



Synthesis and Properties of New Aromatic Polyimides Based on 2,6-Bis(4-aminophenoxy)naphthalene and Aromatic Tetracarboxylic Dianhydrides

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Abstract

A series of new aromatic polyimides containing bis(phenoxy)naphthalene units were synthesized from 2,6-bis(4-aminophenoxy)naphthalene (2,6-BAPON) and various aromatic tetracarboxylic dianhydrides by the conventional two-stage procedure with thermal imidization of poly(amic acid) films. The intermediate poly(amic acid)s obtained had inherent viscosities of 1.60–3.31 dL/g, and they could be solution cast and thermally converted into transparent, flexible, and tough polyimide films. The resulting polyimide films had tensile moduli of 1.5–2.3 GPa, tensile strengths of 105–124 MPa, and elongations at break of 7–22%. The polyimide derived from 2,2-bis(3,4-dicarboxyphenyl)hexafluoropropane dianhydride (6FDA) was readily soluble in polar aprotic solvents. The glass-transition temperatures of these polyimides, except for that from pyromellitic dianhydride (PMDA), were recorded between 255 and 295 °C by differential scanning calorimetry (DSC). The softening temperatures of all the polyimide films stayed within 246–286 °C according to thermomechanical analysis (TMA). Thermogravimetric analyses (TGA) established that these polymers were fairly stable up to 500 °C, and the 10% weight loss temperatures were recorded in the range of 543–563 °C in nitrogen and 535–563 °C in air atmosphere.

Introduction

Aromatic polyimides are well accepted as high-performance polymeric materials for their excellent heat and chemical resistance, favorable electrical insulating properties as well as superior mechanical characteristics [1, 2]. They are widely used for interlayer dielectric for semiconductor devices or as substrates for flexible printed circuits. The most widespread route for the preparation of aromatic polyimides is the two-stage polyaddition and polycondensation of a dianhydride with a diamine in an aprotic solvent, such as *N,N*-dimethylacetamide (DMAc). A soluble poly(amic acid) is obtained as polyimide prepolymer in the first stage; then cyclodehydration of this intermediate polymer, either by heat or chemical reagents, yields the polyimide. Unless carefully designed, however, polyimides are often insoluble and intractable in the fully imidized form; thus, their applications were limited in some fields. Therefore, preparation of soluble or thermoplastic polyimides has been a major research interest. The concepts for structural modifications such as the incorporation of flexible bridging linkages [3, 4] or *meta*-oriented or *ortho*-oriented aromatic units [5–8] into polymer backbone and the introduction of bulky groups into or along polymer skeleton [9–15] have been used to enhance the solubility and to lower the transition temperatures.

It has been generally recognized that aromatic ether linkages inserted in aromatic main chains provide them with a significantly lower energy of internal rotation. In general, such a structural modification leads to lower glass transition temperatures (T_g s) and crystalline melting temperatures (T_m s), as well as significant improvements in solubility and other process characteristics of the polymers without greatly sacrificing other advantageous polymer properties. On the other hand, the introduction of a naphthalene ring into the polymer backbone is expected to lead to a decrease in linearity of polymer chain while maintaining comparable thermal stability in comparison with the benzene ring. Thus, the combination of aryl ether and naphthalene units into the polymer chain may be proposed as a choice for increasing the tractability of rigid aromatic polymers without extreme loss of thermal stability. It has been reported in our previous articles [16–21] that some polyimides containing isomeric 1,4-, 1,5-, 1,6-, 1,7-, 2,3-, and 2,7-substituted bis(phenoxy)naphthalene units were soluble in polar organic solvents or exhibited moderate T_g s suitable for thermoforming processing, which suggests that bis(phenoxy)naphthalene-containing diamines would be the potential monomers for preparation of more easily tractable polyimides. In a continuation of this study, the present

article describes the synthesis and basic characterization of a series of new polyimides derived from 2,6-bis(4-aminophenoxy)naphthalene with standard aromatic tetracarboxylic dianhydrides.

