

SYNTHESIS AND PROPERTIES OF POLYACETYLENES CONTAINING CARBAZOLE AND AMINO ACID MOIETIES*

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Abstract Novel 9-propylcarbazole monomers containing amino acid moieties, 2-*N*-(*tert*-butoxycarbonyl)-L-alanine-9-propylcarbazole ester (1), 2-*N*-(*tert*-butoxycarbonyl)-L-*O*-cyclohexyl-L-glutamic acid-9-propylcarbazole ester (2) and 2-*N*-(*tert*-butoxycarbonyl)-L-phenylalanine-9-propylcarbazole ester (3) were synthesized and polymerized with (nbd)Rh⁺[η⁶-C₆H₅B[−](C₆H₅)₃] to give the corresponding polymers with number-average molecular weights ranging from 7050 to 10500 in 70%–86% yields. The polymers were completely soluble in toluene, CHCl₃, CH₂Cl₂, THF and DMSO, but insoluble in hexane, diethyl ether and MeOH. The specific rotation studies revealed that poly(1)–poly(3) do not took predominantly one-handed helical structures in the solvents although they possess chiral groups. The polymers emitted fluorescence in 0.40%–2.35% quantum yields. The cyclic voltammograms of the polymers indicated that the polymers exhibited electrochemical properties.

Keywords: Amino acid; Carbazole; Substituted polyacetylenes; Electro-optical properties.

INTRODUCTION

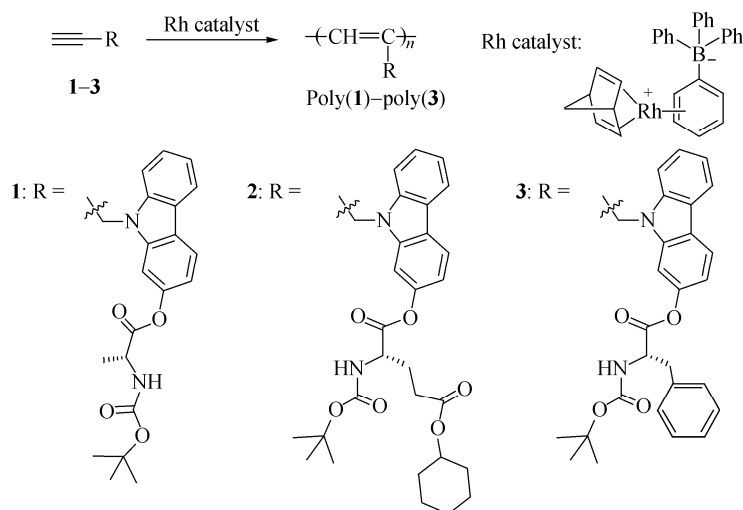
Carbazole is widely used as hole-transporting and electroluminescent units. Polymers containing carbazole moieties in the main chain or side chain have attracted much attention because of their unique properties, which allow them to be applied to various photonic applications such as photoconductive, electroluminescent and photorefractive materials^[1–3]. On the other hand, polyacetylene derivatives exhibit unique properties such as semiconductivity, high gas permeability, nonlinear optical properties and the ability to form helical structures^[4, 5]. Incorporation of carbazole into polyacetylene will lead to the development of novel functional polymers based on synergistic actions of carbazole and main chain conjugation^[6–11].

Amino acids are constituents of proteins, typical biological polymers and are not only biologically important but also useful as substances for chiral sources and auxiliaries in organic and polymer synthesis. Appropriately substituted amino acid-containing polyacetylenes take predominantly one-handed helical structures^[12–15], some of which exhibits responsiveness to external stimuli such as heat^[16–18], solvent^[18–20], pH and photo-irradiation^[21–23]. Introduction of carbazole into amino acid-containing helical polyacetylenes is expected to endow the polymers with novel optical and electrochemical properties based on the helical main chain. The present manuscript deals with the synthesis and polymerization of novel acetylene monomers possessing amino acids and carbazole moieties (Scheme 1), and examination of their optical and electrochemical properties.

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Scheme 1 Polymerization of **1-3**

EXPERIMENTAL

Measurements

^1H - and ^{13}C -NMR spectra were recorded on a JEOL EX-400 spectrometer using tetramethylsilane as an internal standard. IR spectra were measured on a Shimadzu FTIR-8100 spectrophotometer. Elemental analysis was carried out at the Kyoto University Elemental Analysis Center. The number- and weight-average molecular weights (M_n and M_w) of the polymer were determined by gel permeation chromatography (GPC) using THF as an eluent calibrated by polystyrene standards at 40°C. Melting point (mp) was measured on a Yanaco micro melting point apparatus. Specific rotations ($[\alpha]_D$) were measured on a JASCO DIP-1000 digital polarimeter with a sodium lamp as a light source. UV-Vis and fluorescence spectra were recorded in a quartz cell (thickness: 1 cm) using a JASCO V-550 and a FP-750 spectropolarimeter, respectively. Cyclic voltammograms were measured with an ALS Electrochemical Analyzer 600A-*n*. The measurements were carried out with a polymer solution in CH_2Cl_2 (1 mmol/L) in the presence of $n\text{-Bu}_4\text{NClO}_4$ (0.1 mol/L) as supporting electrolyte using platinum working and counter electrodes and an Ag/AgNO_3 reference electrode at a scan rate of 0.1 V/s.

