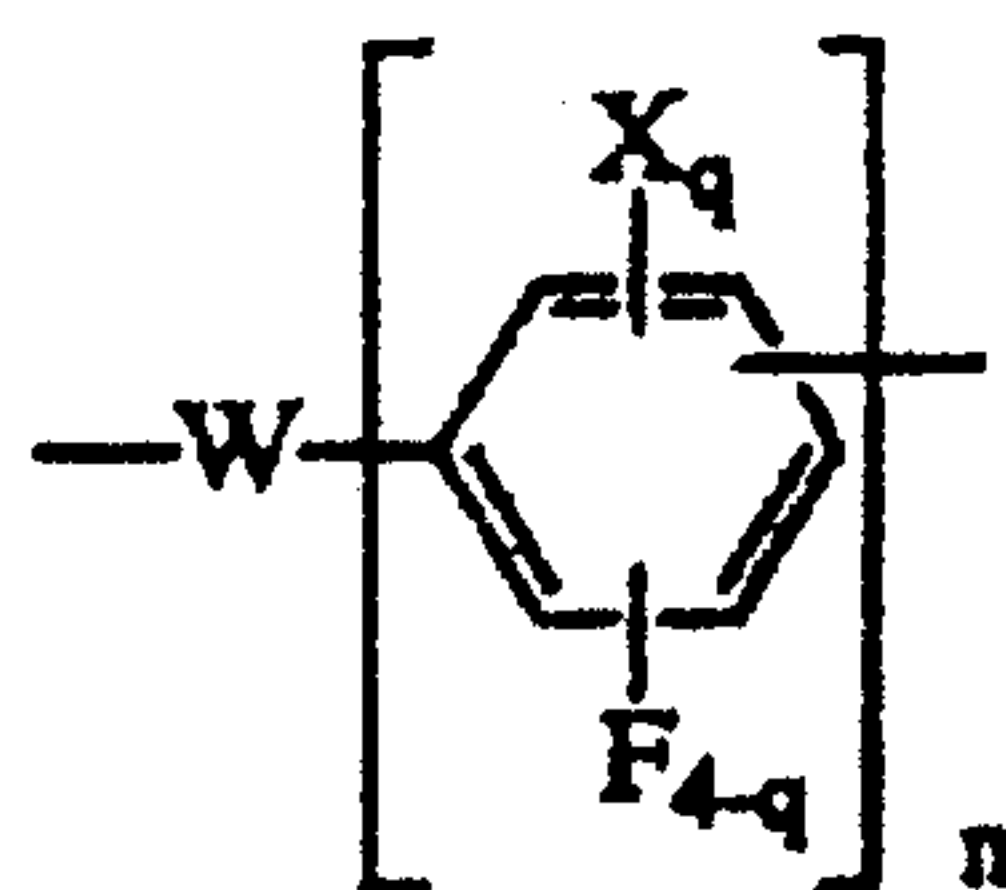
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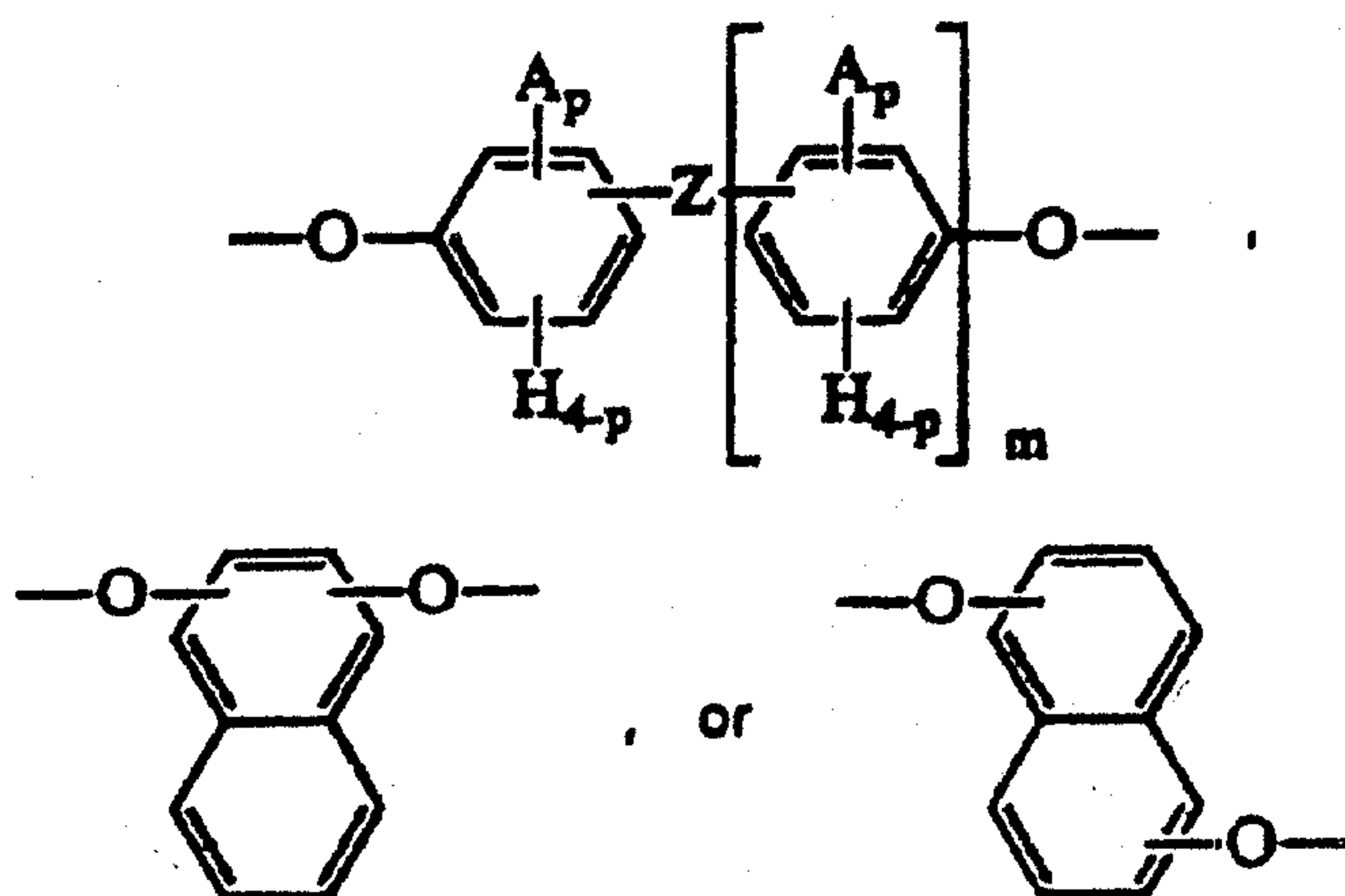
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6. A fluorinated poly(arylene ether) according to claim 1, which is a copolymer comprising at least two different fluorinated poly(arylene ether) repeat units.
7. A fluorinated poly(arylene ether) according to claim 1 or 2, which has been crosslinked by heating in air at a temperature between about 300 and about 400 °C.
8. A fluorinated poly(arylene ether) according to claim 1 or 2, which has been crosslinked by heating an intimate mixture thereof with a peroxydic compound.
9. A fluorinated poly(arylene ether) according to claim 8, wherein the peroxydic compound is selected from the group consisting of cumene hydroperoxide, dicumyl peroxide, and benzoyl peroxide.
10. A method of making a fluorinated poly(arylene ether) comprising a repeat unit of the structure



