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Synthesis of new diacid monomers and poly(amide-imide)s: study of structure–property relationship and applications

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Abstract Two diimide-diacid monomers 4,4'-bis[4"-(trimellitimido)phenyl isopropylidene-4"'-phenoxy]diphenyl sulfone and 4,4'-bis[4"-(trimellitimido)phenylisopropylidene-4"'-phenoxy] were synthesized. The structures of the monomers were characterized by FT-IR and ¹H-NMR spectroscopy. A series of novel poly(amide-imide)s were prepared from this two diacids and aromatic diamines through phosphorylation reaction. The PAIs were characterized by FT-IR, ¹H-NMR, XRD, TGA, and DSC, solution viscosity, solubility test and electrical properties. Poly(amide-imide)s showed excellent solubility due to the presence of flexible groups and isopropylidene unit in the polymer backbone. They also exhibited good thermal stability and the temperatures at which 10% weight loss occurred in the range 385-465 °C. These PAIs found to have a dielectric constant in the range 3.25-4.20 at 10 kHz and have excellent electrical insulation character and can be used as insulation materials for electrical items operating at elevated temperatures.

Keywords Poly(amide-imide)s · Structure–property relationship · Diacids monomer · Phosphorylation reaction

Introduction

Aromatic polyimides [1–6] are one of the most useful classes of high performance polymers. These materials are

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widely used in electrical, electronics, automotive and aerospace industries [7, 8]. Polyimides are used in the form of films, fibres, foams, plastics, adhesives and coatings [9, 10]. The fabrication process for a polymeric material requires that the polymers be either soluble in organic solvents for a casting process or molten below their decomposition temperature for a moulding extrusion process. However, aromatic polyimides are insoluble and infusible and very difficult to fabricate into desired articles. Many significant synthetic efforts have been made to improve the processability without decreasing thermal stability. In order to increase the processability the main approach used for structural modifications include: (a) Incorporation of flexible linkages, to maintain good solubility and thermal stability, it is common to use flexible and thermally stable groups such as $-O_{-}$, $-SO_{2^{-}}$, $-CO_{-}$, $-S_{-}$ and $-C(CF_{3})_{2^{-}}$. (b) Incorporation of kinks in the polyimides chain, the solubility of the polyimides can be increased by the incorporation of a kink in the polyimides backbone through ortho or meta catenation. (c) Incorporation of pendant groups, the polar pendant groups increases the affinity between the polymer and the solvent and hence the solubility increases. The non-polar pendant group in the polyimides backbone decrease the inter chain interaction, leading to amorphous morphology which in turn increase solubility. Another efficient method is synthesizing polyimides as poly(amide-imide)s. The presence of amide group in this poly(amide-imide)s increases the solubility, while the aromatic imide units provide thermal resistance and mechanical properties. Poly(amideimide)s combines the thermal stability property of polyimides and ease of processability of polyamides and be intermediate in properties between polyimides and polyamides [11, 12].

The properties of the polymers depend to a large extent on the monomer's structure and hence the choice of monomers is of prime importance in the design of novel polymers. The present paper describes the synthesis of two novel diimide-diacids monomers containing flexible groups (-O-, -SO₂-, and -C=O) and -C(CH₃)₂- unit. Poly(amide-imide)s were prepared from these new diacids monomers and commercially available diamines containing flexible groups (-O-, -SO₂-, and -CH₂-) via phosphorylation reaction. The phosphorylation methods have several advantages than the conventional methods. The conventional methods involve preparation of preactivated acid derivatives such as acid chlorides and removal of unreacted chlorinating agent etc. Another advantage of this method is the separation of rigid imide groups due to enlargement of repeat unit. In the repeating unit of PAIs the rigid imide groups are separated by flexible groups and isopropylidene unit. These groups give flexibility and disturb the chain packing, while the aromatic imide units provide rigidity to the polymer and this two opposed effects on the properties of the PAIs are investigated.