Materials

N-*tert*-butoxycarbonyl-L-alanine (Boc-Ala-OH), *N*-*tert*-butoxycarbonyl-L-phenylalanine (Boc-Ph-Ala-OH, Watanabe Chemical), *N*-*tert*-butoxycarbonyl-*O*-cyclohexyl-L-glutamic acid [Boc-Glu(OcHex)-OH, Watanabe Chemical], 2-hydroxycarbazole and propargyl bromide (Aldrich) *N*-(3-dimethylaminopropyl)-*N'*-ethylcarbodiimide hydrochloride (EDC·HCl, Eiwiss), 4-dimethylaminopyridine (DMAP, Wako) were purchased and used without further purification. $(\text{nbd})\text{Rh}^+[\eta^6\text{-C}_6\text{H}_5\text{B}^-(\text{C}_6\text{H}_5)_3]$ [(nbd) = 2,5-norbornadiene] was prepared by the reaction of $[(\text{nbd})\text{RhCl}]_2$ with $\text{NaB}(\text{C}_6\text{H}_5)_4$ as described in the literature^[24]. THF used for polymerization was purified by the standard methods.

Monomer Synthesis

Synthesis of 9-propargylcarbazol-2-ol was prepared according to literature^[25]: 2-hydroxycarbazole (10.0 g, 54.6 mmol) was slowly added to a mixture of KOH (3.1 g, 54.6 mmol) and DMF (50 mL), and the resulting mixture was stirred at room temperature for 3 h. After that, propargyl bromide (8.11 g, 68.3 mmol) was added to the mixture and stirred at room temperature overnight. It was poured into a large amount of water and extracted with ethyl acetate. The organic layer was washed with brine and water, dried over anhydrous MgSO_4 , filtered and then concentrated. The residual solid was purified by silica gel column chromatography eluted with hexane/ethyl acetate to obtain the target compound as white solid. Yield 7.85 g (65%). Mp, 123–125°C,

$^1\text{H-NMR}$ (DMSO- d_6 , δ): 3.27 (s, 1H, $\equiv\text{CH}$), 5.01 (s, 2H, $\equiv\text{CCH}_2-$), 7.26 (vt, $J = 3.8$ Hz, 1H, Ar), 7.40–7.42 (m, 2H, Ar), 7.82 (d, $J = 8.8$ Hz, 1H, Ar), 7.87 (d, $J = 8.0$ Hz, 1H, Ar), 8.22 (d, $J = 8.0$ Hz, 1H, Ar), 8.41 (s, 1H, Ar). $^{13}\text{C-NMR}$ (DMSO- d_6 , δ): 32.4, 77.5 ($\text{C}=\text{CH}$), 84.4 ($\text{C}=\text{CH}$), 116.4, 119.4, 119.9, 120.3, 120.5, 123.4, 125.2, 126.2, 127.1, 127.7, 137.9, 138.9. IR (cm^{-1} , KBr): 3440, 3291 ($\equiv\text{C}-\text{H}$), 2105 ($\text{C}=\text{C}$), 2923, 2854, 1601, 1493, 1334, 1203, 823, 763, 747, 647. Anal. Calcd for $\text{C}_{15}\text{H}_{11}\text{NO}$: C 81.43, H 5.01, N 6.33. Found: C 81.21, H 5.24, N 6.47.

