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An alternating copolymer consisting of light emitting and electron transporting units

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An alternating copolymer composed of fluorenedivinylene as the light emitting unit and pyridine as the electron transporting one was synthesized by employing the Wittig reaction. The copolymer which has conjugation throughout the molecular chain is soluble in both polar and nonpolar solvents. The copolymer has a band gap energy of 2.85 eV deduced from an ultraviolet–visible absorption spectrum, and ionization potential and electron affinity of -5.67 and -2.82 eV, respectively, deduced from a cyclic voltammogram. The photoluminescence (PL) emission maximum was observed at 440 or 540 nm depending on the solvent used in making the solution for spin-casting. The copolymer was also capable of transporting electrons and could be used as an electron transporting layer. A light emitting diode (LED) fabricated with a blend of polyvinylcarbazole (PVK) with a fluorene-based light emitting material, and this copolymer as an electron transporting layer, exhibited an electroluminescence (EL) emission maximum at 475 nm with a full width at the half maximum (FWHM) of 50 nm and a quantum efficiency of 0.1%, where indium tin oxide (ITO) and Al were used as the anode and cathode, respectively.

Introduction

It has become a great challenge to fabricate a light emitting diode (LED) for a full color display since the polymer LED was introduced in 1990.[1] There have been synthesized a sizable number of polymers emitting blue,[2–5] green[6–8] and red[9–11] light. A large number of light emitting polymers are listed in the literature.[12] Polymers are attractive since a suitable functional group can be imbedded in the molecule by attaching a chemical group covalently. The solubility of a polymer is easily enhanced by attaching side groups on the polymer chain without disturbing the band gap.[13,14] The band gap of poly(*p*-phenylenevinylene)(PPV) is reduced by attaching alkoxy groups on the phenylene[15–17] or cyano groups on the vinylene group.[9,18,19]

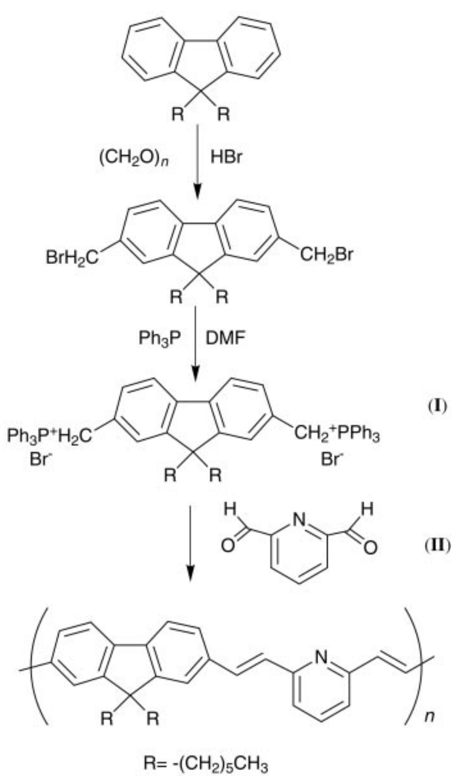
The following statements are generally accepted; the emission center of electroluminescence (EL) is the same as that of photoluminescence (PL) in many cases,[20,21] a blend system between two emitting polymers with different band gaps shows the emission maximum of PL from the emission center with the low band gap on excitation of the chromophore with the high band gap,[22,23] and the EL emission efficiency is high on the balanced injection of the charges from the respective electrodes.[24,25] It is also general practice that the radiative singlet excitons are formed in the emission layer away from the electrodes to prevent exciton quenching at the electrode–emission layer interface.[26,27]

However, the majority of light emitting polymers based on PPV derivatives have the highest occupied molecular orbital (HOMO) level close to the work function of indium tin oxide (ITO) to make the hole injection into the polymer easy and the lowest unoccupied molecular orbital (LUMO) level relatively high compared to the work functions of most of the cathodes to make election injection into the polymer difficult, which leads to formation of excitons close to the cathode in an LED for poor EL emission. Balancing charge injections from the electrodes may be obtained by lowering both the ionization potential and the electron affinity of an emissive material to match the energy levels of the respective electrodes. Matching the energy levels in the system brings a significant improvement to an LED in terms of the quantum efficiency, a low emission bias potential and relocation of emission centers away from either of the electrodes for saturated color. There have been introduced electron transporting polymers in the fabrication of LEDs since low mobility of electrons in the polymer compared to that of holes contributes to poor EL emission. The polymers with an oxadiazole[28] or pyridine[29] unit are n-dopable and capable of electron transporting. These polymers generally have a low LUMO level for an easy electron injection from a cathode, too. Poly(pyridine-2,5-diyl) derivatives are soluble in polar solvents and make it possible to fabricate LEDs of multiple layers by sequential spin-casting.[25,30]