which method comprises polymerizing a diphenol monomer H-W-H, wherein -W- is

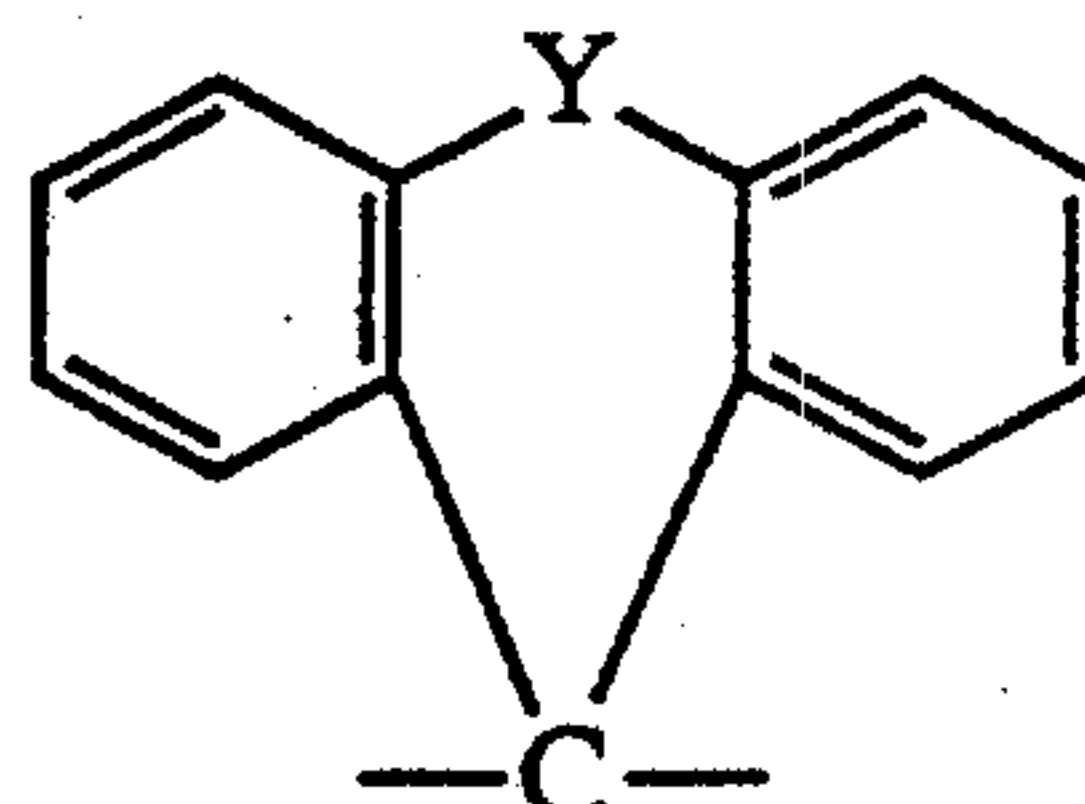


wherein each -A is independently -F, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; p is 0, 1, or 2; -Z- is a direct bond, -C(CH₃)₂-, -C(CF₃)₂-, -O-, -S-, -SO₂-, -CO-, -P(C₆H₅)-, -C(CH₃)(C₆H₅)-, -C(C₆H₅)₂-, -(CF₂)₁₋₆-, or

