Di(hydroxyphenyl)benzimidazole monomers were prepared from phenyl-4-hydroxybenzoate and aromatic bis(o-diamine). These monomers were used in the synthesis of soluble polybenzimidazoles. The reaction involved the aromatic nucleophilic displacement of various di(hydroxyphenyl)benzimidazole monomers with activated aromatic dihalides or activated aromatic dinitro compounds in the presence of an alkali metal base. These polymers exhibited lower glass transition temperatures, improved solubility, and better compression moldability over their commercial counterparts.

4 Claims, No Drawings
The invention described herein was jointly made by employees of the U.S. Government and a contract employee in the performance of work under NASA Grant No. NAG1-448 and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the contractor has elected not to retain title. This is a divisional of copending application Ser. No. 07/790,730 filed on Oct. 30, 1991.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to diol monomers. In particular, it relates to di(hydroxyphenyl)benzimidazole monomers.

2. Description of the Related Art

Polybenzimidazoles (PBIs) are heterocyclic macro-molecules commonly prepared by the condensation reaction of an aromatic bis(o-diamine) with an aromatic diacid or derivative thereof. These polymers possess high thermal, thermooxidative, and chemical stability; good mechanical properties; and excellent flame resistance, making them high-performance/high-temperature materials which are attractive for use in harsh environments. However, despite these properties, the processing of these polymers is somewhat difficult. Buckley et al (Encyclopedia of Polymer Science and Technology, Volume 11, 2nd Ed., 1988, p. 572) review polybenzimidazoles. They specifically review poly[2,2'-(m-phenylene)-5,5'-bibenzimidazole], which is commer-
monomers were prepared by reacting phenyl-4-hydroxybenzoate with various aromatic bis(o-diamine)s. These monomers have the following general structural formula:

\[
\begin{align*}
\text{(a)} & \quad \text{H} \\
\text{(b)} & \quad \text{N} \\
\text{(c)} & \quad \text{O}
\end{align*}
\]

where \( x \) is

These polymers had glass transition temperatures (Tg) ranging from 264° to 352° C., much lower than their commercial counterparts which exhibited Tgs of 400° C. As a result of the lower Tgs, these polymers exhibited much better compression moldability than 55 other PBIs. These polymers were found to be soluble in cold DMAc, as opposed to requiring hot DMAc and pressure to solubilize. The use of benzimidazole monomers to make PBIs proved to be more economical and easier to process than commercial PBIs without showing a loss in their physical and mechanical properties.

An object of the present invention is to prepare di(hydroxyphenyl)benzimidazole monomers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The synthesis of soluble PBIs involved the use of di(hydroxyphenyl)benzimidazole monomers. These monomers undergo a nucleophilic displacement reaction with activated aromatic dihalide or dinitro compounds in the presence of an alkali metal base such as: potassium carbonate, sodium carbonate, potassium hydroxide, and sodium hydroxide. The resulting PBIs are soluble in DMAc and have the following general structural repeat unit:

\[
\begin{align*}
\text{(d)} & \quad \text{H} \\
\text{(e)} & \quad \text{N} \\
\text{(f)} & \quad \text{O}
\end{align*}
\]

where \( z \) is either a direct bond, \(-\text{CH}_2-\), \(-\text{O}-\), or \(-\text{S}-\), and

the catenation of the hydroxy groups may be meta, para-para, or para-meta.

These benzimidazole monomers undergo a nucleophilic displacement reaction with activated aromatic dihalide or dinitro compounds in the presence of an alkali metal base such as: potassium carbonate, sodium carbonate, potassium hydroxide, and sodium hydroxide.
where:
the catenation of oxygen is either meta-meta, para-para, or para-meta;
Ar is any one of the following:

x is any one of the following:

The solubility of these polymers allows for film formation, something which was difficult to achieve in previous PBI systems. These polymers also exhibited
lower Tgs which makes compression and injection molding much easier. The following examples are illustrative of the invention.