The present work has synthesized an alternating copolymer between fluorenedivinylene and pyridine by Wittig reaction, expecting the copolymer to have low HOMO and LUMO levels for reasonable hole blocking and electron transporting properties if it is a poor light-emitting material. It is also expected that the alternating copolymer soluble in a nonsolvent for the fluorene-based light emitting polymer described elsewhere[5] renders a good Coulombic interaction with the light emitting polymer at the interface on sequential spin casting since both the polymers have a fluorenedivinylene unit in the chains.

Experimental

The sequence of the polymer synthesis is shown in Scheme 1. The details of the synthesis of the 2,7-bis(bromomethyl)-9,9′-di-*n*-hexylfluorene triphenylphosphonium salt (**I**) are described in the literature.[31] Pyridine-2,6-dicarbaldehyde (**II**) (TCI) was used as received. Polyvinylcarbazole (PVK) (Aldrich) had a molecular weight (M_W) of 10^6 g mol^{-1} and was purified by dissolving and precipitating three times using THF and methanol as the solvent and precipitant, respectively. Poly(9,9′-dihexylfluorene-2,7-diylvinylene-*m*-phenylenevinylene-*stat*-*p*-phenylenevinylene) (P-3) ($M_w = 32\,500$ g mol^{-1}, MWD = 2.95, $T_g = 125$ °C) with the *meta*:*para* ratio of 7:3 was synthesized as described in the literature.[5] Poly(pyridine-2,5-diyl)[32a] and poly(9,9′-dihexylfluorene-2,7-divinylene) (PFV)[32b] ($M_w = 6\,200$ g mol^{-1}, MWD = 1.87, $T_g = 82$ °C) were synthesized to be used as reference materials for cyclic voltammetry. Scheme 2



Scheme 1 Synthetic route to PFPV by Wittig reaction.

shows the chemical structures of P-3, poly(pyridine-2,5-diyl) and PFV.

Polymer synthesis

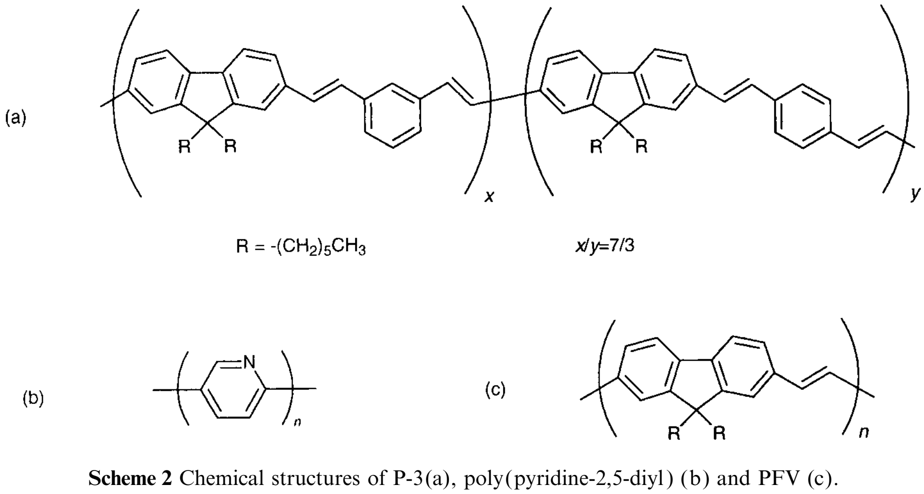
2.09 g (2 mmol) of **I** and 0.27 g (2 mmol) of **II** were dissolved in a mixture of 60 mL of anhydrous ethyl alcohol and 20 mL of chloroform in a three-necked flask, and 2.3 g of 5% solution of sodium metal in anhydrous ethyl alcohol was added dropwise through a syringe. The mixture was kept at room temperature for 12 h and 1 mL of 0.1 M aqueous HCl solution was added to it to end the reaction. The precipitated light-yellow solid, poly(9,9′-di-*n*-hexylfluorene-2,7-diylvinylene-*alt*-2,6-pyridinylenevinylene) (PFPV) was washed thoroughly with water and methyl alcohol, and then dried in a vacuum oven at 40 °C. Yield 0.68 g. ^{1}H-NMR ($CDCl_3$), δ (ppm) : 0.4–2.2 (br, m, aliphatic), 6.6–7.8 (br, m, vinyl and aromatic), weight average molecular weight (M_w) and molecular weight distribution (MWD) measured by gel permeation chromatography (GPC) based on polystyrene standards using THF as an eluent were 35 700 g mol^{-1} and 3.33, respectively.