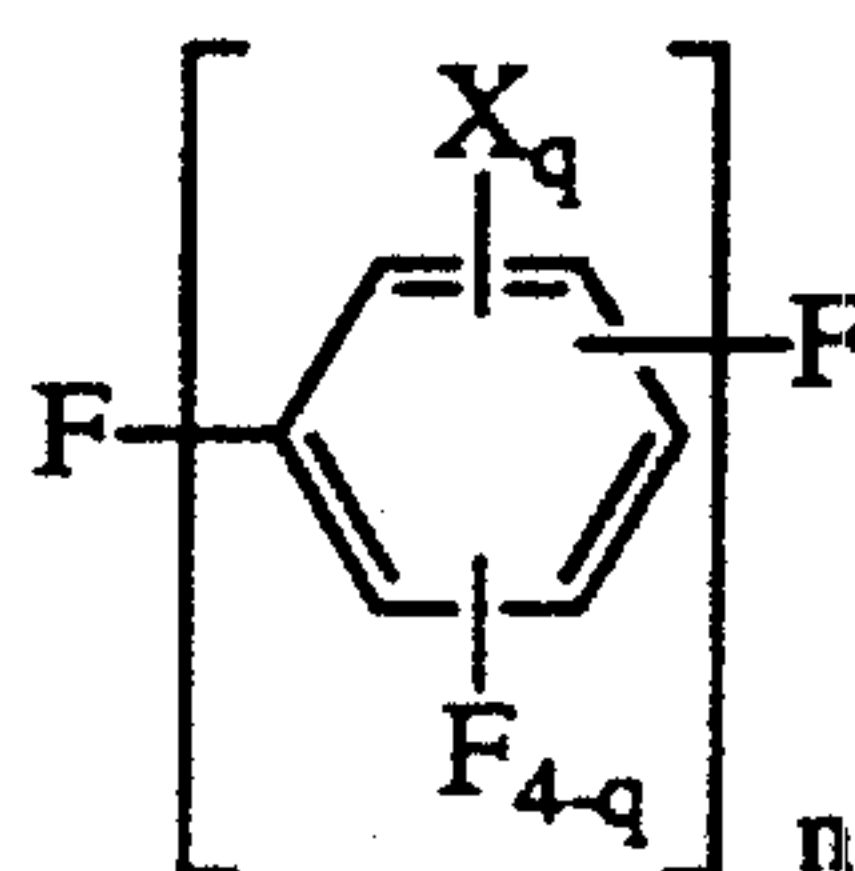
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wherein -Y- is -O- or a direct bond;
 and m is 0, 1, or 2; provided that if -Z- is -C(CH₃)₂-, -S-, or -SO₂- and m is 1, then p and q are not both 0;
 with a fluorinated monomer

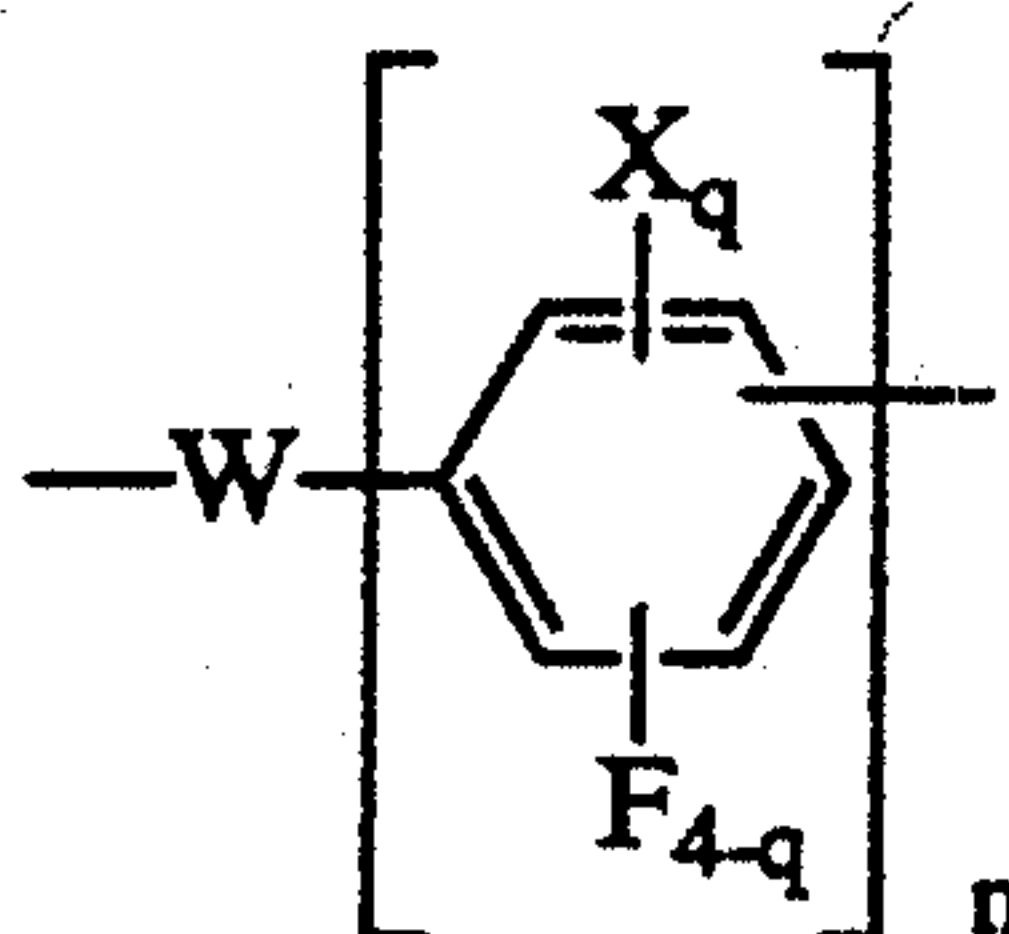


wherein each -X is independently -H, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; q is 0, 1, or 2; and n is 1 or 2.