2-*N*-(*tert*-butoxycarbonyl)-L-alanine-9-propargylcarbazole ester (**1**). Boc-Ala-OH (1.7 g, 9.0 mmol) was added to a solution of EDC·HCl (1.90 g, 9.0 mmol) and DMAP (0.1 g, 0.90 mmol) in CH_2Cl_2 (45 mL) at room temperature. 9-Propargylcarbazol-2-ol (2.0 g, 9.0 mmol) was added to the solution, and the resulting mixture was stirred at room temperature overnight. The reaction mixture was washed with water (50 mL) three times, and the organic layer was dried over anhydrous MgSO_4 . After filtration, the solvent was removed on a rotary evaporator to afford the crude product. It was purified on a silica gel column chromatography eluted with *n*-hexane/ethyl acetate (4/1 volume ratio) as eluent. A white solid of **1** was obtained in 63% yield. Mp, 137–139°C, $[\alpha]_D^{25} = +23^\circ$ ($c = 0.100$ g/dL in CHCl_3). $^1\text{H-NMR}$ (DMSO- d_6 , δ): 1.38 (s, 9H, $\text{C}(\text{CH}_3)_3$), 1.41–1.46 (q, $J = 6.18$ Hz, 3H, NHCHCH_3), 3.11 (s, 1H, $-\text{C}\equiv\text{CH}$), 4.87–4.93 (m, 2H, $\equiv\text{C}-\text{CH}_2-\text{N}$; 1H, $-\text{NHCHCH}_3$), 6.8–8.1 (m, 7H, Ar); $^{13}\text{C-NMR}$ (DMSO- d_6 , δ): 17.5, 28.1, 40.1, 49.3, 72.5 ($-\text{C}\equiv\text{CH}$), 78.1 ($-\text{C}\equiv\text{CH}$), 79.6, 95.9, 108.2, 110.6, 116.8, 118.6, 119.4, 120.9, 122.5, 124.3, 139.8, 140.8, 156.3, ($>\text{C}=\text{O}$), 168.3 ($>\text{C}=\text{O}$). IR (cm^{-1} , KBr): 3388, 3297 ($\equiv\text{C}-\text{H}$), 2128 ($-\text{C}\equiv\text{C}-$), 2979, 2938, 1719, 1630, 1609, 1578, 1499, 1461, 1176, 1162, 1027, 751, 639, 479. Anal. Calcd for $\text{C}_{23}\text{H}_{24}\text{N}_2\text{O}_4$: C 70.39, H 6.16, N 7.14. Found: C 70.40, H 6.39, N 7.23.

2-*N*-(*tert*-butoxycarbonyl)-L-*O*-cyclohexyl-L-glutamic-9-propargylcarbazole ester (**2**). The title compound was synthesized and purified in a similar way to **1** in 62% yield. Mp 136.0–138.0°C. $[\alpha]_D^{25} = +16.4^\circ$ ($c = 0.1$ g/dL in THF at rt). $^1\text{H-NMR}$ (400 MHz, in DMSO- d_6): 1.36 (s, 9H, $\text{C}(\text{CH}_3)_3$), 1.46–1.74 (m, 10H, $-\text{COOCH}(\text{CH}_2)_5$), 3.15 (s, 1H, $-\text{C}\equiv\text{CH}$), 3.91 (m, 1H, $-\text{COOCH}(\text{CH}_2)_5$), 4.68 (m, 1H, COOCHNH), 4.89 (s, 2H, $\equiv\text{C}-\text{CH}_2-\text{N}$), 6.80–8.11 (m, 7H, Ar); $^{13}\text{C-NMR}$ (DMSO- d_6 , δ): 23.1, 25.7, 26.5, 27.4, 28.1, 31.0, 40.3, 55.7, 71.3, 72.5 ($-\text{C}\equiv\text{CH}$), 78.1 ($-\text{C}\equiv\text{CH}$), 79.6, 95.9, 108.2, 110.6, 116.8, 118.6, 119.4, 120.9, 122.5, 124.3, 139.8, 140.8, 156.3, ($>\text{C}=\text{O}$), 167.3 ($>\text{C}=\text{O}$), 173.1 ($>\text{C}=\text{O}$). IR (cm^{-1} , KBr): 3385, 3309 ($\equiv\text{C}-\text{H}$), 2135 ($-\text{C}\equiv\text{C}-$), 3051, 2928, 2860, 1703, 1627, 1609, 1572, 1493, 1459, 1176, 1121, 1022, 749, 644, 487. Anal. Calcd for $\text{C}_{31}\text{H}_{36}\text{N}_2\text{O}_6$: C 69.90, H 6.81, N 5.26. Found: C 69.70, H 6.89, N 5.23.