Experimental

Materials

2,6-Dihydroxynaphthalene (from Fluka), *p*-fluoronitrobenzene (from Janssen), and 10% palladium on activated carbon (Pd/C) (from Fluka) were used as received. Reagent-grade aromatic tetracarboxylic dianhydrides such as pyromellitic dianhydride (PMDA, **1a**; from TCI), 3,3',4,4'-biphenyltetracarboxylic dianhydride (BPDA, **1b**; from Chriskev), 4,4'-oxydiphthalic anhydride (ODPA, **1c**; from Chriskev), 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA, **1d**; from TCI), 3,3',4,4'-diphenylsulfonetetracarboxylic dianhydride (DSDA, **1e**; from New Japan Chemical Co.) and 2,2-bis(3,4-dicarboxyphenyl)hexafluoropropane (6FDA, **1f**; from Hoechst) were purified by recrystallization from acetic anhydride or vacuum sublimation prior to use. DMAc was purified by distillation under reduced pressure over calcium hydride and stored over 4 Å molecular sieves.

2,6-Bis(4-nitrophenoxy)naphthalene (2,6-BNPON)

This compound was synthesized by the reaction of 2,6-dihydroxynaphthalene (16 g, 0.1 mol) and *p*-fluoronitrobenzene (28.2 g, 0.2 mol) in the presence of potassium carbonate (27.6 g, 0.2 mol) in DMAc (180 mL) at 120 °C for 12 h. The mixture was then cooled and 100 mL of methanol was added. The precipitated solid was filtered and washed with methanol and hot water; the crude product (40 g) was recrystallized from dimethyl sulfoxide to provide 35.6 g (89% yield) of pure 2,6-BNPON as light yellow crystals (mp = 264–266 °C). Anal. calcd. for C₂₂H₁₄N₂O₆ (402.36): C, 65.67%; H, 3.48%; N, 6.96%. Found: C, 65.48%; H, 3.49%; N, 6.80%.

IR (KBr): 1342, 1582 (NO₂), 1250 cm⁻¹ (C–O–C). ¹H NMR (DMSO-d₆) δ (ppm): 8.28 (d, 4H, phenylene), 8.07 (d, 2H, naphthalene), 7.80 (s, 2H, naphthalene), 7.44 (d, 2H, naphthalene), 7.22 (d, 4H, phenylene). ¹³C NMR (DMSO-d₆): δ (ppm): 162.83, 151.95, 142.46, 131.62, 130.28, 126.26, 121.39, 117.70, 116.95.

2,6-Bis(4-aminophenoxy)naphthalene (2,6-BAPON)

A suspension solution of 2,6-BNPON (10 g, 0.025 mol), 10% Pd/C (0.1 g), and hydrazine monohydrate (10 mL) in ethanol (80 mL) was heated at the reflux temperature for about 5 h. To the reaction mixture, 100 mL of tetrahydrofuran was added to redissolve the precipitated product, and refluxing was continued for another 1 h. The resultant clear, darkened solution was filtered while hot to remove the Pd/C and afforded colorless crystal product on cooling. Yield: 7.8 g (91%); mp = 202–203 °C. Anal. calcd. for

C₂₂H₁₈N₂O₂ (342.40): C, 77.17%; H, 5.30%; N, 8.18%. Found: C, 77.04%; H, 5.20%; N, 8.11%.

IR (KBr): 3406, 3314, 3224 (N–H), 1250 cm⁻¹ (C–O–C). ¹H NMR (DMSO-d₆) δ (ppm): 7.70 (d, 2H, naphthalene), 7.11 (s, 2H, naphthalene), 6.81 (d, 4H, phenylene), 6.63 (d, 4H, phenylene), 4.99 (s, 4H, amino). ¹³C NMR (DMSO-d₆): δ (ppm): 155.61, 148.77, 145.44, 129.82, 128.63, 120.82, 119.92, 114.78, 110.93.