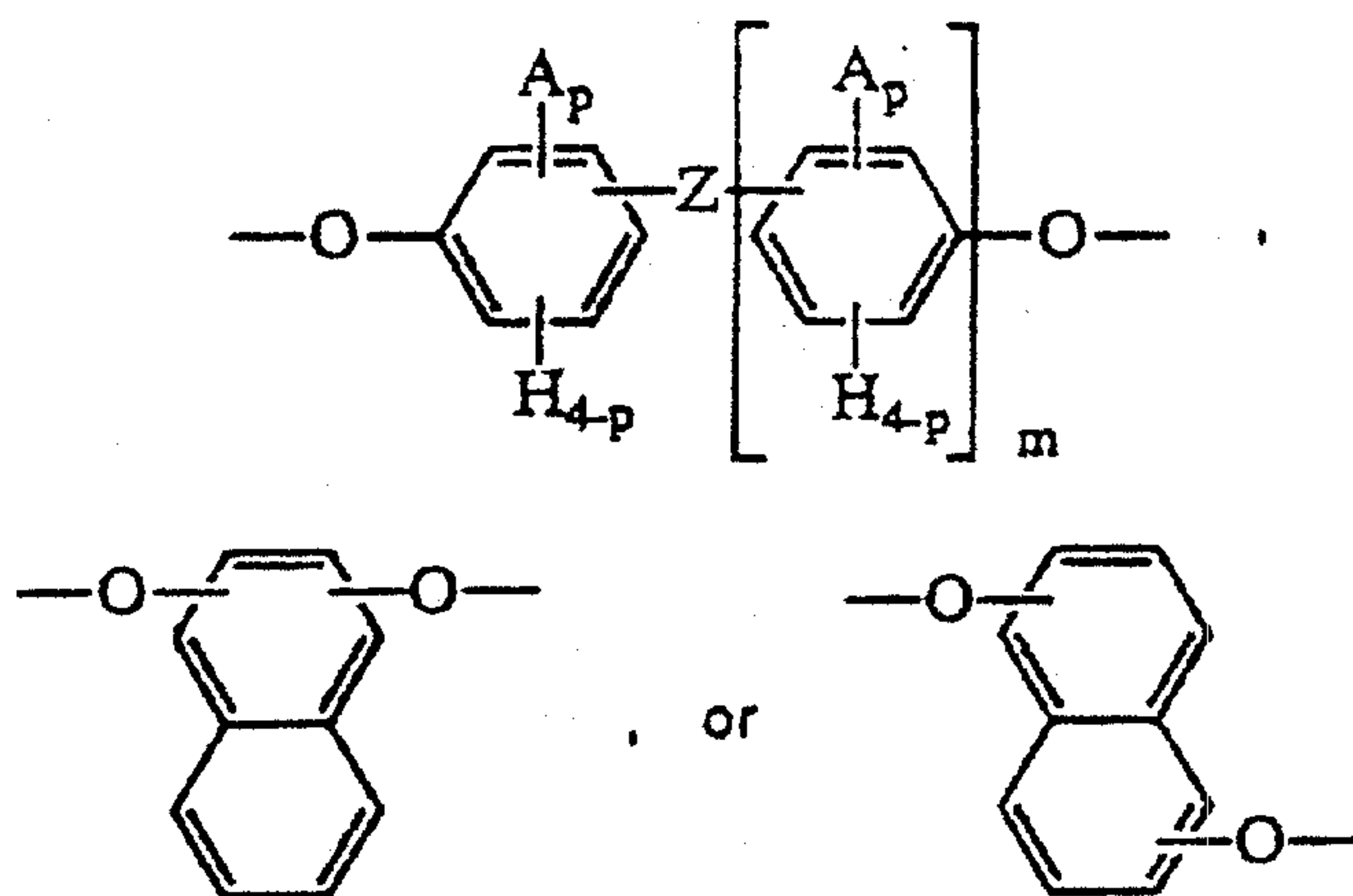
11. A method according to claim 10, wherein the diphenol monomer is selected from the group consisting of 4,4'-(hexafluoroisopropylidene)diphenol, 4,4'-isopropylidene-di(2,6-dimethylphenol), 4,4'-(1-phenylethylidene) bisphenol, 9,9'-bis(4-hydroxyphenyl)fluorene, 2,7-dihydroxynaphthalene, 1,5-dihydroxynaphthalene, resorcinol, 4,6-dichlororesorcinol, and combinations thereof.

12. A method according to claim 10, wherein the fluorinated monomer is selected from the group consisting of hexafluorobenzene, decafluorobiphenyl, pentafluorobenzene, octafluorotoluene, 1,4-dibromotetrafluorobenzene, chloropentafluorobenzene, allylpentafluorobenzene, 2,2',3,3',5,5',6,6'-octafluorobiphenyl, and combinations thereof.

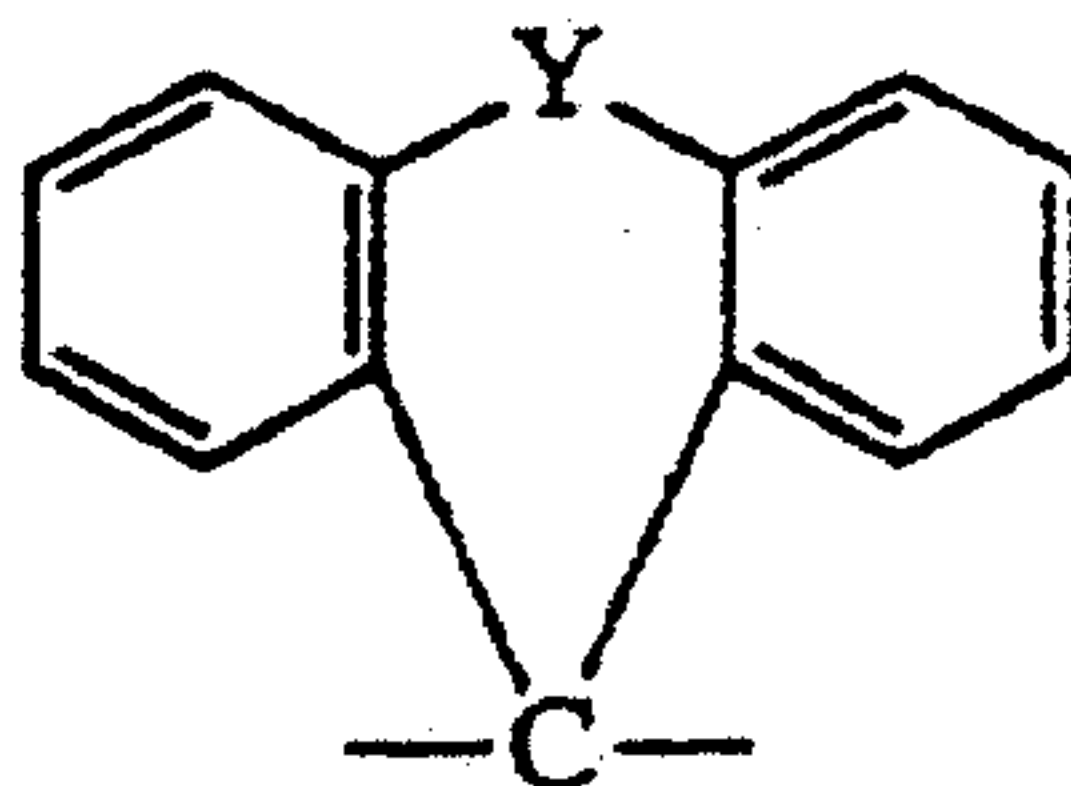
13. A method of crosslinking a fluorinated poly(arylene ether) comprising a repeat unit of the structure