Experimental

Materials

The commercial 4,4'-dichlorodiphenylsulfone, 4,4'-difluorobenzophenone, trimellitic anhydride, 4,4'-oxydianiline (ODA), 4,4'-methylenedianiline (MDA), 4,4'-diamino diphenyl sulfone (DDS), triphenyl phosphite (TPP) and lithium chloride were purchased from Sigma Aldrich Chemicals Company. The compound (4-aminophenyl)-2,2-(4'-hydroxyphenyl)propane, 4,4'-bis[(4"-aminophenylisopropylidene-4"'-phenoxy)] diphenyl sulfone and 4,4'-bis[(4"-aminophenylisopropylidene-4"'-phenoxy)]benzophenone were synthesized in the laboratory and recrystalised before use. Pyridine and N-Methyl-2-pyrrolidone (NMP) were dried with molecular sieves before use.

Measurements

IR spectra were obtained on Perkin Elmer spectrum one and ¹H-NMR spectra were recorded on a Bruker 300 MHz instrument. X-ray diffractograms were obtained on PANalytical-model: X'per PRO using CuKá radiation. Thermogravimetric (TG) and differential scanning calorimetric (DSC) analysis were preformed on TA Instruments model SDT Q600 at a heating rate 10 °C/min under nitrogen atmosphere. Dielectric constant and dissipation factor measurements were carried out with HIOKI LCR HiTester 3532-50 at a frequency of 10 KHz. The solubility of PAIs was determined at a 5% concentration in various

solvents at room temperature or on heating. Inherent viscosities were determined at a concentration of 0.5 g/dL in dimethyl sulfoxide (DMSO).

Synthesis of diacid monomers

The starting materials 4,4'-bis [(4"-aminophenylisopropylidene-4"'-phenoxy)]diphenyl sulfone and 4,4'-bis[(4"-aminophenylisopropylidene-4"'-phenoxy)]benzophenone were prepared in the laboratory starting from 4,4'-dichlorodiphenylsulfone and 4,4'-difluorobenzophenone respectively by the nucleophilic substitution reaction of 2-(4-aminophenyl)-2-(4'-hydroxyphenyl) propane as per the procedure reported in our previous publication [13].

The monomer IIIa was prepared as per the following procedure [14-18]. To a stirred solution of 4,4'-bis[(4"aminophenylisopropylidene-4"'-phenoxy)]diphenyl sulfone (8.0 g, 0.012 mol) in NMP (30 mL), trimellitic anhydride (4.592 g, 0.024 mol) was added under nitrogen atmosphere and was stirred at room temperature for 6 h. To this, toluene (20 mL) was added, the reaction mixture was heated at 120 °C in nitrogen atmosphere for 6 h, while removing water azeotropically using Dean-Stark trap. After complete removal of water, the temperature was raised to 160 °C and the remaining toluene was removed. The reaction mixture was allowed to cool and then poured into water, the precipitated diacid monomer 4.4'-bis[4"-(trimellitimido)phenylisopropylidene-4"'-phenoxy]diphenyl sulfone was filtered, washed with water, and dried. The diacid monomer 4,4'-bis[4"-(trimellitimido)phenylisopropylidene-4"'-phenoxy] benzophenone IIIb was also prepared by using the similar procedure as adopted for IIIa using 4,4'-bis[(4"amino phenylisopropylidene-4"'-phenoxy)]benzophenone and trimellitic anhydride. The two diacids monomers were characterized by melting point, FT-IR and ¹H-NMR.

Synthesis of poly(amide-imide)s

Poly(amide-imide)s (PAI-1 to PAI-6) were prepared from diacids and diamine in a single step through phosphorylation reaction [19–24]. A typical procedure adopted was as follows, a mixture of 4,4'-diaminodiphenyl methane (0.488 g, 2.46×10^{-3} mol), diacid IIIa (2.5 g, 2.46×10^{-3} mol), triphenylphosphite (1.3 mL, 4.52×10^{-3} mol), LiCl (0.25 g), dry pyridine (5 mL) and dry NMP (15 mL) was heated at 100 °C in nitrogen atmosphere for 6 h. The mixture was allowed to cool and then poured into methanol and the precipitated poly(amide-imide) PAI-1 was collected by filtration and dried. The poly(amide-imide)s PAI-2 to PAI-6 were also prepared by the same procedure as adopted for PAI-1 using the corresponding diacids and diamine.

