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Preparation of Nonlinear Optical Poly(Alkyl Vinyl Ethers). 4.¹ Synthesis and Characterization of Poly[3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-4-nitrostilbene] and Poly[3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene]

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3',5'-Dimethoxy-4'-(2-vinyloxyethoxy)-4-nitrostilbene **2** and 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene **5** were prepared by the reactions of 2-iodoethyl vinyl ether with 3',5'-dimethoxy-4'-hydroxy-4-nitrostilbene **1** and 3',5'-dimethoxy-4'-hydroxy-2,4-dinitrostilbene **4**, respectively. Monomers **2** and **5** were polymerized with cationic initiators to obtain polymers with 3',5'-dimethoxy-4'-oxy-4-nitrostilbene and 3',5'-dimethoxy-4'-oxy-2,4-dinitrostilbene, which are presumably effective chromophores for second-order nonlinear optical application in the side chain. The resulting polymers **3** and **6** were soluble in DMSO and DMF. The inherent viscosities of the polymers were in the range of 0.28-0.33 dL/g in DMSO. Polymers **3** and **6** showed a thermal stability up to 250 °C in TGA thermogram, and the T_g values obtained from DSC thermograms were in the range of 81-87°.

Introduction

Functional polymers of nonlinear optical (NLO) activity have long been the subject of curiosity and have caused recent interest.²⁻⁶ It is well known that organic and polymeric materials with highly dipolar electronic systems exhibit NLO properties. Compared to other organic and inorganic substances, NLO polymers offer many advantages such as high nonlinear optical activity, light weight, chemical resistance, and good processability.

A potential NLO polymer must contain a highly polarizable π -electronic systems and these polymers have to be mechanically very strong. There are tremendous challenges in designing and synthesis of polymers of large NLO effects. Various polymers with the NLO-phores in the side chain such as polymethacrylates⁷⁻¹³ and polystyrene¹⁴ were reported. Polyesters,¹⁵⁻¹⁹ polyurethanes,²⁰ polyamides,²¹⁻²² and poly(phenyleneethynyls)²³ containing the chromophoric main chain were also prepared. Dix etc.²⁴ prepared poly(ethyl vinyl ether) partly grafted with azo dyes by the reaction of poly(2-chloroethyl vinyl ether) with 4'-amino-4-nitroazobenzene. However, examples of polyalkyl vinyl ethers with the chromophoric side chain prepared directly by the polymerization of monomeric alkyl vinyl ethers are seldom found in the literature. Recently we have prepared clean poly(ethyl vinyl ethers) containing the NLO-phores *p*-oxybenzylidenemalononitrile, methyl *p*-oxybenzylidenecyanoacetate,²⁵ and 4'-oxy-4-

nitrostilbene²⁶ in the side chain by cationic polymerization of the corresponding monomers.

This work is now extended with the synthesis and characterization of another poly(ethyl vinyl ethers) containing the NLO-phores 3',5'-dimethoxy-4'-oxy-4-nitrostilbene and 3',5'-dimethoxy-4'-oxy-2,4-dinitrostilbene in the side chain. The present report describes the synthesis and cationic polymerization of 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-4-nitrostilbene **2** and 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene **5**.

Experimental

Materials. 2-Chloroethyl vinyl ether, 3,5-dimethoxy-4-hydroxybenzaldehyde, *p*-nitrophenylacetic acid, piperidine, and 2,4-dinitrotoluene (Aldrich) were used as received. Sodium iodide was dried for 4 h at 100 °C under vacuum. Acetone was purified by drying with anhydrous potassium carbonate, followed by distillation under nitrogen. N,N-Dimethylformamide (DMF) was purified by drying with anhydrous calcium sulfate, followed by distillation under reduced pressure. Dichloromethane was washed with concentrated sulfuric acid and then with water, dried with anhydrous calcium chloride, refluxed with calcium hydride, and distilled under nitrogen before use. Toluene was washed with cold concentrated sulfuric acid and then with water, aqueous 5% sodium bicarbonate, again with water, dried with anhydrous calcium

sulfate, refluxed with phosphorus pentoxide, and distilled. Boron trifluoride etherate was treated with a small amount of diethyl ether and distilled under reduced pressure.