Instrumentation

A Waters GPC 150 was employed to deduce M_w and MWD based on polystyrene as standards. The thermal properties were determined by using a Perkin-Elmer DSC-7 for T_g and a Du Pont TGA 951 for degradation. For studies on electrochemical behavior, thin films were prepared on platinum wire. Cyclic voltammograms (CV) were obtained using a potentiostat (EG&G PAR 273) with a data acquisition module. The concentration of electrolyte, tetrabutylammonium tetrafluoroborate, in acetonitrile in the electrochemical study was 0.1 M to reduce solution resistance. An internal standard ferrocene/ferrocenium system was employed to calibrate the redox peaks by adding a small amount of ferrocene to the system and then obtaining the complete CV. The HOMO and LUMO values were determined from the first oxidation and reduction potential values with respect to ferrocene with an Ag/AgCl reference electrode. The reduction of PFPV is accompanied by a change in color from yellow to dark brown, which is completely reversed upon reoxidation. Specimens for PL measurement were spin-cast on glass plates from 2 wt% solution of each copolymer in chlorobenzene. Liquid cells for PL measurement of the solution were fabricated with two glass plates separated by 75 µm thick spacers. Single-layered LEDs were assembled with 100 nm thick spin-cast copolymer on ITO glass followed by thermal evaporation of aluminum. Multiple-layered LEDs were fabricated by sandwiching sequentially spin-cast layers with ITO and Al. UV–visible absorption (AB) spectra were recorded with a HP 8452A Diode Array Spectrophotometer. The copolymers were photoexcited by a xenon lamp, and PL and EL spectra were recorded with an ISS PL-1 Fluorometer. *I–V–L* characteristics were recorded on a Keithley 236 Source/Measure Unit for voltage–current relationship and by a Newport 818-SL photodiode for voltage–electroluminescence intensity.

Results and discussion

Fig. 1 shows the thermal properties of PFPV. The glass transition temperature (T_g) was measured as 100 °C and the copolymer started degrading at 380 °C. Cyclic voltammetry reveals that the copolymer has the onset oxidation and reduction potentials at 1.07 (Fig. 2-c) and −1.78 V (Fig. 2-b), respectively, as shown in Fig. 2. Ferrocene exhibited a reversible oxidation wave in the positive region with a neutral point at 0.2 V as shown in Fig. 2-e. The HOMO and LUMO values of PFPV were deduced as −5.67 and −2.82 eV, respectively, based on the value of ferrocene of −4.8 eV.[33] The oxidation reaction was irreversible in the scan range. When the electrochemical scan was extended to 1.5 V in the positive region, the oxidation reaction became a two electron



Scheme 2 Chemical structures of P-3(a), poly(pyridine-2,5-diyl) (b) and PFV (c).

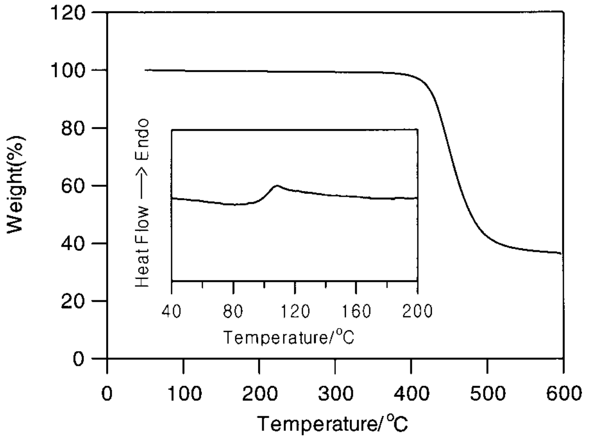


Fig. 1 TGA and DSC (inset) thermograms of PFPV.