2-*N*-(*tert*-butoxycarbonyl)-L-phenylalanine-9-propargylcarbazole ester (**3**). The title compound was synthesized and purified in a similar way to **1** in 84% yields. Mp: 101.0–103.0°C. $[\alpha]_D^{25} = +26.4^\circ$ ($c = 0.1$ g/dL in THF at rt). $^1\text{H-NMR}$ (400 MHz, in DMSO- d_6): 1.35 (s, 9H, $\text{C}(\text{CH}_3)_3$), 2.82–2.92 (m, 2H, Ar- CH_2CH), 3.14 (s, 1H, $-\text{C}\equiv\text{CH}$), 4.68 (m, 1H, COOCHNH), 4.89 (s, 2H, $\equiv\text{C}-\text{CH}_2-\text{N}$), 6.80–8.11 (m, 12H, Ar); $^{13}\text{C-NMR}$ (DMSO- d_6 , δ): 28.1, 35.7, 40.6, 55.7, 72.5 ($-\text{C}\equiv\text{CH}$), 78.1 ($-\text{C}\equiv\text{CH}$), 79.6, 95.8, 108.2, 110.6, 116.8, 118.6, 119.4, 120.9, 122.5, 124.3, 139.8, 140.8, 156.3, ($>\text{C}=\text{O}$), 168.3 ($>\text{C}=\text{O}$). IR (cm^{-1} , KBr): 3384, 3310 ($\equiv\text{C}-\text{H}$), 2136 ($-\text{C}\equiv\text{C}-$), 3030, 2975, 2926, 2860, 1702, 1629, 1610, 1577, 1494, 1459, 1177, 1106, 1022, 750, 644, 488. Anal. Calcd for $\text{C}_{29}\text{H}_{28}\text{N}_2\text{O}_4$: C 74.34, H 6.02, N 5.98. Found: C 74.60, H 6.39, N 5.93.

Polymerization Procedure

The polymerizations were carried out in a Schlenk tube equipped with a three-way stopcock under nitrogen. A solution of a monomer in THF ($[\text{M}]_0 = 0.50$ mol/L) was added to a solution of $(\text{nbd})\text{Rh}^+[\eta^6\text{-C}_6\text{H}_5\text{B}^-(\text{C}_6\text{H}_5)_3]$ in THF ($[\text{M}]_0/[\text{cat}] = 100$) under dry nitrogen, and the solution was kept at 30°C for 24 h. The polymerization mixture was poured into a large amount of MeOH to precipitate the formed polymer. It was separated by filtration using a membrane filter (ADVANTEC H100A047A) and dried under reduced pressure.

Spectroscopic Data of the Polymers

Poly(**1**): $^1\text{H-NMR}$ (DMSO- d_6 , δ): 0.82–1.39 (br, 9H, $\text{C}(\text{CH}_3)_3$), 1.45–1.46 (br, 3H, NHCHCH_3), 3.83–4.10 (br, 1H, $-\text{NHCHCH}_3$), 4.24 (br, 2H, $=\text{C}-\text{CH}_2-\text{N}$), 6.30–8.10 (m, 7H, Ar), 6.31 (br, 1H, $>\text{C}=\text{CH}-$ in main chain of polyacetylene). IR (KBr): 3406, 2925, 1719, 1609, 1578, 1489, 1461, 1290, 1162, 746, 724 cm^{-1} .

Poly(**2**): $^1\text{H-NMR}$ (DMSO- d_6 , δ): 0.80–1.37 (br, 9H, $\text{C}(\text{CH}_3)_3$), 1.46–1.51 (br, 10H, $-\text{COOCH}(\text{CH}_2)_5$),

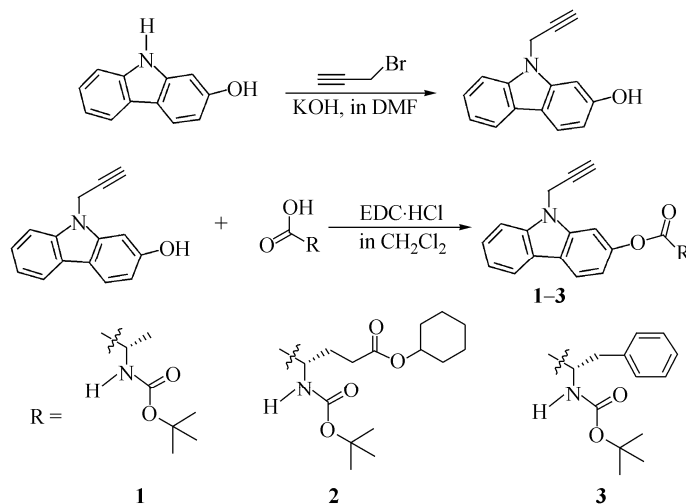
3.81–3.93 (br, 1H, $-\text{COOCH}(\text{CH}_2)_5$), 4.32 (br, 1H, COOCHNH), 4.42 (br, 2H, $=\text{C}-\text{CH}_2-\text{N}$), 6.30–8.11 (br, 7H, Ar); IR (KBr): 3409, 3058, 2933, 2859, 1710, 1631, 1579, 1460, 1367, 1164, 1020, 746 cm^{-1} .