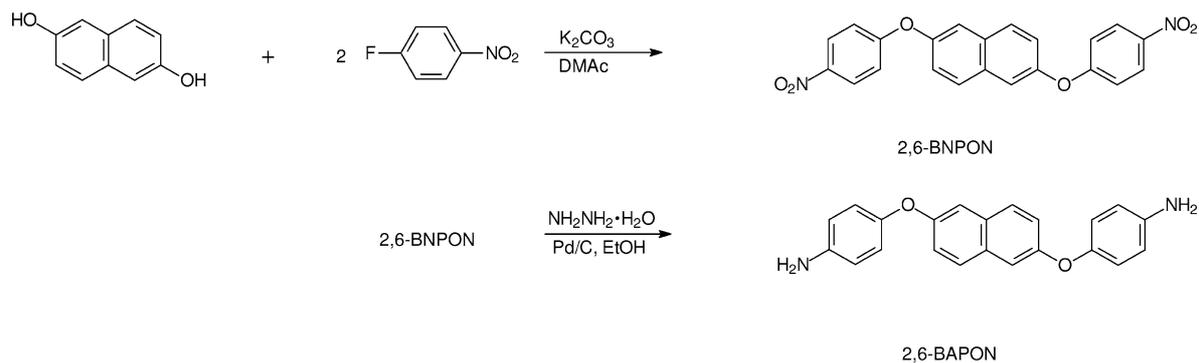
For X-ray structure analysis, single crystals of 2,6-BAPON were grown during slow crystallization of its ethanol solution. A crystal size of 0.05 × 0.25 × 0.43 mm was used for X-ray structure determination. Intensity data were collected on an Enraf-Norius FR 590 CAD-4 diffractometer at 293 K with graphite monochromatized Mo Kα radiation (λ = 0.7107 Å). This compound crystallized in a monoclinic system with space group P2₁/c [weight-average molecular weight = 342.39, *a* = 6.9247, *b* = 26.971, *c* = 4.9519 Å; α = 90, β = 110.534(12), γ = 90°, where *D*_{calc} = 1.313 g/cm³ for *Z* = 2 and *V* = 866.10(21) Å³]. The structure was solved on a VAX-3300 computer using NRCC SDP (Structure Determination Package) software. The molecular structure for 2,6-BAPON is shown in Figure 1.

Preparation of Polyimides

A typical example of polymerization is as follows. Into a solution of 0.4280 g (1.25 mmol) of 2,6-BAPON in 6.8 mL of DMAc, 0.2725 g (1.25 mmol) of PMDA was added portionwise within 30 min. After the complete addition of PMDA, the viscosity of the reaction solution increased dramatically within 20–30 min. An extra amount of DMAc must be added into the highly viscous solution before gelation occurred. The inherent viscosity of the obtained poly(amic acid) (**2a**) was 3.31 dL/g, measured at a concentration of 0.5 g/dL at 30 °C in DMAc. The poly(amic acid) solution was spread on a glass plate and baked at 80 °C overnight for the slow release of the casting solvent. The semi-dried poly(amic acid) film was further dried and transformed into polyimide by sequential heating at 120 °C, 140 °C, 160 °C, 180 °C, 220 °C, and 250 °C each for 30 min. The polyimide (**3a**) film was stripped from the glass substrate by being soaked in hot water and dried at 100 °C under vacuum. The other polyimides (**3b–3f**) were prepared by the same procedure from 2,6-BAPON and other tetracarboxylic dianhydrides (**1b–1f**).

Characterization Methods

Melting points were measured in capillaries on a Yamato mp apparatus (Model MP-21) without correction. ¹H NMR and ¹³C NMR spectra of the synthesized compounds were recorded on a Jeol EX-400 NMR spectrometer operated at 30 °C in perdeuterodimethyl sulfoxide (DMSO-d₆) with tetramethylsilane (TMS) as an internal standard. IR spectra were recorded on a Jasco FT/IR-7000 Fourier-transform infrared spectrometer. Elemental analyses were run in a Perkin-Elmer model 2400 C, H, N analyzer. The inherent viscosities of all the poly(amic acid)s were measured at 0.5 g/dL concentration with a Cannon-Fenske viscometer thermostated at 30 °C. Thermogravimetric analysis (TGA)



Scheme 1. Synthesis of diamine 2,6-BAPON.

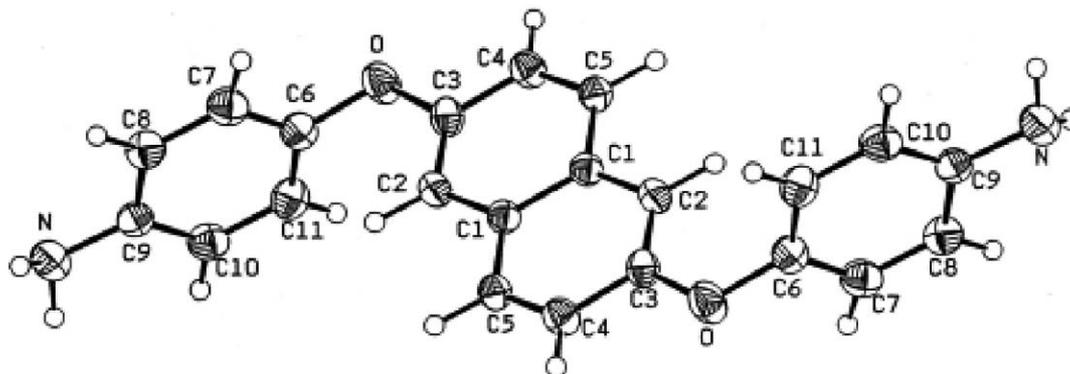


Figure 1. The ORTEP structure of diamine 2,6-BAPON.