Result and discussion

Synthesis of diacid monomers

The starting materials isopropylidene unit containing diamine 4, 4'-bis [(4"-amino phenylisopropylidene-4"'-phenoxy)]diphenyl sulfone and 4,4'-bis[(4"-amino phenyl isopropylidene-4"'-phenoxy)]benzophenone were prepared in the laboratory from 4,4'-dichlorodiphenylsulfone and 4,4'-difluorobenzophenone respectively by the nucleophilic substitution reaction of 2-(4-aminophenyl)-2-(4'-hydroxyphenyl) propane. The two diacid monomers (IIIa & IIIb) were prepared by the condensation of trimellitic dianhydrides with the corresponding diamine under nitrogen atmosphere using NMP as solvent (Scheme 1).

Structural characterization of diacid monomers

The IR spectra of the monomers showed characteristic absorption band for the imide ring at about 1720–1721 cm⁻¹ (–C=O symmetrical stretching), 1779–1772 cm⁻¹ (–C=O asymmetrical stretching), 720–726 cm⁻¹ (–C=O bending). The absorption bands at 2965–2967 cm⁻¹ are characteristic for methyl groups. The aromatic carboxylic group showed absorption band in the range 3435–3446 cm⁻¹. The IR spectral data confirmed the formation of imide ring between the trimellitic anhydride and the diamine containing isopropylidene unit (Table 1).

Scheme 1 Synthesis of diacid monomers

The ¹H-NMR spectrum of monomer IIIa is given in Fig. 1.The aromatic proton ortho and meta to the carboxylic group and flanked between by imide carbonyl and carboxylic group appeared as a doublet at 8.42–8.40 δ ppm and 8.08–8.06 δ ppm respectively. The aromatic proton flanked by imide carbonyl and carboxylic group appeared as a singlet at 8.30 δ ppm. The aromatic proton *ortho* to the sulphonyl group appeared as a doublet at 7.92–7.90 δ ppm. The aromatic proton meta to the ether group designated in Fig. 1 as "d" merged with aromatic protons ortho and meta to the imide nitrogen and flanked between imide nitrogen and isopropylidene groups and appeared as a broad peak at 7.12–7.06 δ ppm. The aromatic protons *ortho* to the ether group designated in Fig. 1 as "b" and "c" appeared as a doublet at 7.40–7.28 δ ppm. The aliphatic proton appeared in the high field region as a singlet at 1.60 δ ppm. The protons designated in Fig. 1 as "h", "i" and "j" appeared in the farthest downfield in the range 8.42–8.06 δ ppm due to the influence of the electron withdrawing carboxylic group and imide groups.

The ¹H-NMR spectrum of monomer IIIb is given in Fig. 2. The aromatic proton *ortho* and *meta* to the carboxylic group and flanked between by imide carbonyl and carboxylic group appeared as a doublet at 8.16–8.14 δ ppm and 7.81–7.79 δ ppm respectively. The aromatic proton flanked by imide carbonyl and carboxylic group appeared as a singlet at 8.04 δ ppm. The aromatic proton *ortho* to the



Table 1 Characteristics and spectral data of diacid monomers	Monomer	yield %	melting point °C	IR (KBr) cm ⁻¹	¹ H-NMR chemical shifts (δ) in DMSO-d ₆
	IIIa	93	155–157	3445 (-СООН)	8.42–8.40(d,2H,Ar)
				1780, 1720,725 (imide ring)	8.30(s,2H,Ar)
				1150 (sulfone)	8.08-8.06(d, 2H,Ar)
					7.92–7.90(d,4H,Ar)
					7.40-7.28(b,12H,Ar)
					7.12–7.06(b,8H,Ar)
					1.60(s,12H,Ali)
	IIIb	90	150-153	3435 (-СООН),	8.16-8.14(d,2H,Ar)
				1770,1720,720 (imide ring)	8.04(s,2H,Ar)
				1650 (keto)	7.81–7.79(d, 2H,Ar)
					7.53-7.50(d,4H,Ar)
					7.15-7.05(b,12H,Ar)
					6.85-6.81(b,8H,Ar)
Ar aromatic, s singlet, d doublet					1.52(s,12H,Ali)