Poly(3): ^1H -NMR ($\text{DMSO}-d_6$, δ): 0.91–1.33 (br, 9H, $\text{C}(\text{CH}_3)_3$), 2.25–2.45 (br, 2H, $\text{Ar}-\text{CH}_2\text{CH}$), 4.23 (br, 1H, COOCHNH), 4.42 (br, 2H, $=\text{C}-\text{CH}_2-\text{N}$), 6.90–7.95 (br, 12H, Ar). IR (KBr): 3374, 2977, 2939, 2862, 1728, 1631, 1515, 1454, 1369, 1254, 1052, 864, 782 cm^{-1} .

RESULTS AND DISCUSSION

Monomer Synthesis

Scheme 2 illustrates the synthetic routes for the amino acid-containing monomers **1–3**. 9-Propargylcarbazol-2-ol was synthesized by reaction of 2-hydroxycarbazole with propargyl bromide catalyzed by KOH in DMF. Monomers **1–3** were synthesized by the condensation of the corresponding amino acids [Boc-Ala-OH, Boc-ph-Ala-OH and Boc-Glu(OcHex)-OH] with 9-propargylcarbazol-2-ol using EDC·HCl and DMAP as condensation agents. The structures of the monomers were confirmed by IR, ^1H -, and ^{13}C -NMR spectroscopies besides elemental analysis. The monomers are completely soluble in THF, DMSO and dimethylformamide (DMF) and insoluble in hexane and Et_3N .



Scheme 2 Synthesis of monomer **1–3**

Polymerization

Table 1 summarizes the results of the polymerization of carbazole and amino acid-based monomers **1–3** catalyzed by $\text{Rh}^+(\text{nbd})[\eta^6\text{-C}_6\text{H}_5\text{B}^-(\text{C}_6\text{H}_5)_3]$. Monomers **1–3** satisfactorily underwent polymerization to afford grey white polymers [poly(**1**)–poly(**3**)] with M_n 's ranging from 7050 to 10500 in 70%–86% yields. The polymers were completely soluble in toluene, CHCl_3 , CH_2Cl_2 , THF and DMSO, but insoluble in hexane, diethyl ether and MeOH. All the polymers displayed a unimodal GPC chromatogram, indicating that the polymerization proceeded through a single propagating species.

Table 1. Polymerization of **1–3** catalyzed with $(\text{nbd})\text{Rh}^+[\eta^6\text{-C}_6\text{H}_5\text{B}^-(\text{C}_6\text{H}_5)_3]^\text{a}$

Monomer	Yield ^b (%)	M_n^c	M_w/M_n^c	Color	$[\alpha]_\text{D}^\text{d}$ (°)
1	78	10500	1.90	Grey white	−3.5
2	86	10300	1.74	Grey white	+6.8
3	70	7050	1.66	Grey white	+12.3

^a $[\text{M}]_0 = 0.50 \text{ mol/L}$, $[\text{M}]_0/[\text{Rh}] = 100$, in THF, 30°C, 24 h; ^b MeOH-insoluble part; ^c Determined by GPC in THF on the basis of a polystyrene calibration; ^d Measured by polarimetry ($c = 0.1 \text{ g/dL}$ in THF)

Polymer Structure

The structures of poly(**1**)–poly(**3**) were examined by IR and ^1H -NMR spectroscopies. The monomers exhibited IR absorption peaks around 3300 and 2120 cm^{-1} associated with the $\equiv\text{C}-\text{H}$ and $-\text{C}\equiv\text{C}-$ stretching vibrations, respectively, while the polymers did not exhibit these peaks. Accordingly, the polymers displayed no ^1H -NMR signal at $\delta = 2.8\text{--}3.5$ assignable to an ethynyl proton in Fig. 1. The results clearly indicate that the acetylene polymerization took place to form polymers containing alternating single and double bonds along the main chain. It was impossible to determine the *cis/trans* ratio of the main chain by ^1H -NMR spectroscopy, because the olefinic proton signal of the polyacetylene main chain overlapped with aromatic proton signals. Since Rh catalysts predominantly afford polyacetylenes with *cis* structure^[13], it is assumed that the steric structure of polymer in the present study is also the case.