Measurements. IR spectra were taken on a Hitachi Model 260-30 infrared spectrophotometer. ^1H NMR spectra were obtained on a Varian EM 360L NMR spectrometer (60 MHz). UV-VIS spectra were obtained on a Kontron UVikon 860 spectrophotometer. Elemental analyses were performed using a Perkin-Elmer 2400 CHN elemental analyzer. The glass transition temperatures (T_g) were measured on a DuPont 910 differential scanning calorimeter in a nitrogen atmosphere. DuPont 951 thermogravimetric analyzer with a heating rate of $10\text{ }^\circ\text{C}/\text{min}$ up to $700\text{ }^\circ\text{C}$ was used for the thermal degradation study of polymers under nitrogen. Melting points were measured with Buchi 530 melting point apparatus and are corrected. Viscosity values were obtained by using a Cannon-Fenske viscometer.

Preparation of 2-Iodoethyl vinyl ether. Anhydrous sodium iodide (45.0 g, 0.30 mol) was dissolved in 320 mL of dry acetone contained in a 500 mL round-bottom flask fitted with a reflux condenser protected by a calcium chloride tube, and heated on a heating mantle for 1 h with stirring. 2-Chloroethyl vinyl ether (25.0 g, 0.23 mol) was added to the mixture, and refluxed for an additional 25 h with stirring to complete the reaction. The resulting solution was cooled to room temperature and filtered with suction. The sodium chloride on the filter was washed with 55 mL of acetone and the filtrate was concentrated by distillation off about 260 mL of the solvent. The residue was poured into 260 mL of water contained in a separate funnel, then shaken. The lower layer was washed successively with 55 mL of 10% sodium bisulfite solution, 55 mL of 5% sodium bicarbonate, and 30 mL of water. It was dried with anhydrous magnesium sulfate (1.8 g) and fractionated under reduced pressure to give 32.8 g (72% yield) of 2-iodoethyl vinyl ether. bp $50\text{--}52\text{ }^\circ\text{C}$ (20 mmHg). ^1H NMR (CDCl_3) δ 6.22-6.57 (q, =CH-O-), 3.50-4.37 (m, CH_2 = and -O- CH_2 -), 2.82-3.47 (t, - CH_2 -I). IR (neat): 3105, 3034, 2960, 2922, 2845 (m, C-H), 1635, 1612 (vs, C=C) cm^{-1} .

Preparation of 3',5'-dimethoxy-4'-hydroxy-4-nitrostilbene (1). Compound 1 was prepared by a known method²⁷ from 3,5-dimethoxy-4-hydroxybenzaldehyde and p-nitrophenylacetic acid, and recrystallized from ethanol. mp $186\text{--}187\text{ }^\circ\text{C}$. ^1H NMR (acetone- d_6) δ 6.76-7.03 (d, aromatic 2H), 7.43-7.70 (d, aromatic 4H), 8.10-8.80 (m, aromatic 3H). IR (neat) 3536 (s, O-H), 3010 (m, =C-H), 2936, 2832 (m, C-H), 1630, 1596, 1587 (vs, C=C), 1508, 1329 (vs, N=O) cm^{-1} .