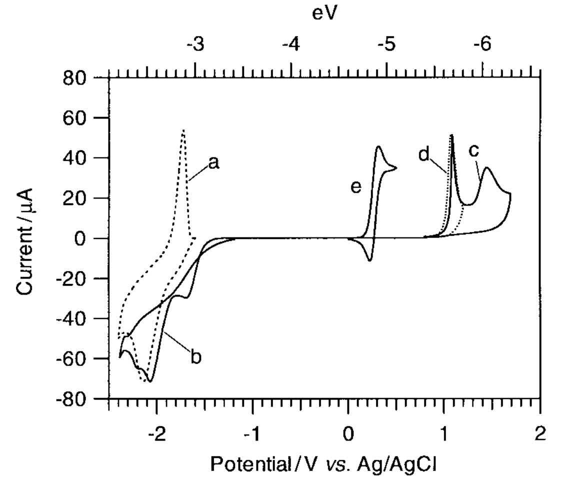


Fig. 2 Cyclic voltammograms of poly(pyridine-2,5-diyl) (a) and PFPV (b) in reverse and PFPV (c), PFV (d) and ferrocene (e) in forward sweep with 0.1 M $TBABF_4$ solution in acetonitrile.

process.[34] The copolymer seems to have a capacity to lose each electron independently and the chemical structure changes on losing electrons at the high potential. The copolymer film coated on the Pt electrode degraded at the high potential and dissolved in the solution.

Fig. 2-b shows that the reduction current started flowing at -1.5 V probably due to a secondary reaction and the main reaction took place at -1.78 V accompanying a color change of the film to yellow from dark brown. The onset potential on reduction was the same as that of poly(pyridine-2,5-diyl) whose cyclic voltammogram is shown in Fig. 2-a. The reduction cycle of poly(pyridine-2,5-diyl) in the negative potential region was reversible but the reversibility went down with the cycling.

It is observed that the copolymer is reduced as well as oxidized in the neutral state, which implies that it has the capability for both electron and hole transporting. The cyclic voltammograms as shown in Figs. 2-d and 2-a displayed only the oxidation potential for PFV and only the reduction potential for poly(pyridine-2,5-diyl), respectively. It is important to note that when the fluorenedivinylene and pyridine units are linked alternately by a sigma bond, the two units keep their own electrochemical characteristics intact. Furthermore, PFPV was soluble in both polar and nonpolar solvents while PFV and P-3 were soluble only in nonpolar solvents but poly(pyridine-2,5-diyl) was soluble only in polar solvents, which would make stacking a charge transporting film on a light emitting layer or *vice versa* possible by spin-casting.

Fig. 3 shows the absorption (AB) and photoluminescence (PL) spectra of PFPV films cast from solutions in chlorobenzene and formic acid. The chemical structures of PFPV cast from the different solutions are not identical to each other. The AB spectrum of the film cast from formic acid solution was red-shifted from that from chlorobenzene solution and had a vibronic structure which was not clearly seen in the film cast from chlorobenzene solution. The band edge of the film cast from formic acid is located at 450 nm while that from chlorobenzene solution is at 435 nm, revealing the energy difference of 0.1 eV. Since the nonbonding electrons on nitrogen in pyridine are expected to form a hydrogen bond with the proton of formic acid, there is a good possibility of protonation of the polymer cast from the formic acid solution. The chain morphology could be a stretched one and the conjugation might be extended compared to that of the film cast from chlorobenzene solution.

The effect of the solvent on PL was significant as also shown in Fig. 3. The PL spectrum of the copolymer film cast from chlorobenzene solution shows the PL emission maximum at 440 nm with a strong vibronic peak at 470 nm, and a shoulder and a broad secondary emission at 490 and 540 nm, respectively, on photoexcitation at 365 nm. The peak at 540 nm might be assigned as the emission of aggregates or excimers since the peak disappeared in dilute solution in chlorobenzene.[35] When the PL spectrum was taken from the film cast from formic acid solution, the PL emission maximum appeared at 540 nm and there were two weak shoulders at 440 and 490 nm. The structureless main spectrum suggests that the emission center is aggregate or excimer and the emission peak at 440 nm, where the PL emission spectrum of the solution in chlorobenzene has the maximum, is the primary singlet exciton emission. The copolymer tends to develop aggregates or excimers on spin-casting and the effect becomes overwhelming on spin-casting from solution in formic acid due to the hydrogen bond developed intermolecularly.