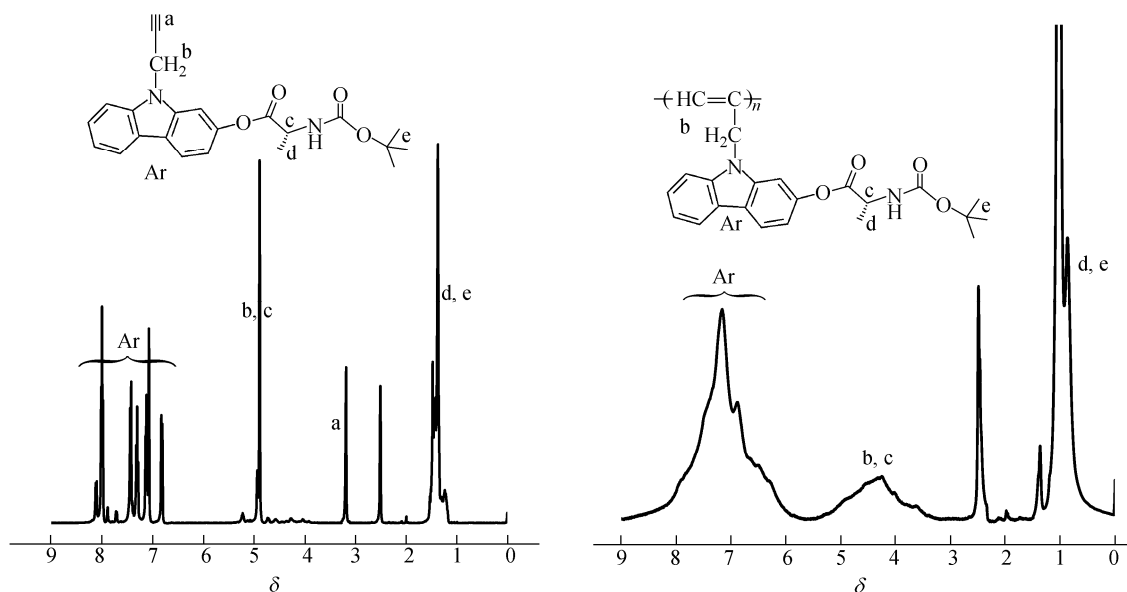


Fig. 1 The ^1H -NMR spectra of **1** and poly(**1**) measured in $\text{DMSO}-d_6$

Properties of Poly(**1**)–Poly(**3**)

The secondary structure of poly(**1**)–poly(**3**) was examined by polarimetry and UV-Vis spectroscopies. As listed in Table 1, the polymers displayed small optical rotations ($[\alpha]_D -3.5^\circ$ to $+12.3^\circ$) in THF, suggesting that they did not take a helical structure with predominantly one handed screw sense in the solvent. It is probably attributed to polymers possessing methylene groups between polyacetylene main chain and carbazole side chain. This structure may increase the flexibility of the side chains between the polymer and decrease the steric repulsion between the side chains as compared with 9-(1*R*,2*S*,5*R*)-menthyloxycarbonyl-2-ethynylcarbazole which forms stability helical conformations^[9]. Figure 2 shows the UV-Vis spectra of poly(**1**)–poly(**3**) and monomers. The peaks at 300 nm are attributed to the absorption by the $\pi-\pi^*$ and $n-\pi^*$ of carbazoyl. The UV-Vis spectroscopic patterns of the polymers were almost the same as those of the monomers, but the absorption bands were positioned at a longer wavelength region in the range 350–500 nm than those of the monomers presumably due to the $\pi-\pi^*$ absorption of the polyacetylene main chain.

Figure 3 shows the fluorescence spectra of poly(**1**)–poly(**3**) along with those of the monomers. The polymer solution emitted fluorescence at 350 and 500 nm upon excitation at 300 nm, the first peak was attributed to the carbazole moieties, and the last peak was assignable to emission from excimers formed at the side chains^[26]. The fluorescence quantum yield (ϕ) of poly(**1**)–poly(**3**) was in the range of 0.40%–2.35%, and smaller than that of the corresponding monomers (ϕ of **1**, **2**, and **3** were 21.0%, 19.3% and 17.7%, respectively). The reason may be associated with the differences in the chain stereoregularity and/or packing arrangements of

the polymers in solutions. The polyacetylene backbone commonly functions as a quenching site for light emission to absorb light emitted from appendages with energy dissipated *via* nonradiative decay, thus resulting in low photoluminescence efficiency^[27]. On the other hand, the amino groups in the side chain presumably prevent pendent carbazole groups from overlapping each other due to the rigid structure, leading to a low population of excimers and weak excimer-based fluorescence, this is probably the another reason for the low ϕ values.