wherein -W- is



wherein each -A is independently -F, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; p is 0, 1, or 2; -Z- is a direct bond, -C(CH₃)₂-, -C(CF₃)₂-, -O-, -S-, -SO₂-, -CO-, -P(C₆H₅)-, -C(CH₃)(C₆H₅), -C(C₆H₅)₂-, -(CF₂)₁₋₆-, or



wherein -Y- is -O- or a direct bond;

and m is 0, 1, or 2;

each -X is independently -H, -Cl, -Br, -CF₃, -CH₃, -CH₂CH=CH₂, or -C₆H₅; q is 0, 1, or 2; and n is 1 or 2;

provided that if -Z- is -C(CH₃)₂-, -S-, or -SO₂- and m is 1, then p and q are not both 0, which method comprises heating an intimate mixture of the fluorinated poly(arylene ether) and a peroxydic compound.

14. A method according to claim 13, wherein the peroxydic compound is present in the intimate mixture in an amount of between about 5 and about 20 % by weight based on the combined amounts of fluorinated poly(arylene ether) and peroxydic compound.

15. A method according to claim 13, wherein the intimate mixture is heated to a temperature between about 350 °C and about 425 °C.

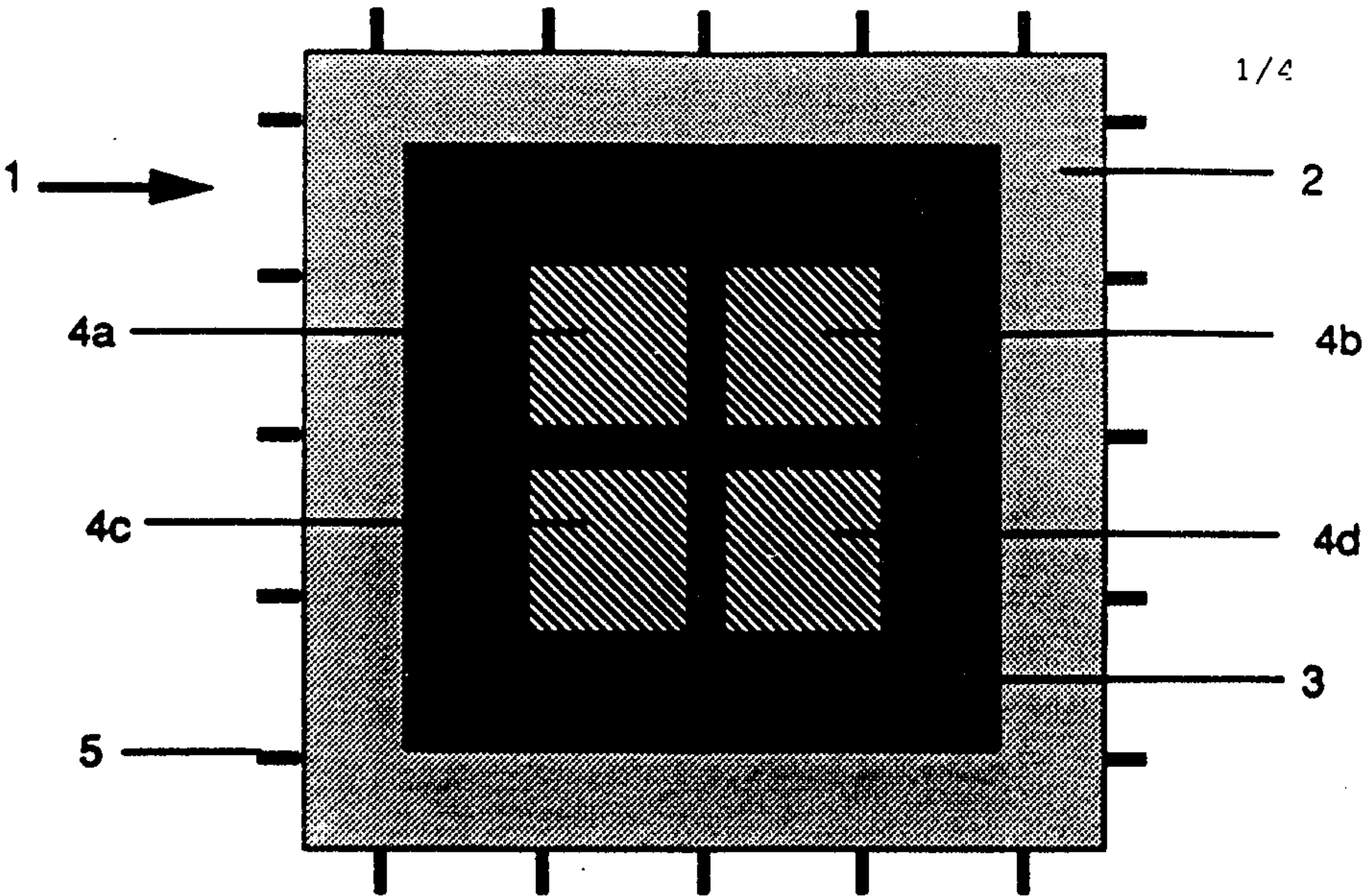


Fig. 1a

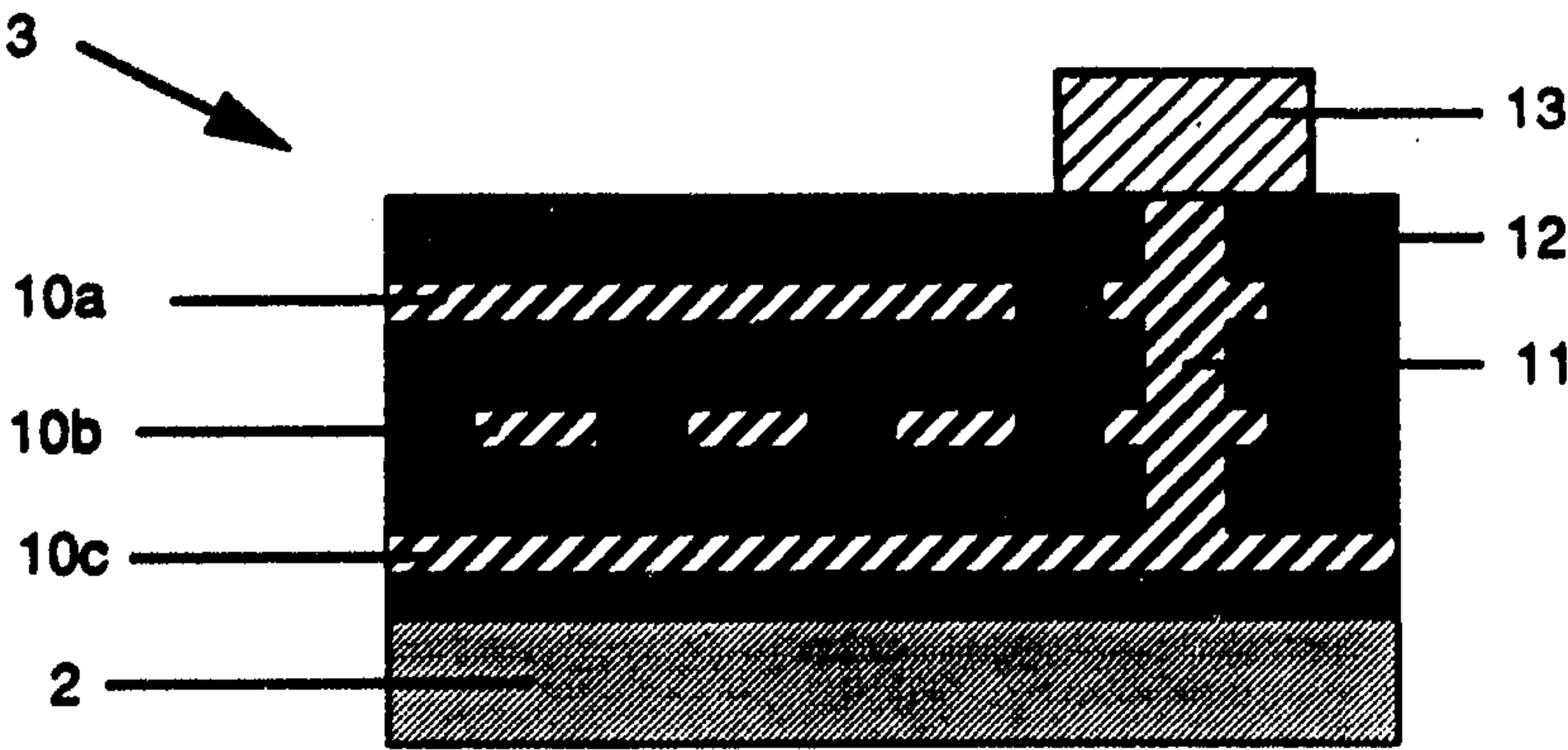
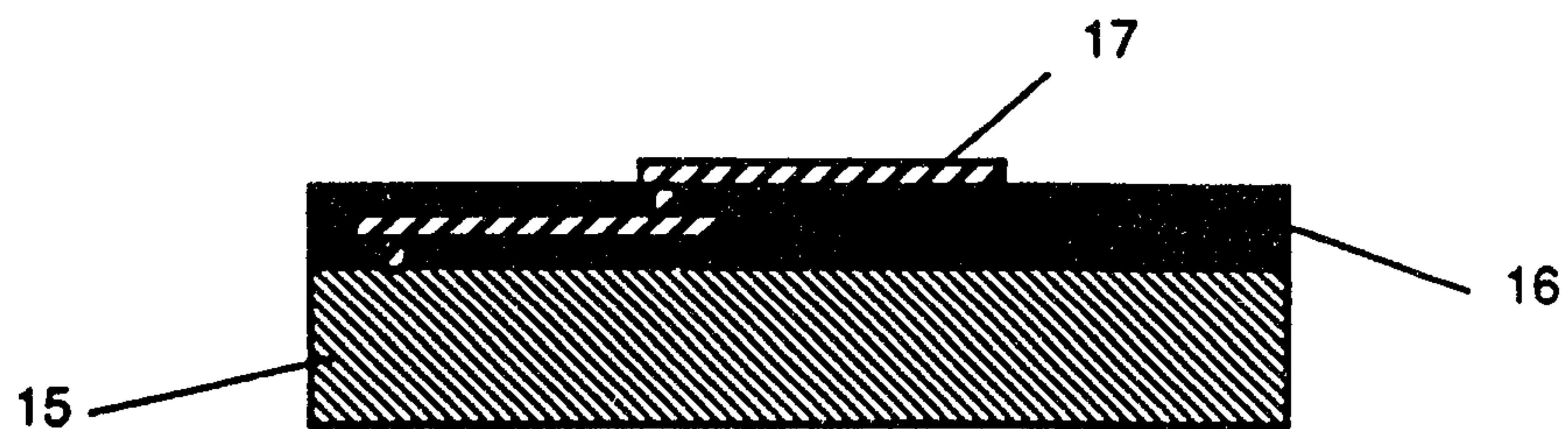
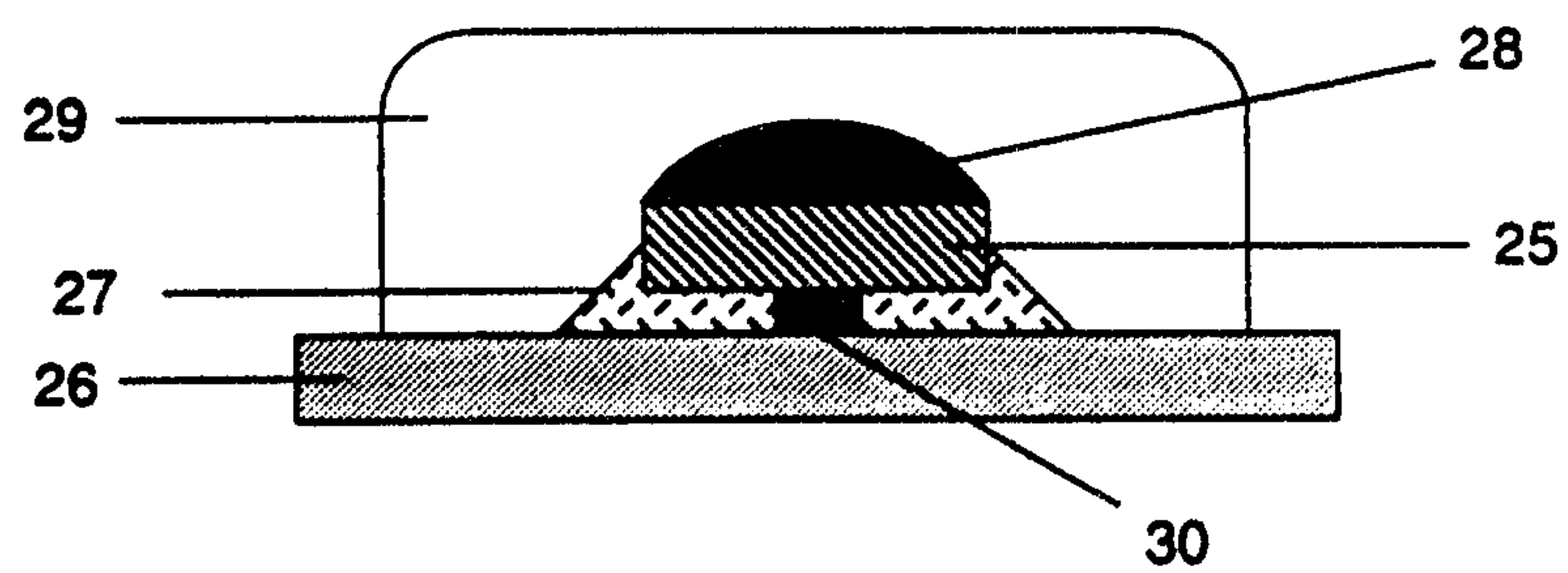