**EXAMPLE 1**

**Preparation of the di(hydroxyphenyl)benzimidazole monomers**

5,5'-Bis[2-(4-hydroxyphenyl)benzimidazole]

A mixture of 3,3',4,4'-tetraaminobiphenyl (commercially available from Hoechst-Celanese Corporation) (25.80 g, 0.120 mol), phenyl-4-hydroxybenzoate (commercially available from K and K Laboratories) (52.62 g, 0.246 mol), diphenylsulfone (95.30 g), and toluene (100 ml) was heated under a nitrogen atmosphere for 2.5 hours at 150°C. The toluene was removed and the temperature increased to 250°C and maintained for 1.25 hours. A vacuum was subsequently applied and the temperature increased to 270°C and maintained for 1 hour. The cooled yellow reaction mixture was washed successively in hot toluene and water and subsequently dried at 110°C to afford 39.83 g (96% crude yield) of a yellow powder. The endothermic peak as determined by DTA was 387°C (broad). The yellow solid was dissolved in DMAc, treated with activated charcoal, filtered, and poured into water to afford a yellow precipitate. The solid was dried under vacuum at 245°C to afford 31.52 g (76% yield) of a brown powder. The endothermic peak as determined by DTA was 346°C (broad). Analysis calcd. for C_{27}H_{18}N_{4}O_{3}: C, 72.64%; H, 4.06%; N, 12.55%. Found: C, 71.96%; H, 4.20%; N, 12.42%. The resulting monomer had the following structural formula:

---

5,5'-Oxy-bis[2-(4-hydroxyphenyl)benzimidazole]

Oxydianiline was acetylated, nitrated, and the acetylated group hydrolyzed to give 3,3'-dinitro-4,4'-diaminodiphenyl ether. The 3,3'-dinitro-4,4'-diaminodiphenyl ether was then reduced with stannous chloride and hydrochloric acid to give bis(3,4-diaminophenyl)ether.

A mixture of bis(3,4-diaminophenyl)ether (22.00 g, 0.096 mol), phenyl-4-hydroxybenzoate (41.00 g, 0.194 mol), diphenylsulfone (110.17 g), and toluene (135 ml) was heated under a nitrogen atmosphere for 3.5 hours at 150°C. The toluene was removed and the temperature increased to 250°C and maintained for 1.5 hours. A vacuum was subsequently applied and the temperature increased to 280°C and maintained for 1.25 hours. The cooled dark reaction mixture was washed in hot toluene and dried at 110°C. A yellow solid was extracted with acetone to afford 12.39 g (20% yield) of a tan solid. The endothermic peak as determined by DTA was 317°C (broad). Analysis calcd. for C_{26}H_{18}N_{4}O_{2}: C, 71.98%; H, 4.18%; N, 12.90%. Found: C, 71.91%; H, 4.22%; N, 13.08%. The resulting monomer had the following structural formula:

---

5,5'-Carbonyl-bis[2-(4-hydroxyphenyl)benzimidazole]

A mixture of 3,3',4,4'-tetraminobenzophenone (commercially available from Büdick and Jackson) (22.61 g, 0.093 mol), phenyl-4-hydroxybenzoate (40.01 g, 0.187 mol), diphenylsulfone (110.45 g), and toluene (135 ml) was heated under a nitrogen atmosphere for 3 hours at 150°C. The toluene was removed and the temperature increased to 250°C and maintained for 1.25 hours. A vacuum was subsequently applied and the temperature increased to 270°C and maintained for 1 hour. The cooled yellow reaction mixture was washed successively in hot toluene and water and subsequently dried at 110°C to afford 39.83 g (96% crude yield) of a yellow powder. The endothermic peak as determined by DTA was 387°C (broad). The yellow solid was dissolved in DMAc, treated with activated charcoal, filtered, and poured into water to afford a yellow precipitate. The solid was dried under vacuum at 245°C to afford 31.52 g (76% yield) of a brown powder. The endothermic peak as determined by DTA was 346°C (broad). Analysis calcd. for C_{27}H_{18}N_{4}O_{3}: C, 72.64%; H, 4.06%; N, 12.55%. Found: C, 71.96%; H, 4.20%; N, 12.42%. The resulting monomer had the following structural formula:
EXAMPLE 2

Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-bis[2-(4-hydroxyphenyl)benzimidazole] (2.7835 g, 6.7 mmol), 4,4'-difluorobenzophenone (1.4515 g, 6.7 mmol), pulverized anhydrous potassium carbonate (2.4509 g, 17.7 mmol), dry DMAc (22 ml, 18% solids w/w), and toluene (50 ml). The reaction mixture was heated to 140°-150° C. for 3.5 hours and then heated to 155°-160° C. After approximately 2 hours, the viscous reaction mixture was diluted with 21 ml DMAc (9.0% solids w/w) and stirring continued at 155°-160° C. The viscous reaction mixture was diluted with 25 ml DMAc (5.7% solids w/w) after approximately 0.75 hour. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110° C. to provide a light brown polymer (2.48 g, 73% yield) with a Tg of 276° C. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 1.99 dL/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 19.4 ksi, 598 ksi, and 13.1% respectively. The resulting polymer had the following structural repeat unit:

![Structural Repeat Unit 1](image1)

mixture cooled. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110° C. to provide a light brown polymer (3.60 g, 91% yield) with a Tg of 307° C. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 1.11 dL/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 22.8 ksi, 647 ksi, and 11.6%, respectively. Although the activated aromatic dihalide compound contained the halogen fluorine, a chlorine-containing compound may be substituted as is known in those skilled in the area. The resulting polymer had the following structural repeat unit:

![Structural Repeat Unit 2](image2)

EXAMPLE 3

Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-bis[2-(4-hydroxyphenyl)benzimidazole] (2.0686 g, 5.7 mmol), 4,4'-difluorobenzophenone (1.2537 g, 5.7 mmol), pulverized anhydrous potassium carbonate (2.0686 g, 15.0 mmol), dry DMAc (18.5 ml, 18% solids w/w) and toluene (45 ml). The mixture was heated to 140°-150° C. for 3.5 hours and then heated to 155°-160° C. After 1.75 hours the viscous reaction mixture was diluted with 18 ml DMAc (10% solids w/w) and stirring continued at 155°-160° C. The viscous reaction mixture was diluted with 20 ml DMAc (6.7% solids w/w) after 0.25 hours. Stirring was continued for 0.5 hour at 160° C. and the reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110° C. to provide a pale yellow polymer (3.03 g, 84% yield) with no observable Tg by differential scanning calorimetry. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 0.93 dL/g. The polymer had the following structural repeat unit:

![Structural Repeat Unit 3](image3)
EXAMPLE 5

Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-carbonyl-bis[2-(4-hydroxyphenyl)benzimidazole] (2.5712 g, 5.8 mmol), 1,3-bis(4-fluorobenzoyl)benzene (1.8562 g, 5.8 mmol), pulverized anhydrous potassium carbonate (2.200 g, 15.9 mmol), dry DMAc (22 ml, 18% solids w/w), and toluene (50 ml). The mixture was heated to 140°–150° C. for 3.5 hours and then heated to 155°–160° C. After approximately 1.1 hours the viscous reaction mixture was diluted with 20 ml DMAc (10% solids w/w) and stirring continued at 155°–160° C. The viscous reaction mixture was diluted with 25 ml DMAc (6.7% solids w/w) after approximately 1.5 hours. Stirring was continued for 0.25 hour at 160° C. and the reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid mixture, washed successively in hot water and methanol and dried at 110° C. to provide a white polymer (3.60 g, 84% yield) with a Tg of 294° C. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 1.34 dL/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 19.7 ksi, 576 ksi, and 7.0%, respectively. The resulting polymer had the following structural repeat unit:

![Structural Repeat Unit](image)

EXAMPLE 6

Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-oxy-bis[2-(4-hydroxyphenyl)benzimidazole] (2.9733 g, 6.8 mmol), 4,4'-difluorobenzophenone (1.4933 g, 6.8 mmol), pulverized anhydrous potassium carbonate (2.4468 g, 17.7 mmol), dry DMAc (21.5 ml, 18% solids w/w), and toluene (45 ml). The mixture was heated to 140°–150° C. for 3.5 hours and then heated to 155°–160° C. After approximately 3 hours the viscous reaction mixture was diluted with 20 ml DMAc (10% solids w/w) and stirring continued at 155°–160° C. The viscous reaction mixture was diluted with 25 ml DMAc (6.7% solids w/w) after approximately 1.5 hours. Stirring was continued for 0.25 hour at 160° C. and the reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid mixture, washed successively in hot water and methanol and dried at 110° C. to provide a white polymer (3.60 g, 84% yield) with a Tg of 294° C. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 1.34 dL/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 19.7 ksi, 576 ksi, and 7.0%, respectively. The resulting polymer had the following structural repeat unit:

![Structural Repeat Unit](image)