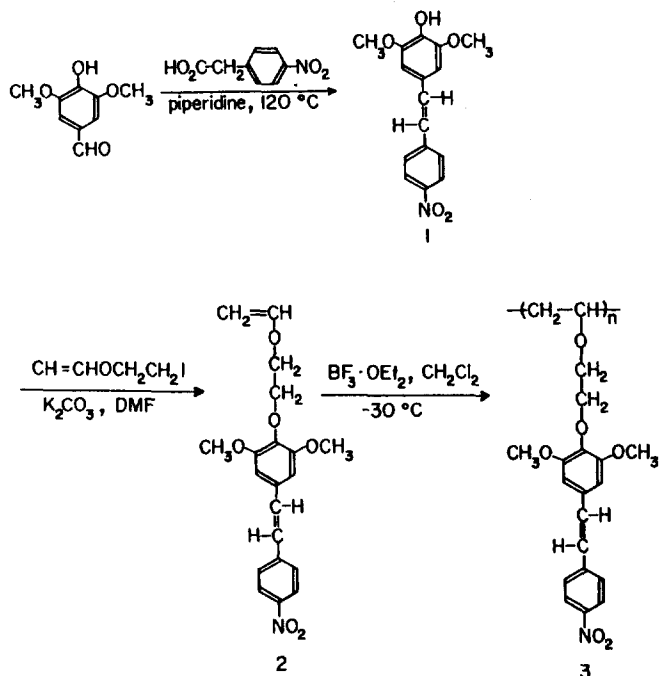
Preparation of 3',5'-dimethoxy-4'-hydroxy-2,4-dinitrostilbene (4). Compound 4 was also prepared by a known method²⁷ from 3,5-dimethoxy-4-hydroxybenzaldehyde and 2,4-dinitrotoluene, and recrystallized from DMSO. mp $272\text{--}273\text{ }^\circ\text{C}$ (dec). ^1H NMR (acetone- d_6) δ 3.81 (s, 2 CH_3 O-), 6.94 (s, aromatic 2H), 7.26-7.47 (d, aromatic 2H), 8.03-8.71 (m, aromatic 3H). IR (neat) 3460 (s, O-H), 3124, 3080, 3008 (m, =C-H), 2940, 2840 (m, C-H), 1628, 1603, 1595 (vs, C=C), 1514, 1340 (vs, N=O) cm^{-1} .

Preparation of 3',5'-dimethoxy-4'-(2'-vinyloxyethoxy)-4-nitrostilbene (2). 3',5'-Dimethoxy-4'-hydroxy-4-nitrostilbene (8.14 g, 0.027 mol), anhydrous potassium carbonate (11.19 g, 0.081 mol), and 2-iodoethyl vinyl ether (7.92 g, 0.040 mol) were dissolved in 50 mL of dry DMF under

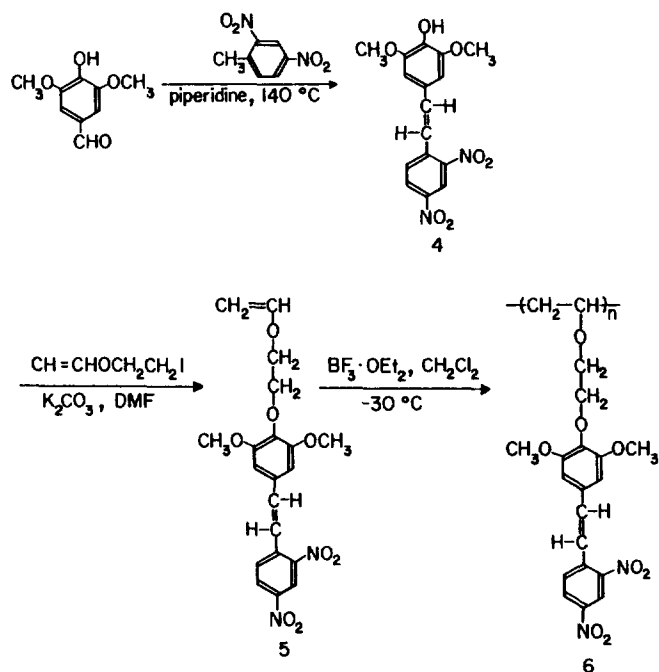
nitrogen. The mixture was refluxed in an oil bath kept at $80\text{ }^\circ\text{C}$ for 6 h under nitrogen. The resulting solution was cooled to room temperature, diluted with 200 mL of water, filtered, and the obtained yellow product was washed successively with 200 mL of diethyl ether, 200 mL of water, and 100 mL of cold ethanol. After separation of the organic layer, the aqueous layer was extracted with 200 mL of diethyl ether twice. Rotary evaporation of the solvent under reduced pressure gave yellow product, which was washed with water (150 mL) and cold ethanol. Recrystallization from ethanol yielded 9.03 g (90% yield) of pure product 2. mp $109\text{--}110\text{ }^\circ\text{C}$. ^1H NMR (acetone- d_6) δ 3.83 (s, 2 CH_3 O-), 3.84-4.33 (m, CH_2 = and -O- CH_2 - CH_2 -O-), 6.26-6.69 (q, =CH-O-), 6.90 (s, aromatic 2H), 7.27 (s, aromatic 2H), 7.49-7.82 (m, aromatic 2H), 7.91-8.26 (m, aromatic 2H). IR (KBr) 3001 (m, =C-H), 2939, 2830 (s, C-H), 1630, 1599, 1582 (vs, C=C), 1507, 1325 (vs, N=O) cm^{-1} . UV/Vis (chloroform) $\lambda_{\text{max}}=370$, $\epsilon=21,930$. Anal. Calcd for $\text{C}_{20}\text{H}_{21}\text{NO}_6$: C, 64.68; H, 5.70; N, 3.77. Found: C, 64.74; H, 5.66; N, 3.71.