Fig. 1b

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**Fig. 2****Fig. 3**

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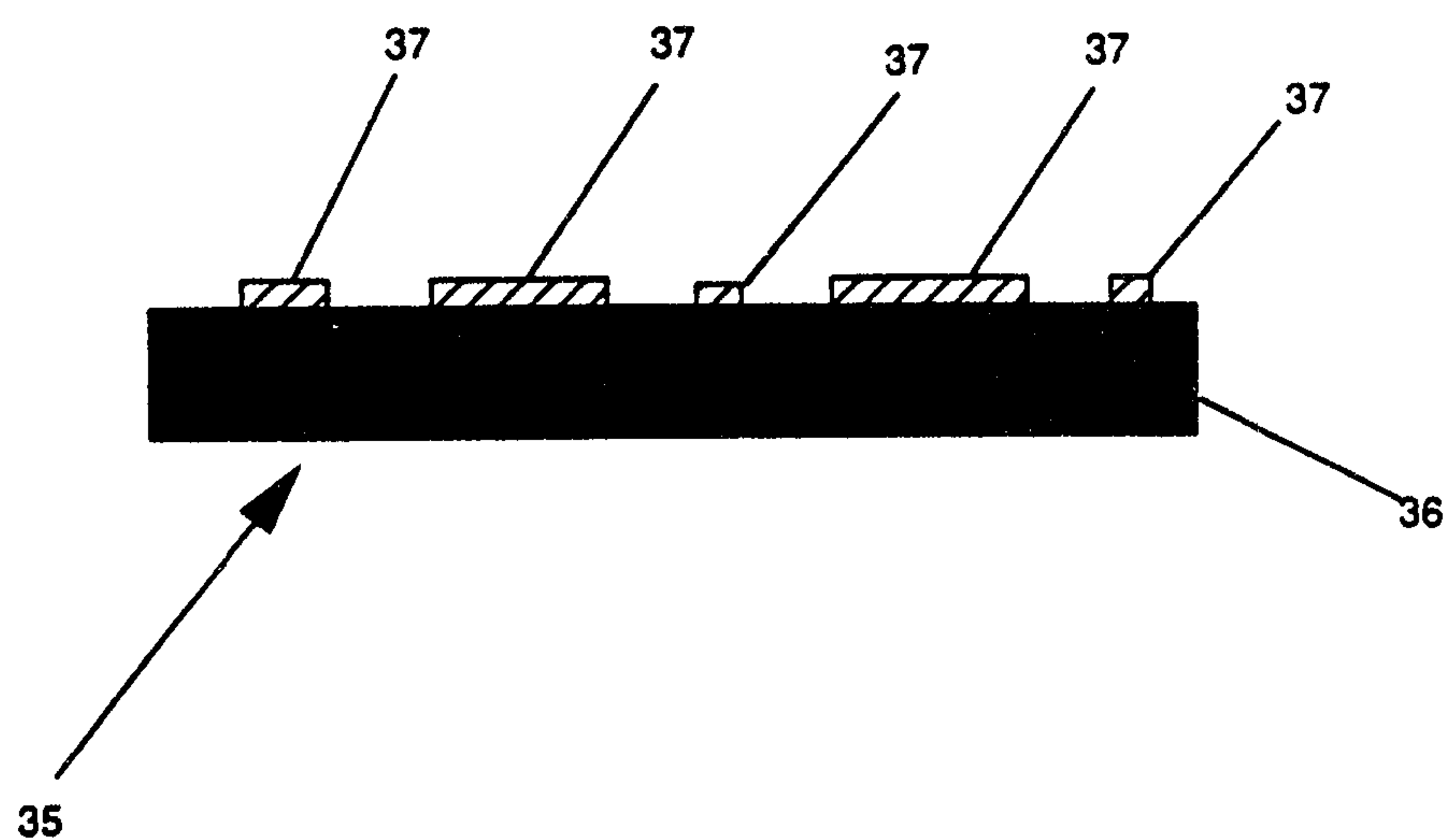