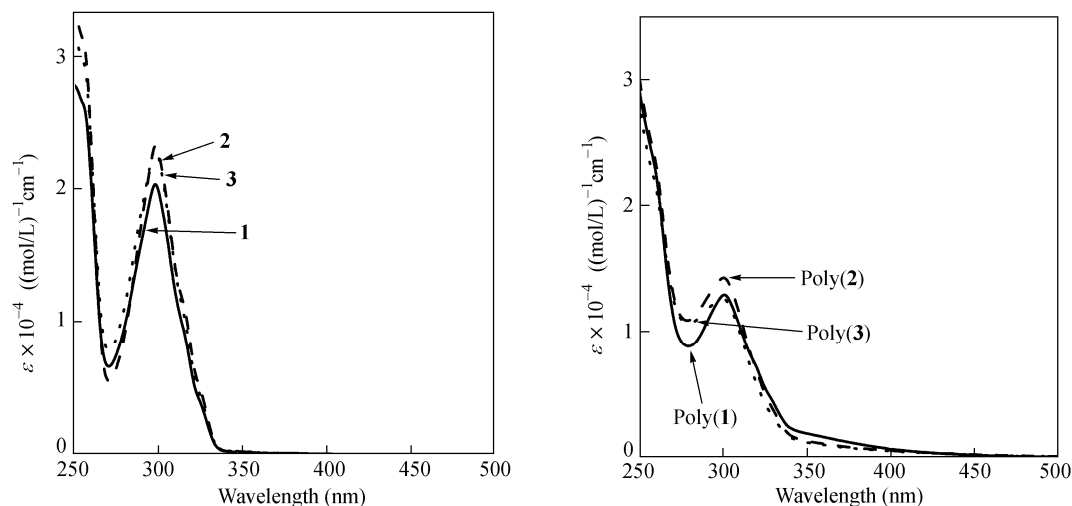


Fig. 2 UV-Vis spectra of **1–3** and poly(**1**)–poly(**3**) measured in CHCl_3 at 22°C

1 and poly(**1**): $c = 2.55 \times 10^{-5} \text{ mol/L}$; **2** and poly(**2**): $c = 1.88 \times 10^{-5} \text{ mol/L}$; **3** and poly(**3**): $c = 2.14 \times 10^{-5} \text{ mol/L}$

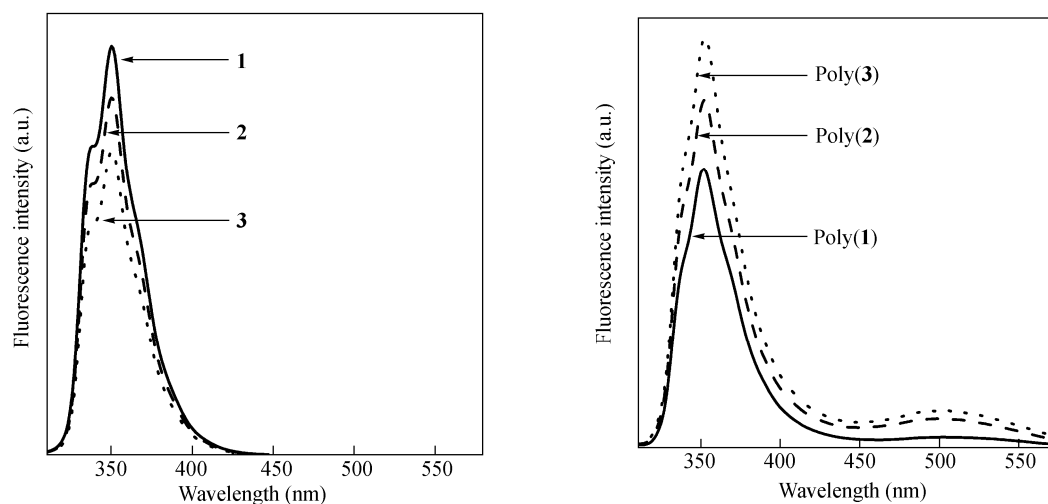


Fig. 3 Fluorescence spectra of **1–3** and poly(**1**)–poly(**3**) measured in CH_2Cl_2 at 22°C excited at 300 nm

1 and poly(**1**): $c = 2.55 \times 10^{-6} \text{ mol/L}$; **2** and poly(**2**): $c = 1.88 \times 10^{-6} \text{ mol/L}$; **3** and poly(**3**): $c = 2.14 \times 10^{-6} \text{ mol/L}$;
The intensities are normalized based on the concentration of carbazole unit.

Figure 4 depicts the cyclic voltammetric (CV) curves of poly(**1**) and poly(**3**) together with **1** and **3**. The oxidation of **1** is initiated at 0.55 V on the first cycle, while poly(**1**) does not exhibit any oxidation peaks. This result may indicate that carbazole moieties of the polymer synergize with the polyacetylene main chain, resulting in low electron density at the nitrogen atom compared to that of the monomer. As the CV scans continued, **1**

exhibited an oxidation peak at a region of 1.1–1.2 V, and the peaks shifted to a higher potential field as the CV scans continued. It seems that a conducting compound film was formed on the working electrode surface, and the film thickness gradually increased upon CV scanning. The potential shift of this maximum provided the information about the increase of the electrical resistance in the film, and over-potential was needed to overcome the resistance. CV curves of **1** exhibited a reduction peak at about 0.60 V, while poly(**1**) exhibited an obvious oxidation peak at 0.10 V in the first scan. Poly(**2**) and poly(**3**) show similar CV curves to those of poly(**1**). Poly(**1**)–poly(**3**) show a clear reduction peak at about 0.10 V indicating present polymers exhibit obvious electrochemical properties.