Preparation of 3',5'-dimethoxy-4'-(2'-vinyloxyethoxy)-2,4-dinitrostilbene (5). 3',5'-Dimethoxy-4'-hydroxy-2,4-nitrostilbene (9.35 g, 0.027 mol), anhydrous potassium carbonate (11.19 g, 0.081 mol), and 2-iodoethyl vinyl ether (7.92 g, 0.040 mol) were dissolved in 50 mL of dry DMF under nitrogen. The mixture was refluxed in an oil bath kept at $80\text{ }^\circ\text{C}$ for 10 h under nitrogen. The resulting solution was cooled to room temperature, diluted with 200 mL of water, filtered, and the obtained yellow product was washed successively with 200 mL of diethyl ether, 200 mL of water, and 100 mL of cold ethanol. Recrystallization from ethanol yielded 10.34 g (92% yield) of pure product 5. mp: $139\text{--}140\text{ }^\circ\text{C}$. ^1H NMR (acetone- d_6) δ 3.81 (s, 2 CH_3 O-), 3.82-4.30 (m, CH_2 = and -O- CH_2 - CH_2 -O-), 6.19-6.62 (q, =CH-O-), 6.86 (s; aromatic 2H), 7.37 (s, aromatic 2H), 7.98-8.68 (m, aromatic 3H). IR (KBr) 3063 (m, =C-H), 2960, 2938 (m, C-H), 1643, 1617, 1593, 1588 (vs, C=C), 1518, 1503, 1343, 1324 (vs, N=O) cm^{-1} . UV/Vis (chloroform) $\lambda_{\text{max}}=395$, $\epsilon=11,150$. Anal. Calcd for $\text{C}_{20}\text{H}_{20}\text{N}_2\text{O}_8$: C, 57.69; H, 4.84; N, 6.73. Found: C, 57.77; H, 4.78; N, 6.66.