was conducted with a Rigaku thermoflex TG 8110 coupled to a Rigaku TAS-100 thermal analysis station. Experiments were carried out on 10 ± 2 mg samples heated in flowing nitrogen or air ($50 \text{ cm}^3/\text{min}$) at a heating rate of $20 \text{ }^\circ\text{C}/\text{min}$. The differential scanning calorimetry (DSC) traces were performed on a PerkinElmer Pyris 1 DSC at a heating rate of $20 \text{ }^\circ\text{C}/\text{min}$ under a nitrogen flow ($20 \text{ cm}^3/\text{min}$). Thermomechanical analysis (TMA) was conducted with a PerkinElmer TMA 7 instrument. The TMA experiments were conducted from $40 \text{ }^\circ\text{C}$ to $350 \text{ }^\circ\text{C}$ at a scan rate of $10 \text{ }^\circ\text{C}/\text{min}$ using a penetration probe of 1.0 mm in diameter under an applied constant load of 10 mN. The wide-angle X-ray diffraction patterns were obtained on a Rigaku Geiger D-Max IIIa X-ray diffractometer, using Ni-filtered Cu-K α radiation (40 kV, 15 mA) with film specimens of about 0.1 mm in thickness. The scanning rate was $2 \text{ }^\circ/\text{min}$. An Instron universal tester model 1130 with a load cell of 5 kg was used to study the stress-strain behavior of the samples. A gauge of 2 cm and a crosshead speed of 5 mm/min were used for this study. Measurements were performed at room temperature with film specimens (0.5 cm wide, 6 cm long, and 0.1 mm thick); an average of at least three replicas was used.

Results and Discussion

Monomer Synthesis

According to the synthetic route shown in Scheme 1, 2,6-BAPON was synthesized in two steps from 2,6-dihydroxynaphthalene and *p*-fluoronitrobenzene. The first

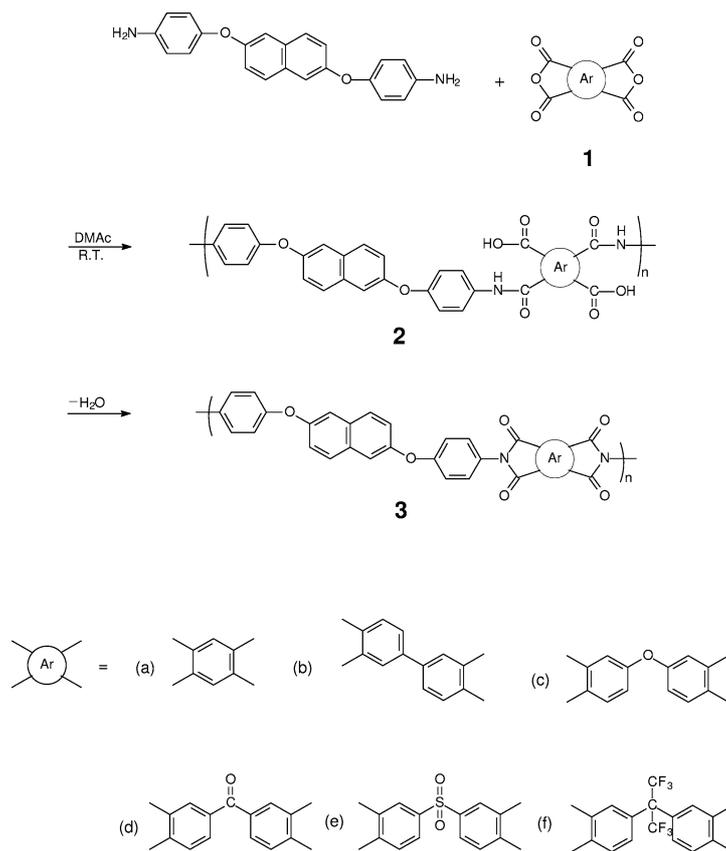
Table 1. Selected bond angles and bond distances for 2,6-BAPON^a