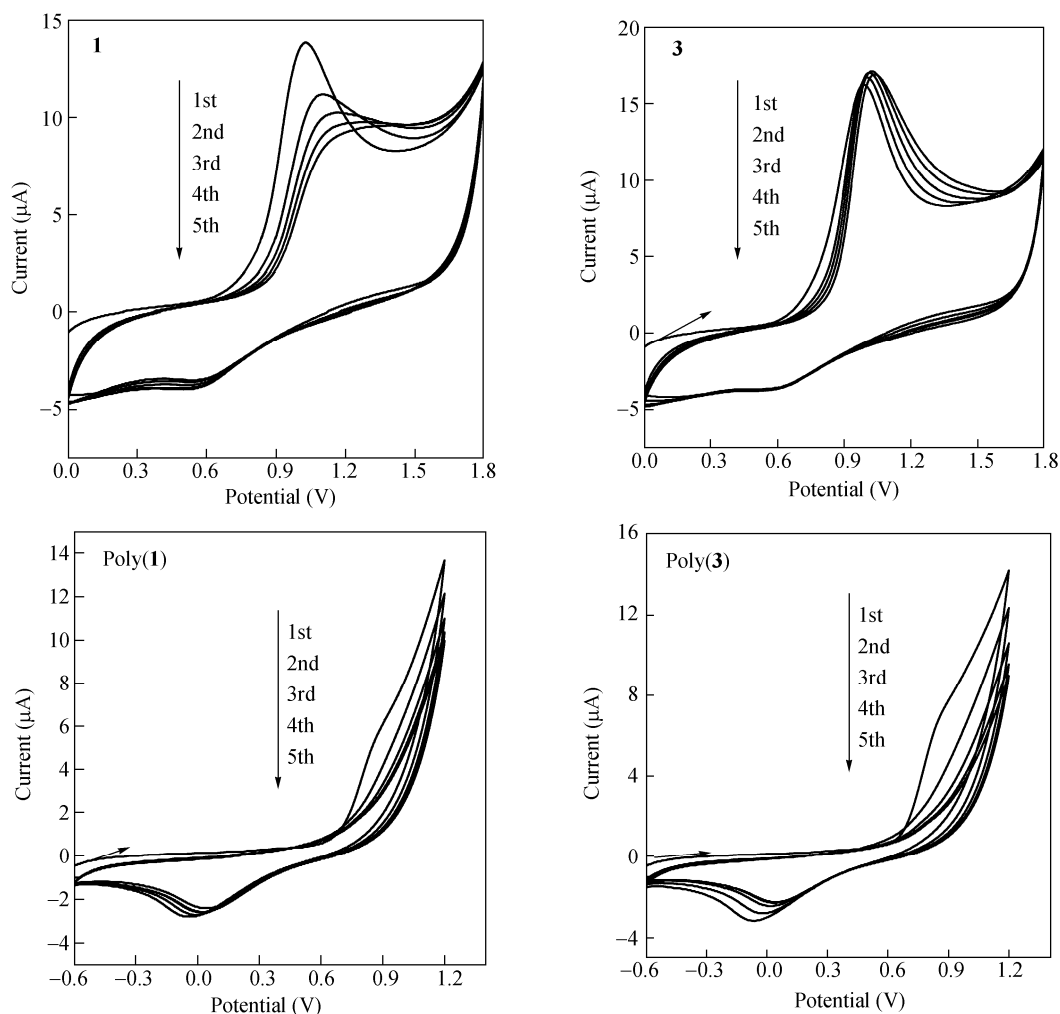


Fig. 4 Cyclic voltammograms of **1**, **3**, poly(**1**), and poly(**3**) measured at a scan rate of 0.1 V/s, versus Ag/Ag⁺ in a solution of TBAP (0.2 mol/L) in CH₂Cl₂

CONCLUSIONS

In this research, we have synthesized and polymerized carbazole- and amino acid-based optically active novel acetylene monomers **1**–**3** to obtain polymers with moderate molecular weights in good yields. The polymers were completely soluble in CHCl₃, CH₂Cl₂, THF and DMSO, but insoluble in hexane, diethyl ether and MeOH. The polymers do not take predominantly one-handed helical structures in the solvents although they possess chiral groups. The polymers emitted fluorescence in 0.40%–2.35% quantum yields and exhibited redox activity based on carbazole.

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