Cationic polymerization of 2 and 5. A representative cationic polymerization procedure (the case of 2) was as follows: A solution of 2 (0.74 g, 2.0 mmol) in dichloromethane (2.5 mL) was placed in a glass ampule through a rubber septum under nitrogen. The resulting solution was flushed with nitrogen for 20 min. The ampule was then placed in an ethanol-acetone bath kept at $-30\text{ }^\circ\text{C}$ under nitrogen, and 0.0034 mL (0.030 mmol) of boron trifluoride etherate was added to the solution. After 10 h the ampule was taken out and the polymerization mixture was poured into 500 mL of methanol. The precipitated polymer was collected and reprecipitated from DMSO into methanol to give 0.67 g (90% yield) of polymer 3; $\eta_{\text{inh}}=0.30\text{ dL/g}$ (c 0.5 g/dL in DMSO at $25\text{ }^\circ\text{C}$). 3: ^1H NMR (DMSO- d_6) δ 0.76-1.93 (m, - CH_2 -), 3.05-4.35 (m, -CH-O- CH_2 - CH_2 -O- and 2 CH_3 O-), 6.45-7.50 (m; aromatic 4H), 7.52-8.75 (m, aromatic 4H). IR (KBr) 3068 (w, =C-H), 2936, 2871, 2840 (s, C-H), 1628, 1595, 1578 (vs, C=C), 1508, 1341 (vs, N=O) cm^{-1} . UV/Vis (chloroform) $\lambda_{\text{max}}=374$. Anal. Calcd for $(\text{C}_{20}\text{H}_{21}\text{NO}_6)_n$: C, 64.68; H, 5.70; N, 3.77. Found: C, 64.77; H, 5.64; N, 3.84. 6: ^1H NMR (DMSO- d_6) δ 0.82-1.94 (m, - CH_2 -), 3.06-4.35 (m, -CH-O- CH_2 - CH_2 -O- and 2 CH_3 O-), 6.50-8.37 (m, aromatic 7H). IR (KBr)



Scheme 1.



Scheme 2.

3078 (m, =C-H), 2932, 2860, 2828 (s, C-H), 1620, 1596, 1575 (vs, C=C), 1518, 1502, 1344 (vs, N=O) cm^{-1} . UV/Vis (chloroform) $\lambda_{\text{max}}=399$. Anal. Calcd for $(\text{C}_{20}\text{H}_{20}\text{N}_2\text{O}_6)_n$: C, 57.69; H, 4.84; N, 6.73. Found: C, 57.78; H, 4.76; N, 6.67.

Results and Discussion

Synthesis of monomer 2 and 5. 3',5'-Dimethoxy-4'-hydroxy-4-nitrostilbene 1 and 3',5'-dimethoxy-4'-hydroxy-2,4-dinitrostilbene 4 were synthesized by the reactions of 3,5-dimethoxy-4-hydroxybenzaldehyde with *p*-nitrophenylacetic

Table 1. Cationic polymerization of 2 and 5 under various conditions

Monomer	Solvent	[M] (mol/L)	Initiator ^a to monomer (mol%)	Temp (°C)	Time (h)	Yield (%)	η_{inh}^b (dL/g)
2	CH_2Cl_2	0.80	1.5	-30	10	90	0.30
2	CH_2Cl_2	0.57	1.2	-60	16	86	0.28
2	$\text{C}_6\text{H}_5\text{CH}_3$	0.80	1.5	-30	12	88	0.32
2	$\text{C}_6\text{H}_5\text{CH}_3$	0.67	1.2	-60	20	90	0.33
5	CH_2Cl_2	0.59	1.5	-30	10	95	0.32
5	CH_2Cl_2	0.80	1.2	-60	20	92	0.30
5	$\text{C}_6\text{H}_5\text{CH}_3$	0.67	1.5	-30	20	90	0.28
5	$\text{C}_6\text{H}_5\text{CH}_3$	0.80	1.8	-60	24	95	0.31

^aInitiator: Boron trifluoride etherate. ^bInherent viscosity measured in the concentration of 0.5 g/dL in DMSO at 25 °C.

acid and 2,4-dinitrotoluene respectively, according to a literature procedure,²⁷ and recrystallized from ethanol and DMSO. 2-Iodoethyl vinyl ether was prepared by the well known halogen exchange reaction²⁸ from 2-chloroethyl vinyl ether and sodium iodide, and reacted with 3',5'-dimethoxy-4'-hydroxy-4-nitrostilbene 1 and 3',5'-dimethoxy-4'-hydroxy-2,4-dinitrostilbene 4 to yield 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-4-nitrostilbene 2 and 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene 5.¹⁸ The chemical structures of the compounds was confirmed by ¹H NMR (Figure 1a), IR (Figure 2a), UV-Vis spectra, and elemental analyses. Spectral data indicated that stilbene compounds 2 and 5 were isolated as the trans-isomers. Compound 2 and 5 showed a strong uv absorption bands near 375-395 nm measured in the chloroform as shown in Figure 3a.