EXAMPLE 7

Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-oxy-bis[2-(4-hydroxyphenyl)benzimidazole] (2.3330 g, 5.4 mmol), 1,3-bis(4-fluorobenzoyl)benzene (1.7308 g, 5.4 mmol), pulverized anhydrous potassium carbonate (1.9948 g, 14.1 mmol), dry DMAc (19.5 ml, 18% solids w/w), and toluene (45 ml). The mixture was heated to 140°–150° C. for 3.5 hours and then heated to 155°–160° C. After approximately 1 hour the viscous reaction mixture was diluted with 20 ml DMAc (7.0% solids w/w) after approximately 0.15 hour. The viscous solution was precipitated in a water/acetic acid mixture, washed successively in hot water and methanol and dried at 110° C. to provide a pale yellow polymer (3.13 g, 75% yield) with a Tg of 264° C. The inherent viscosity of a 0.5% solution in DMAc at 25° C. was 1.43 dL/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 19.6 ksi, 612 ksi, and 5.6% respectively. The polymer had the following structural repeat unit:

![Structural Repeat Unit](image)
DMAc solution gave tensile strength, tensile modulus, and elongation at 23°C of 18.4 ksi, 591 ksi, and 6.1%, respectively. The resulting polymer had the following structural repeat unit:

![Structural repeat unit](image)

Although these polymers were made using DMAc as the solvent, other solvents known to those skilled in the art, such as N-methylpyrrolidinone, diphenylsulfone, and sulfolane may also be used. In addition to the polymers made in the foregoing examples, additional polymers were made and their properties are tabulated in Tables 1 and 2.

### TABLE 1

**POLYMER CHARACTERIZATION**

<table>
<thead>
<tr>
<th>Y</th>
<th>X</th>
<th>nlnh,¹</th>
<th>Tg⁻²</th>
<th>Temp. of 5% wt. loss, °C ³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>dL/g</td>
<td>°C</td>
<td>air</td>
</tr>
<tr>
<td>SO₂</td>
<td>nil</td>
<td>1.87</td>
<td>352</td>
<td>441</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1.42</td>
<td>322</td>
<td>435</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>0.93</td>
<td>N.D. ⁴</td>
<td>422</td>
</tr>
<tr>
<td></td>
<td>nil</td>
<td>1.11</td>
<td>307</td>
<td>466</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1.34</td>
<td>294</td>
<td>442</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>0.93</td>
<td>N.D. ⁴</td>
<td>433</td>
</tr>
<tr>
<td></td>
<td>nil</td>
<td>1.19</td>
<td>295</td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1.23</td>
<td>282</td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>0.79</td>
<td>276</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>nil</td>
<td>1.99</td>
<td>276</td>
<td>476</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1.97</td>
<td>269</td>
<td>454</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>1.43</td>
<td>264</td>
<td>467</td>
</tr>
</tbody>
</table>

¹Inherent viscosity measured in DMAc on 0.5% (v/v) solutions at 25°C.
²Glass transition temperature determined by DSC at a heating rate of 20°C/min
³TGA measured on powdered samples at a heating rate of 2.5°C/min after preheat sample to 180°C and holding for 0.5 h before analysis
⁴Not detected

### TABLE 2

**UNORIENTED THIN FILM TENSILE PROPERTIES AT 23°C**

<table>
<thead>
<tr>
<th>Y</th>
<th>X</th>
<th>nlnh, ¹</th>
<th>Strength, ksi</th>
<th>Modulus, ksi</th>
<th>Elong. at break, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>dL/g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>nil</td>
<td>1.87</td>
<td>22.5</td>
<td>652</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>1.42</td>
<td>18.8</td>
<td>569</td>
<td>7.6</td>
</tr>
</tbody>
</table>
What is claimed is:

1. A di(hydroxyphenyl)benzimidazole monomer having the following structure:

   ![Structure 1](image1)

   where z is a direct bond or is selected from the group consisting of: 
   -CH₂-, -O-, -S-.

2. The di(hydroxyphenyl)benzimidazole monomer of claim 1, having the following structural formula:

   ![Structure 2](image2)

   the catenation of the hydroxy groups is selected from the group consisting of: meta-meta, para-para, and para-meta.

3. The di(hydroxyphenyl)benzimidazole monomer of claim 1, having the following structural formula:

   ![Structure 3](image3)

4. The di(hydroxyphenyl)benzimidazole monomer of claim 1, having the following structural formula:

   ![Structure 4](image4)