Table 1 Characteristics an spectral data of diacid mon

carbonyl group appeared as a doublet at 7.53–7.50 δ ppm. The aromatic proton meta to the ether group designated in Fig. 2 as "d" merged with aromatic protons ortho and meta to the imide nitrogen and flanked between imide nitrogen and isopropylidene groups and appeared as a broad peak at 7.15–7.05 δ ppm. The aromatic protons *ortho* to the ether group designated in Fig. 2 as "b" and "c" appeared as a broad peak at 6.85-6.81 & ppm. The aliphatic proton appeared in the high field region as a singlet at 1.52δ ppm. The protons designated in Fig. 2 as "h", "i" and "j" appeared in the farthest downfield in the range 8.16–7.79 δ ppm due to the influence of the electron withdrawing carboxylic group and imide groups. The characterization by ¹H-NMR and FT-IR confirmed that all the monomer have the expected chemical structures.

Synthesis and structural characterization of poly(amide-imide)s

The poly(amide-imide)s (PAI-1 to PAI-6) were prepared by direct polycondensation of diimide-diacids with aromatic diamines through phosphorylation reaction at 100 °C (Scheme 2). The various characteristics of the polymerized products are given in Table 2. The inherent viscosities which is a measure of molecular weight of the polymer was measured by using DMSO as solvent at 30 °C were in the range of



4,4'-bis[4"-(trimellitimido) phenyl isopropylidene-4"'-phenoxy] benzophenone



VI =

SO₂

(DDS)

Table 2 Characteristics of poly(amide-imide)s

PAIs	Diacid	Diamine	Yield%	$\eta_{inh}{}^a \; dL/g$	IR(KBr), cm^{-1}
PAI-1	IIIa	IV (MDA)	88	0.69	1775,1720,735
					3365,1655,1505
PAI-2	IIIa	V (ODA)	90	0.65	1775,1710,745
					3390,1650,1505
PAI-3	IIIa	VI (DDS)	85	0.57	1775,1715,740
					3365,1655,1500
PAI-4	IIIb	IV (MDA)	80	0.63	1780,1720,730
					3390,1660,1505
PAI-5	IIIb	V (ODA)	82	0.45	1780,1720,720
					3390,1650,1510
PAI-6	IIIb	VI (DDS)	84	0.44	1780,1725,720
					3330,1650,1510

^a Measured with 0.5 g/dL at 30 °C, in DMSO

0.44-0.69 dL/g, indicating formation of polymers of moderate molecular weight.

The IR spectra of PAIs showed characteristic amide absorption at about 3330–3390 cm⁻¹(N-H), 1650–1660 cm⁻¹ (-C=O band I) and 1500-1510 cm⁻¹(band II). In addition the PAIs showed characteristic imide ring absorption at about 1775–1780 cm⁻¹ (imides –C=O asymmetrical stretching), 1715-1725 cm⁻¹ (imides -C=O symmetrical stretching) and 720-745 cm⁻¹ (-C=O bending). The IR spectral data of PAIs (Table 2) indicate the formation of amide groups between diacids and diamines monomer. The ¹H-NMR spectrum of PAI-2 showed absorption at 8.30-8.35 (b,4H,Ar) δ ppm, 7.91-7.84δ (d,4H,Ar) δ ppm, 7.58-7.60 (b,2H,Ar) δ ppm, 7.40-25(b,16H,Ar) δppm, 7.15–6.96 (b,12H,Ar) δ ppm and 1.69–1.56 (b,12H,Ar) δ ppm. The shifting of the farthest downfield signal that was present in the monomer IIIa in the range 8.42-8.06 δ ppm (due to electron with withdrawing –COOH and imide ring) and appearance of signals at 8.30–8.35 δ ppm (due to less electron withdrawing -CONH- and imide ring) confirmed the conversion of carboxylic acid into amide group. The observed ¹H-NMR spectra were fully consistent with the chemical structure of the poly (amide-imide)s.