Atoms	Angle (deg.)	Atoms	Distance ^b (Å)
C3–O–C6	116.6 (3)	O–C3	1.389 (4)
C1–C1–C2	119.3 (3)	O–C6	1.403 (5)
C1–C1–C5	118.2 (3)	N–C9	1.405 (5)
C2–C1–C5	122.5 (3)	C1–C1	1.423 (6)
C1–C2–C3	120.3 (3)	C1–C2	1.410 (5)
O–C3–C2	125.1 (3)	C1–C5	1.411 (5)
O–C3–C4	114.4 (3)	C2–C3	1.355 (5)
C2–C3–C4	120.5 (3)	C3–C4	1.405 (5)
C3–C4–C5	120.7 (3)	C4–C5	1.348 (5)
C1–C5–C4	120.9 (3)	C5–C1	1.411 (5)
O–C6–C7	120.6 (3)	C6–C7	1.365 (6)
O–C6–C11	119.2 (3)	C6–C11	1.374 (5)
C7–C6–C11	120.1 (4)	C7–C8	1.369 (6)
C6–C7–C8	120.2 (3)	C8–C9	1.375 (5)
C7–C8–C9	121.1 (3)	C9–C10	1.372 (6)
N–C9–C8	120.6 (3)	C10–C11	1.379 (6)
N–C9–C10	121.2 (3)		
C8–C9–C10	118.0 (3)		
C9–C10–C11	121.6 (3)		
C6–C11–C10	119.0 (4)		

^aThe atom labeling used here is the same as in Figure 1.

^bEstimated standard deviations in the least significant figure are given in parentheses.

step was a Williamson etherification of 2,6-dihydroxynaphthalene with *p*-fluoronitrobenzene in the presence of anhydrous K_2CO_3 in DMAc. The bis(ether amine) 2,6-BAPON was obtained in high yields by the Pd/C-catalyzed reduction



of intermediate dinitro compound 2,6-BNPON with hydrazine in refluxing ethanol. The structures of 2,6-BNPON and 2,6-BAPON were ascertained by elemental analysis and IR, ^1H NMR and ^{13}C NMR spectroscopy, as demonstrated in the Experimental Part. X-ray crystal data for 2,6-BAPON were acquired from a colorless crystal obtained by slow evaporation of an ethanol solution of 2,6-BAPON. Refinement results in the structure are shown in Figure 1. Selected bond distances and bond angles are summarized in Table 1. The structure is coincident with that deduced from the spectroscopic data.

Polyimide Synthesis

New bis(phenoxy)naphthalene-containing aromatic polyimides **3a–3f** were prepared from 2,6-BAPON and six commercially available dianhydrides by the conventional two-step procedure as shown in Scheme 2. In the preparation of poly(amic acid)s from aromatic diamines and dianhydrides in a polar solvent, the process of monomer addition plays an important role for successful polymerization. Generally, the addition mode of adding solid PMDA to the solution of diamine produced poly(amic acid)s of higher molecular weight than the reverse addition mode or mixing the reactants together before polymerization [22]. Thus, the poly(amic acid)s **2a–2e** were prepared by adding the solid dianhydride portionwise into the diamine solution. Initially, the reaction was carried out on a reactant concentration of about 10 wt%. However, in almost all cases the viscosity of the reaction solution increased dramatically to gelation

Table 2. Inherent viscosities of poly(amic acid)s prepared from 2,6-BAPON and various aromatic tetracarboxylic dianhydrides^a

Polymer code	Dianhydride	Solid content (wt%)		η_{inh}^b (dL/g)
		Initial	Final ^c	
3a	1a ; PMDA	10	3.7	3.31
3b	1b ; BPDA	10	5.3	3.00
3c	1c ; ODPDA	10	10.0	1.67
3d	1d ; BTDA	10	6.3	1.60
3e	1e ; DSDA	10	5.0	3.20
3f	1f ; 6FDA	10	3.9	3.13

^a2,6-BAPON was first dissolved in DMAc, then the dianhydride was added in four portions of about 90, 5, 3, and 2% within 30 min.

^bInherent viscosity of poly(amic acid) measured at a concentration of 0.5 g/dL in DMAc at 30 °C.

^cSupplemental addition of DMAc to the initial poly(amic acid) solution before gelation occurs.