Cationic polymerization of monomer 2 and 5. 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-4-nitrostilbene 2 and 3',5'-dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene 5 were polymerized in solution at -30 °C with boron trifluoride etherate as cationic initiator to obtain the polymers 3 and 6 (Scheme 1 and Scheme 2). The polymerization results are summarized in Table 1.

Monomer 2 and 5 were quite reactive toward cationic initiator and polymerized readily at low temperature. The chemical structures of the polymers were confirmed by ¹H NMR (Figure 1b), IR (Figure 2b), UV-Vis (Figure 3) spectra, and elemental analyses. Each characteristic stretching band of =C-H and C=C near 3060-3080 cm^{-1} and 1580-1630 cm^{-1} of monomers is also shown in their IR spectra of polymers. However, ¹H NMR spectra of polymers do not show any resonance peak by vinyl proton (=CH-O-) near 6.20-6.70 ppm. These spectral evidences seem to indicate that the internal double bond in stilbene moiety did not participate in the vinyl polymerization and any cross-linking was not occurred during the polymerization. As in the monomers, polymer 3 and 6 showed a strong uv absorption bands near 374-399 nm by the chromophores 3',5'-dimethoxy-4'-oxy-4-nitrostilbene and 3',5'-dimethoxy-4'-oxy-2,4-dinitrostilbene in the side chain measured in chloroform, as shown in Figure 3. In most cases, conversions were quite high, but the molecular weights were rather low as indicated by the inherent viscosities.

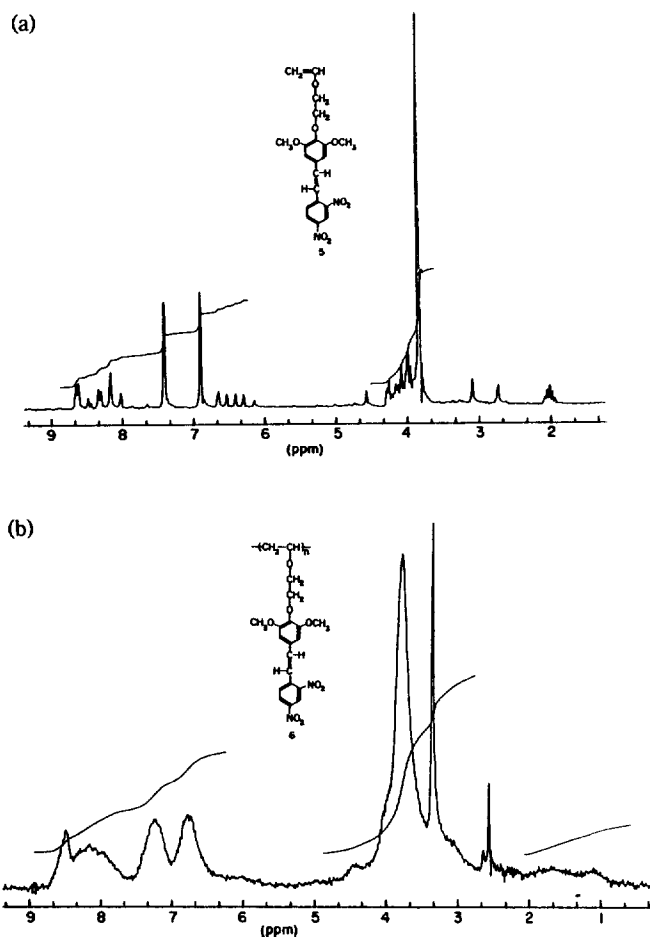


Figure 1. ^1H NMR spectra of 3',5'-Dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene **5** (a) and polymer **6** (b) taken in acetone- d_6 and DMSO- d_6 respectively at room temperature.