Solubility characteristics of poly(amide-imide)s

The solubility characteristics of the PAIs are shown in Table 3. A 5% (w/v) concentration has taken as criteria for solubility. All these PAIs were soluble in polar aprotic solvents either at room temperature or on heating. Most of the PAIs were soluble in less polar solvents like THF, pyridine and *m*-cresol. The diacid monomer IIIa based PAIs (PAI-1 to PAI-3) showed higher solubility when compared to the corresponding PAIs (PAI-1 to PAI-3) derived from diacid monomer IIIb. Similarly the PAIs derived from the diamine MDA showed higher solubility when compared to the corresponding PAIs derived from ODA and DDS. Thus the solubility was governed by the structure of diacid and diamine monomers. In general, the PAIs displayed a higher solubility. The improved solubility of the PAIs may be explained by the fact that the incorporation of flexible linkages (-O-, -SO₂-, -C=O and -CH₂-) and isopropylidene unit $(-C(CH_3)_2)$ into the PAIs backbone disturb the hydrogen bonding between the amide groups, which leads to increase in free volume. Thus, solvent molecules can more easily penetrate into the PAIs chains and increases in solubility.

Thermal characteristics of poly(amide-imide)s

The thermal stability of the PAIs was evaluated by TG in nitrogen atmosphere at a heating rate of 10 °C/min. The thermal analysis data is summarized in Table 4. The TG curves are given in Fig. 3. The TG curve indicated that these PAIs undergo rapid degradation around 450-600 °C. The onset of thermal degradation occurred in the temperature range 450–500 °C. The char yield at 800 °C was in the range 19–30%. The low char yields of these polymers may be due to the presence of heat sensitive isopropylidene linkages in the chain. A 10% weight loss occurred in the temperature range 385-465 °C. PAIs derived from diacid monomer IIIb showed higher thermal stability when compared to the corresponding PAIs derived from the diacid monomer IIIa. TG analysis indicated that these PAIs were thermally stable.

The behavior of the PAIs towards the heat was evaluated by DSC in nitrogen atmosphere at a heating rate of 10 °C/min (Fig. 4). The DSC thermogram of these PAIs showed a broad exothermic peak due to the degradation of the polymers in the

Table 3Solubility ofpoly(amide-imide)s	PAIs	NMP DMSO	DMF DMAc	Pyridine	THF	<i>m</i> -cresol	CHCl ₃ CH ₃ OH acetone
	PAI-1	+	+	+	+	+	_
	PAI-2	+	+	+	+ -	+	_
	PAI-3	+	+ -	+ -	+	+	_
	PAI-4	+	+ -	+ -	+ -	+	_
a^{+} = Soluble at room	PAI-5	+ -	_	+	+ -	-	_
temperature, $+-$ = Soluble on	PAI-6	+	+ -	+ -	+	+ -	_

heating, - = Insoluble

Table 4 Thermal properties of poly(amide-imide)s

PAIs	$T_{10}^{\ a}$	T ₂₀	T ₃₀	Char yield% ^b	LOI ^c	Tg	T _{exo} ^d
PAI-1	385	480	520	22	26	174	630
PAI-2	420	495	520	25	28	_	650
PAI-3	425	495	525	24	27	180	620
PAI-4	420	490	530	19	25	175	580
PAI-5	450	490	530	30	30	_	600
PAI-6	465	510	540	22	26	185	580

^a Temperature at 10%, 20% or 30% weight loss in N₂ atmosphere

^b Percentage char yield at 800 °C

^c Limited oxygen index

^d Temperature at which maximum exothermic peak observed

temperature range 580–650 °C. The glass transition temperature was observed in the temperature range 174–185 °C. The low Tg value was due to presence of flexible linkages and isopropylidene unit in the chain leading to amorphous character and was supported by X-ray diffraction study and enhanced solubility. The negligible difference in Tg might be explained by the fact that PAIs have almost the same conformations