(a state of nonagitation) about 30 min after the complete addition of the dianhydride. To maintain a degree of agitation, some additional DMAc were supplemented prior to gelation. As shown in Table 2, the poly(amic acid)s thus obtained exhibited inherent viscosity of 1.60 dL/g at least, with four of them being higher than 3.00 dL/g. The high viscosities of the polymers confirm that the monomer synthesis was successful in producing pure materials. Films were cast from the poly(amic acid) solutions onto glass culture dishes, and imidization was achieved thermally by stepwise increase of the temperature, with a maximum imidization tempera-

Table 3. Elemental analysis of 2,6-BAPON polyimides

Polymer code	Formula (Formula weight)	Elemental analysis					
		Calcd (%)			Found (%)		
		C	H	N	C	H	N
3a	(C ₃₂ H ₁₆ N ₂ O ₆) _n (524.49) _n	73.28	3.07	5.34	72.41	3.38	5.23
3b	(C ₃₈ H ₂₀ N ₂ O ₆) _n (600.59) _n	76.01	3.36	4.66	75.47	3.46	4.67
3c	(C ₃₈ H ₂₀ N ₂ O ₇) _n (616.59) _n	74.02	3.27	4.54	72.87	3.58	4.49
3d	(C ₃₉ H ₂₀ N ₂ O ₇) _n (628.60) _n	74.52	3.21	4.46	73.01	3.44	4.60
3e	(C ₃₈ H ₂₀ N ₂ O ₈ S) _n (664.65) _n	68.67	3.03	4.21	67.05	3.26	4.29
3f	(C ₄₁ H ₂₀ N ₂ O ₆ F ₆) _n (750.61) _n	65.61	2.69	3.73	63.58	2.96	3.71

Table 4. Tensile properties of polyimide films

Polymer code	Tensile strength (MPa)	Elongation to break (%)	Initial modulus (GPa)
3a	125	22	1.9
3b	121	19	1.8
3c	105	10	1.7
3d	109	7	2.3
3e	118	16	1.7
3f	107	9	1.5

ture of 250 °C for 30 min. Completion of the imidization by this procedure was checked by dynamic thermogravimetry of a sample of the poly(amic acid). It was found that the weight loss was complete around 220 °C, according to the TGA curve. The formation of polyimide also could be confirmed by IR spectroscopy. The IR spectra of the polyimides showed characteristic imide absorption bands at around 1780 and 1720 cm⁻¹ (coupled carbonyls), and 1100 and 725 cm⁻¹ (cyclic structures). Elemental analyses of the polyimides are generally in a good agreement with the proposed structures, missing only the values found for the C-percentages that are always lower than the theoretical ones (Table 3). That certainly can be attributed to the very aromatic nature of these polymers, which commonly leave a small coal residue in the standard conditions of microanalysis.

Properties of Polyimides

The solubility of the polyimides was tested qualitatively in various solvents. The 6FDA-based polyimide **3f** was readily soluble in polar solvents such as DMF, DMAc, NMP, and DMSO. However, the other polyimides **3a–3e** were all insoluble in all the available organic solvents. The high solubility of polyimide **3f** can be explained mainly by the presence of hexafluoroisopropylidene units, which result in

Table 5. Thermal properties of polyimides based on 2,6-BAPON

Polymer	Dianhydride component	T_g^a (°C)	T_s^b (°C)	T_d (°C) ^c		Char yield ^d (%)
				In N ₂	In air	
				3a	PMDA	
3b	BPDA	273	260	555	554	54
3c	ODPA	255	246	556	553	52
3d	BTDA	269	252	556	546	54
3e	DSDA	295	278	558	552	51
3f	6FDA	280	279	563	563	57

^aMidpoint temperature of baseline shift on the second DSC heating trace (rate = 20 °C/min) of the sample after quenching from 400 °C.

^bSoftening temperature measured by TMA (penetration method) with a constant applied load of 10 mN at a heating rate of 10 °C/min. The film samples were heated at 300 °C for 1 h prior to TMA experiments.

^cDecomposition temperature at which a 10% weight loss was recorded by TGA at a heating rate of 20 °C/min.

^dResidual weight % at 800 °C in nitrogen.