Table 2. Thermal properties of polymer **3** and **6**

Polymer	T_g^a , $^\circ\text{C}$	Degradation temperature, $^\circ\text{C}^b$		
		5%-loss	20%-loss	40%-loss
3	87	310	350	480
6	81	290	320	440

^aDetermined by DSC at a heating rate of $10^\circ\text{C}/\text{min}$ under nitrogen atmosphere. ^bDetermined by TGA at a heating rate of $10^\circ\text{C}/\text{min}$ under nitrogen atmosphere.

The polymers **3** and **6** were soluble in DMF and DMSO, but were not soluble in methanol and diethyl ether. The inherent viscosities of polymers were in the range of 0.28–0.33 dL/g indicating moderate molecular weights. The thermal behavior of the polymers were investigated by thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC) to determine the thermal degradation pattern and glass transition temperature (T_g). The results are summarized in Table 2. TGA thermograms of polymers (Figure 4) showed double phase degradation patterns, probably due to the presence of two benzene rings in the pendant group. Polymers **3** and **6** showed a good thermal stability and were

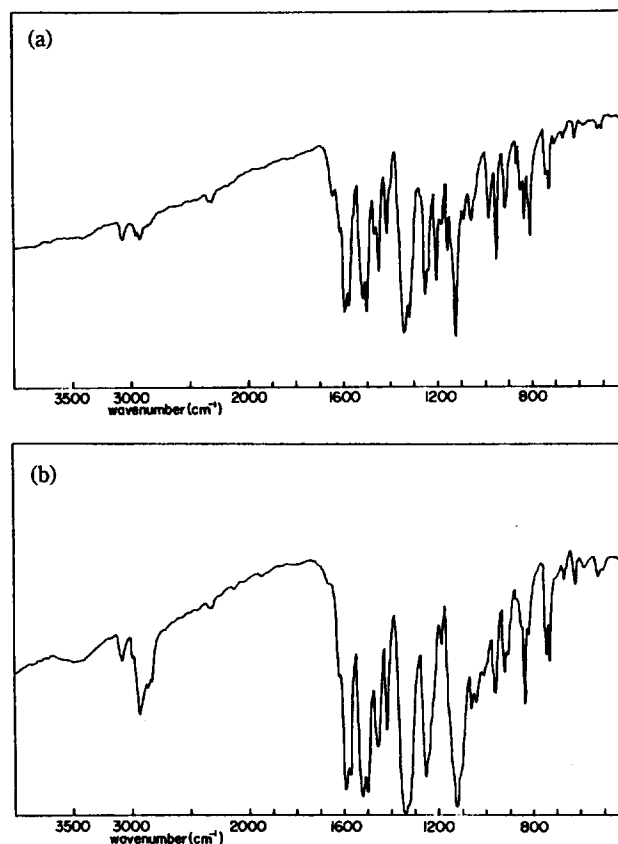


Figure 2. IR spectra of 3',5'-Dimethoxy-4'-(2-vinyloxyethoxy)-2,4-dinitrostilbene **5** (a) and polymer **6** (b).