Limited oxygen index-self extinguishing polymer

The limiting oxygen index (LOI) is a measure of the percentage of oxygen to be present to support combustion of the material. The LOI value can be used to evaluate the flame-retardancy of polymers [25–27]. The percentage of oxygen in the air is around 21%, it is clear that all materials with an LOI lower than this level will burn easily, while those with a higher LOI will tend not to burn. Theoretically, char yield can also be used as criteria for evaluating limiting oxygen index of polymers. According to Van Krevelan– Hoflyzers equation LOI=17.5+0.4 CR where CR is the char



Fig. 3 TG curves of poly(amide-imide)s PAI-1, PAI-3, PAI-5 & PAI-6



Fig. 4 DSC curves of poly(amide-imide)s PAI-1 & PAI-3

yield. The LOI values of PAIs had in the range 25–30 (Table 4). On the basis of the LOI values, such PAIs can be used as self-extinguishing polymers.

X-ray diffraction studies of poly(amide-imide)s

The crystallinity of the PAIs was examined by X-ray diffraction. X-ray diffraction patterns are given in Fig. 5. The results of X-ray analysis and the groups present in the repeat unit are given in the Table 5. In general the diffraction patterns were broad which indicated that most of these PAIs were amorphous. The amorphous character is due to the presence of flexible -O-, -SO2-, -CH2- and -C(CH3)2groups in the chain, which prevents the chain-chain interaction leading to amorphous morphology. Diacid monomer IIIb based PAIs are partially crystalline compared to IIIa based PAIs. The PAI-3, PAI-4, PAI-5 and PAI-6 are partially crystalline and showed reflections at $2\theta = 12(d=7.37A^{\circ})$, 28 $(d=3.18A^{\circ})$ and $30(d=2.98 A^{\circ})$ which is also reflected in their poor solubility compared to amorphous PAIs. The crystallinity associated with PAI-3, PAI-4, PAI-5 and PAI-6 is due to the rigid imide group and inter chain interaction leading to ordering of polymer chain. The diffraction pattern indicated that the order of crystallinities is PAI-6>PAI-4> PAI-5>PAI-3>PAI-1>PAI-2, suggesting that the polymer PAI-2 which contain three -O-, -SO₂- and two -C(CH₃)₂unit in the repeat unit was the most amorphous character polymer among them. The solubility behavior was consistent with the results of X-ray diffraction studies. The polymer PAI-2 derived from the diacid monomer IIIa and diamine ODA showed high amorphous character than the other corresponding PAIs, thus the amorphous character of the PAI depends on structure of diacid and diamine monomers.

Electrical properties of poly(amide-imide)s

Polyimides are used as high temperature electrical insulation materials. Newer polymeric materials are being investigated





to meet demand of various types. The dielectric constant of the polyimides depends upon the monomers involved and the structural arrangement. More flexible meta-linked system gives lower dielectric constant values than the corresponding para-linked system. This may be related to free volume in the polymer, the meta-substituted systems have a higher degree of entropy. The 6F based polyimides have the lowest overall dielectric constant values. The incorporation of fluorinated substituents into polymers reduces the dielectric constant because of the mutual repulsion of the outermost shell electrons of fluorine atoms and large free volume of trifluoromethyl groups resulting in low intermolecular cohesive energy and low chain packing efficiency. The PAIs were studied for