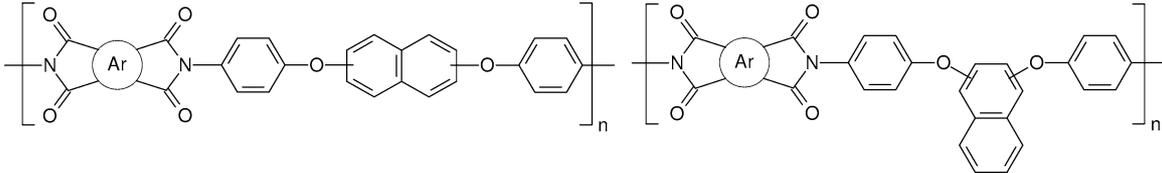
^eNo discernible transition.

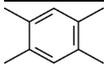
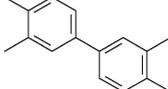
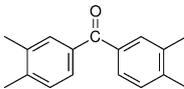
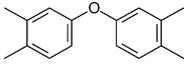
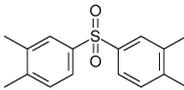
a less efficient chain packing and a decrease in chain-chain interactions.

Wide-angle X-ray diffraction diagrams examined crystallinity of the polymers. The polyimide films obtained by thermal imidization were employed as the samples. The scattering curve for the polyimide (**3d**) from BTDA showed two medium to strong reflection peaks around $2\theta = 20^\circ$ and 24° , indicating of a semicrystalline nature. The other polyimides revealed an almost completely amorphous pattern. All polyimides could be cast into flexible and strong films. These films had tensile strengths of 105–125 MPa, elongation to breaks of 7–22%, and initial modulus of 1.5–2.3 GPa (Table 4).

DSC, TMA, and TGA were used to evaluate the thermal behavior of the polymers. The thermal properties of all the polyimides are reported in Table 5. DSC measurements were conducted with a heating rate of 20 °C/min. Quenching from the elevated temperatures (ca. 400 °C) to room temperature

Table 6. Glass transition temperatures of isomeric polyimides



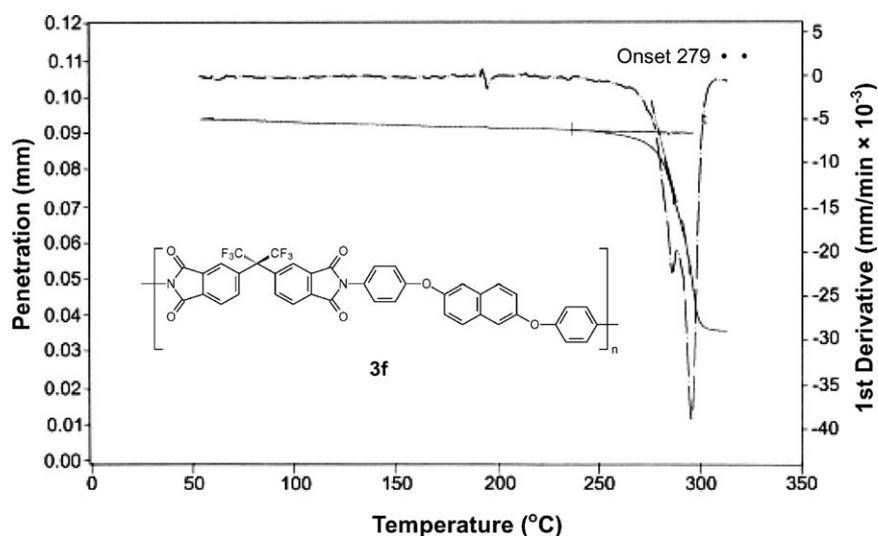
Ar	T_g^a ($^{\circ}\text{C}$) of polyimides having different naphthalene catenation positions						
	2,6	1,5	1,6	1,7	2,7	1,4	2,3
	b						315
	273		273	263	269	277	267
	269	268	268	260	263	260	269
	255	252	248	247	251	247	241
	295	295	286	274	289	281	278

^a T_g was read at the midpoint temperature of baseline shift on the second DSC heating trace (rate = $20^{\circ}\text{C}/\text{min}$) of the sample after quenching from 400°C . The comparative data of polyimides with 1,5-, 1,6-, 1,7-, 2,7-, 1,4-, and 2,3-naphthalene catenation were reported in [18–20, 17, 21], and [16], respectively.