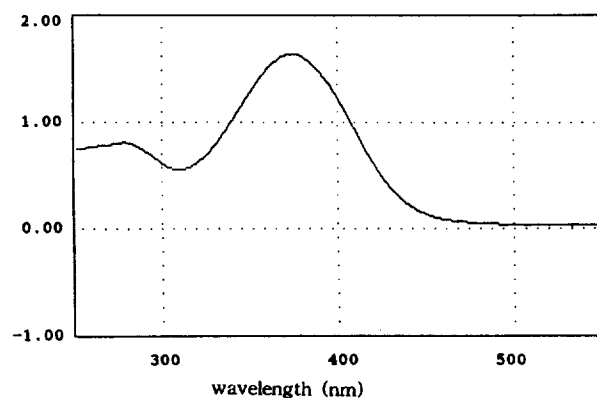


Figure 3. UV-Vis spectrum of polymer **3**.

not decomposed below 300°C as shown in Table 2, which is acceptable for NLO device application. Residues of polymers remained at 700°C were 10.5 and 7.0 weight %, respectively. The T_g values of the polymers obtained from DSC thermograms (Figure 5) were at about $81\text{--}87^\circ\text{C}$. These T_g values are higher than those for poly(ethyl vinyl ether) (-43°C), probably due to the presence of polar and bulky pendant group. The polymers did not show liquid crystalline properties, probably because the alkyl chains of pendant group are rather short.

In summary, we prepared novel poly(ethyl vinyl ethers) **3** and **6** containing the possible NLO-phores 3',5'-dimethoxy-

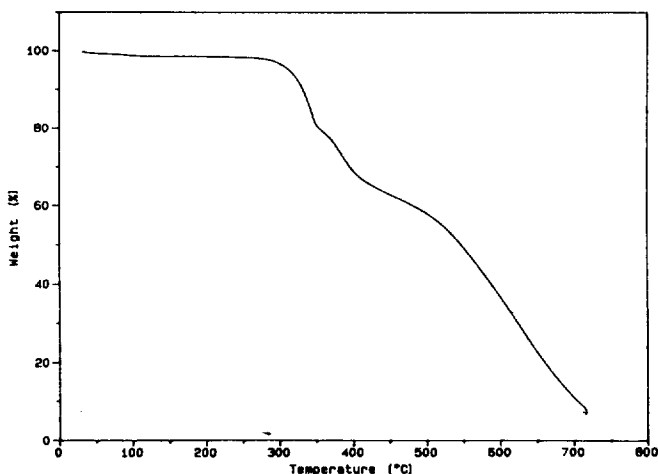


Figure 4. TGA thermogram of polymer 3 (10 °C/min, N₂).

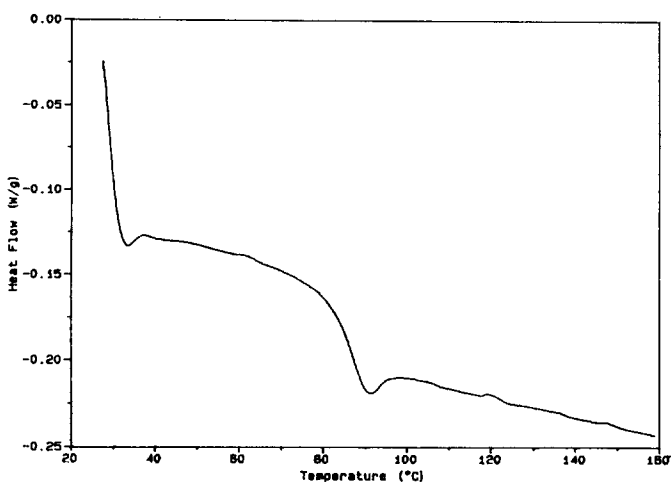


Figure 5. DSC thermogram of polymer 3 (10 °C/min, N₂).

4'-oxy-4-nitrostilbene and 3',5'-dimethoxy-4'-oxy-2,4-dinitrostilbene in the side chain by the cationic polymerization of the corresponding vinyl monomers **2** and **5**. The resulting substituted poly(ethyl vinyl ethers) **3** and **6** were soluble in DMF and DMSO, but were not soluble in methanol and diethyl ether. Polymers **3** and **6** showed a good thermal stability, which is acceptable for NLO device application, showing T_g values around 81-87 °C. Copolymerization with other monomers to increase the T_g values and measurements of NLO activity are in progress, and the results will be reported later.

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