Table 5 X-ray analysis and inter-planar spacing

PAIs	2θ (in degree)	Inter planar spacing A°	Groups present in the repeat unit
PAI-1	N/O	N/O	Two –O–,–SO ₂ –, –CH ₂ – and two –C(CH ₃) ₂ unit
PAI-2	N/O	N/O	Three –O–, –SO ₂ – and two –C(CH ₃) ₂ unit
PAI-3	12.0 28.0	7.37 3.18	Two –O–, two –SO ₂ – and two –C(CH ₃) ₂ unit
DAL 4	30.0	2.98	
PAI-4	28.0	3.18	two $-C(CH_3)_2$ unit
	30.0	2.98	
PAI-5	12.0 28.0	7.37 3.18	Three $-O-$, $-C=O$ and two $-C(CH_3)_2$ unit
	30.0	2.98	
PAI-6	12.0 28.0 30.0	7.37 3.18 2.98	Two –O–, –C=O, –SO ₂ – and two –C(CH ₃) ₂ unit

N/O = crystalline peak not observed

possible application as high temperature electrical insulations. The dielectric constant is an important parameter for selecting electrical insulation material [28]. The dielectric constant and dissipation factor of the PAIs are presented in the Table 6. The dielectric constants of the PAIs are in the range 3.25-4.20 indicating that the polymer have insulation characteristics and can be used as insulation materials. The dielectric constant values are comparable with the well-known commercial polyimide Kapton-Du Pont Co., (ϵ =3.40) produced from the condensation of pyromellitic dianhydride and 4,4'-oxydiphenylamine and UPILEX-ICI America. (ε =3.30–3.50) produced from biphenyltetracarboxylic dianhydride and diamine. The electrical properties indicated that PAIs have electrical insulation character. PAIs can be used as insulation materials for electrical items such as cables, generators, electric motors, and other units operating at elevated temperature.

Conclusion

We have successfully synthesized new diimide-diacids monomers with high yield and a series of aromatic poly(amide-imide)s. Poly(amide-imide)s exhibit good thermal stability and solubility. The poly(amide-imide)s have

Table 6Electricalproperties ofpoly(amide-imide)s	PAIs	Dissipation factor (tan δ)	Dielectric constant (ϵ)	
	PAI-1	0.28	4.20	
	PAI-2	0.27	3.70	
	PAI-3	0.29	3.50	
	PAI-4	0.27	3.25	
	PAI-5	0.25	3.80	
	PAI-6	0.24	4.00	

insulation characteristics and can be used as insulation materials for electrical items operating at elevated temperatures. These properties could make the aromatic poly(amide-imide) s as promising processable high performance polymers.

References

- Shu JZ, Yan FL, Xiao LW, Xin Z, Yu S, Tao M (2007) Synthesis and characterization of soluble polyimides derived from the polycondensation of 2,6-bis (4-amino-2-trifluoromethylphenoxy-4'benzoyl) pyridine with some aromatic dianhydrides. High Perform Polymer 19:462–476
- Hossein B, Parvaneh B (2010) Heat stable and organosoluble polyimides containing laterally-attached phenoxy phenylene groups. J Polym Res 17:511–518
- Xingzhong F, Zhenghus Y, Suobo Z, Lianxum G, Mengxian D (2002) Polyimides derived from mellophanic dianhydride. Macromolecules 35:8708–8717
- Ju YL, Jin HK, Bum KR (2007) Novel Y-Type polyimide with highly enhanced thermal stability of second harmonic generation. Macromol Res 15:234–237
- Gholam AK, Najmeh M (2011) Synthesis and characterization of some new thermally stable polyimides and copolyimides bearing bipyridine side-chain groups. J Polym Res 18:983–991
- Revathi P, Bilal M, Muthiahpillai P (2011) Effect of chemical structure of aromatic dianhydrides on the thermal, mechanical and electrical properties of their terpolyimides with 4,4'-oxydianiline. J Polym Res 18:1597–1604
- Denton DD, Ray DR, Priore DF, Senturia SD, Anolick ES, Scheider D (1985) Moisture diffusion in polyimides films in integrated circuit. J Electron Mater 14:119–136
- 8. Wilson D, Stenzenberger HD, Hergenrother PM (1990) Polyimide. Chapmen and Hall, New York
- Suleyman K, Aziz P, Ergun E, Bulent A, Turgay S (2008) Synthesis, characterization of phosphine oxide-containing polyimides and their use as selective membrane for dopamine. J Polym Res 15:249–257
- Jeong HK, Soo BL, Sang YK (2000) Incorporation effects of fluorinated side groups into polyimide membranes on their physical and gas permeation properties. J Appl Polym Sci 77:2756– 2767
- Sonia Z, Zahoor A (2007) Soluble aromatic polyamide bearing ether linkages: synthesis and characterization. Colloid Polym Sci 285:1749–1754
- Moslem ML, Masoud M (2009) Synthesis of polyamides from pxylylene glycol and dinitriles. J Polym Res 16:681–686
- Thiruvasagam P, Venkatesan D (2010) Synthesis and characterization of processable aromatic polyimides. High Perform Polymer 22:682–693