Fig. 3a

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Dielectric Constant of Polymers

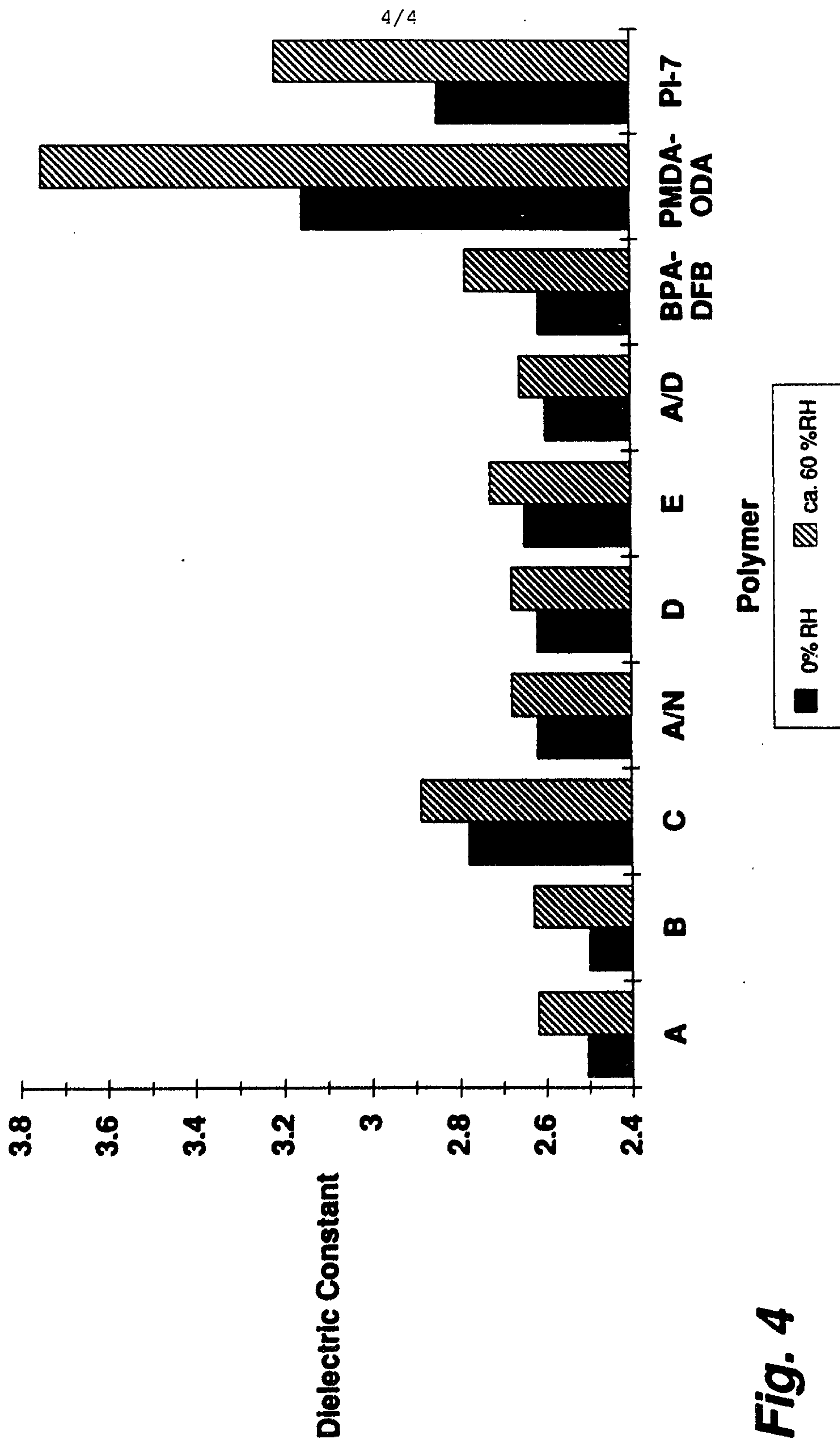


Fig. 4

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