^bNo discernible transition on the DSC trace.

gives predominantly amorphous samples so that the glass transition temperature (T_g s) of all the polyimides except for **3a** could be easily measured in the second heating traces of DSC. The T_g s of these polyimides were recorded in the range of 255 – 295°C . The PMDA-based polyimide **3a** did not show discernible T_g , possibly due to structural rigidity. The ODPA-derived polyimide **3c** exhibited the lowest T_g of 255°C . This is reasonable because its dianhydride moiety has a flexible ether linkage. The high T_g associated with polyimide **3e** derived from DSDA may be attributable to the

presence of polar sulfonyl group, which enhance intermolecular attraction between polymer molecules. The T_g data of some isomeric polyimides with different naphthalene catenation positions are compared in Table 6. There is no clear dependence on the isomeric attachment in the naphthalene unit, but it is possible to recognize some trends. For example, the T_g values are higher for the more symmetric systems. Generally speaking, the T_g values of the 2,6 polymers are similar to those of 1,5 polymers and are slightly higher than those of 1,6, 1,7, and 2,7 polymers, and those of 1,4 poly-

Figure 2. The TMA curve of polyimide **3f**.

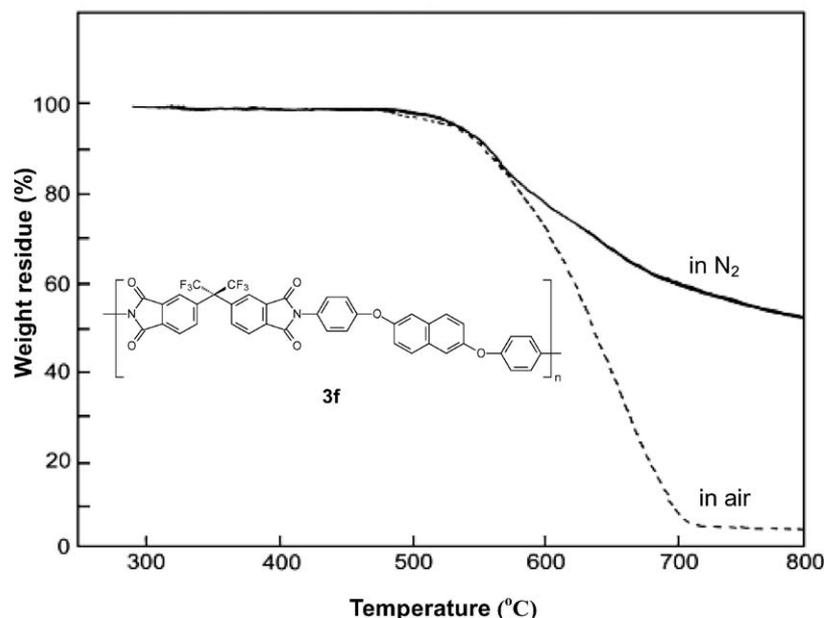


Figure 3. TGA curves for polyimide **3f** at a heating rate of 20 °C/min.

mers are slightly higher than of 2,3 polymers. The T_s s (or apparent T_g s) of the polyimide films were determined by the TMA method with a loaded penetration probe. They were read from the onset temperature of the probe displacement on the TMA thermograms. As a representative example, the TMA trace of polyimide **3f** is illustrated in Figure 2. The T_s values of these polyimide films stayed within 246–286 °C, and the trend of T_s variation with the chain rigidity was similar to that of T_g observed in the DSC measurements. The thermal stability of the polyimides was evaluated by TGA measurements in both air and nitrogen atmospheres. Typical TGA thermograms for polyimide **3f** are reproduced in Figure 3. As shown in Table 5, the decomposition temperatures (T_d s) at which a 10% weight loss was observed are in the range of 543–563 °C in nitrogen and 535–563 °C in air. They left more than a 50% char yield at 800 °C in nitrogen. The TGA data indicated that these polyimides had fairly high thermal stability comparable with that of conventional aromatic polyimides. There is a large window between T_g or T_s and the decomposition temperature of each polymer, which could be advantageous in the processing of these polymers by the thermoforming technique.

Conclusion

A series of high-molecular-weight polyimides based on 2,6-bis(4-aminophenoxy)naphthalene and various aromatic tetracarboxylic dianhydrides have been prepared as flexible and tough films. Almost all the polyimides showed an amorphous nature. The incorporation of 2,6-bis(phenoxy)naphthalene units into the polyimide backbone seems do not lead to a significant increase in solubility. However, these polyimides exhibited a good combination of properties that included high strength, excellent thermal stability, and large window between decomposition temperature and T_g .

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