- Shahram MA, Shahriar K (2003) Use of diimide-dinaphthols in preparation of novel thermally stable poly(ester-imide)s. J Appl Polym Sci 89:2567–2572
- Shahram MA, Shahriar K (2003) Synthesis and characterization of novel diimide-dinaphthols and resulting poly(urethane-imide)s. Polym Int 52:1487–1492
- Thiruvasagam P, Venkatesan D (2009) Synthesis and characterization of polyetherimides derived from AB monomers. J Macromol Sci A Pure Appl Chem 46:419–424
- 17. Thiruvasagam P, Venkatesan D (2011) Synthesis and characterization of polyetherimides via nitrodisplacement reaction. High Perform Polymer 23:22–31
- Thiruvasagam P, Shiva C, Sundararaman C, Venkatesan D (2011) Synthesis and characterization of new diimide diols and processable polyesterimides derived therefrom. Polym Polym Compos 19:763–771
- Seyed M, Amini N, Mousa G (2011) Synthesis and characterization of new polyamides and polyimides containing dioxypyrimidine moiety in the main chain with bulky imidazole pendent group: solubility, thermal and photophysical properties. J Polym Res 18:1575–1586
- Zongli X, Buu D, Jonathan H, Manh H, Anita H, Stephen G (2011) Synthesis and characterization of hybrid organic–inorganic materials based on sulphonated polyamideimide and silica. J Polym Res 18:965–973
- Wenjeng G, Wen TL, Sheng HH (2007) Synthesis and properties of ortho linked aromatic poly(ester-amides)and poly(ester-imides) bearing 2,3–bis(benzoyloxy) naphthalene units. J Polym Res 14:1693–1703
- Jyh CC, Kuppachari R, Sheng WH, Hui WC (2011) Synthesis and characterization of aromatic polyamides derived from various derivatives of 4,4'-oxydianiline. J Polym Res 18:1693–1703
- 23. Sheng HH, Wenjeng G, Yi CK, Yi JL (2011) Redox-active and electrochromic aromatic poly(amide-imide)s with 2,4-dimethoxy-triphenyl amine chromophores. J Polym Res 18:1353–1364
- Shadpour M, Hojjat S (2009) Ionic liquid catalyzed synthesis of organosoluble wholly aromatic optically active polyamides. Polym Bull 62:605–614
- Tiwari A, Gupta MK, Nema SK (2004) Effect of oxygen plasma asher on poly(methylphenylsiloxane)-polyimide blends. J Mater Sci 39:1695–1701
- Khalil F, Meisam S, Mohsen H, Yasser M (2011) Synthesis and characterization of new poly(ether–ester–imide)s as a generation of soluble and thermally stable polymers. Polym Bull 66:37–49
- 27. Khalil F, Mohsen H, Meisam S (2010) New photosensitive and optically active organo-soluble poly(amide–imide)s from N, N'-(bicyclo[2,2,2]oct-7-enetetra carboxylic)-bis-L-amino acids and 1,5-bis(4-aminophenyl)penta-1,4-dien-3-one: synthesis and characterization. J Polym Res 17:379–390
- Tomoko M, Takafumi F, Toshiyuki O, Tako I, Masao T (2003) Photosensitive fluorinated polyimides with a low dielectric constant based on reaction development patterning. J Polymer Sci, Part A: Polymer Chem 41:861–871