We tried to suppress the secondary PL peak at 540 nm by blending the copolymer with PVK for dilution. Fig. 4 shows the PL spectrum of the copolymer excited at 365 nm and the PL spectra of a 1:4 blend of the copolymer with PVK at four different excitation energies; two for excitation of PVK at 295 and 340 nm where it shows maximum extinction coefficients, and two for the copolymer at 365 and 410 nm where it has high extinction coefficients. The excitation of the blend at 365 or 410 nm displayed the same PL spectrum as that of the copolymer excited at 365 nm but the PL intensity was reduced. It is apparent that PVK in the blend failed to give a dilution effect to the copolymer. The reduced chromophore concentration of the copolymer in the blend resulted in a reduction in PL intensity. The secondary emission peak at 540 nm was

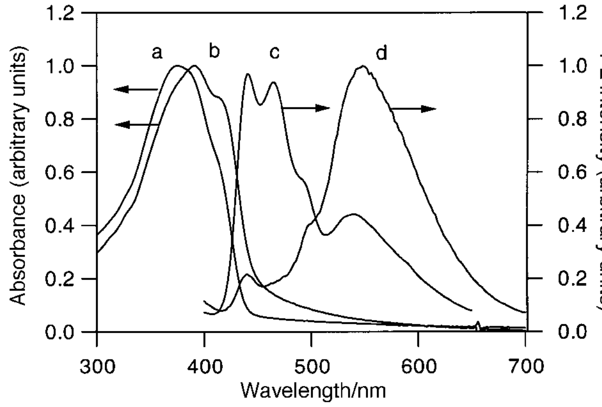


Fig. 3 AB and PL spectra of PFPV films cast from chlorobenzene [(a), (c)] and formic acid [(b), (d)] solutions.

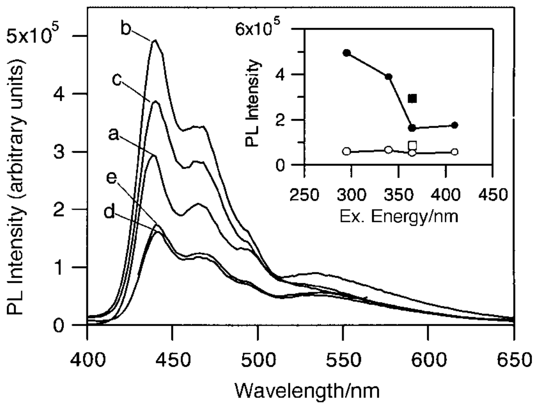


Fig. 4 PL spectra of PFPV (a) excited at 365 nm and PFVP–PVK (1 : 4) blend excited at 295 (b), 340 (c), 365 (d) and 410 nm (e), respectively. The inset shows the PL intensity of blends at 440 (●) and 540 nm (○) with different excitation energy. The PL intensity of PFPV is marked as squares.

also reduced indicating no disturbance in the molecular morphology for the secondary emission by blending.

However, when the blend was excited at 295 or 340 nm, the PL intensity at 440 nm was enhanced while that of the secondary peak at 540 nm remained the same. The inset of Fig. 4 reveals that the excitation energy rendered a large effect on the primary emission at 440 nm but little effect on the secondary emission at 540 nm. It also shows that the PL intensity at 440 nm is higher for the copolymer than for the blend on excitation of the chromophores at 365 or 410 nm while no difference in the secondary emission at 540 nm is noticed.

When the PL spectra were normalized as shown in Fig. 5, it was observed that the relative intensity of the vibronic structure remained the same but the secondary emission intensity at 540 nm was changed depending on the excitation energy, revealing a higher intensity when excited at 365 or 410 nm. The inset of Fig. 5 shows that the blending brought no improvement in suppressing the secondary emission on the direct excitation of the PFPV fluorophores. The suppression of the emission at 540 nm on excitation of the blend at 295 and 340 nm suggests that radiative primary singlet excitons are formed more effectively by the indirect excitation.

The enhancement of the intensity at 440 nm may be attributed to the energy transfer from PVK to the copolymer. The excited PVK chromophores after some relaxation may transfer energy with the right level to the copolymer fluorophores to develop more radiative singlet excitons than in the case of the direct excitation of the copolymer fluorophores. There should be an energy level distribution of the excited states at the moment of direct excitation of the copolymer chromophores. Before relaxing to the lowest excited state, there are some excitons with above-average energy which are not confined in fluorophores but participate in the formation of the secondary emission centers. The excitons formed by indirect excitation, in contrast, may be confined in the chains for efficient radiative decay and at the same time form a lower concentration of the secondary emission centers. The extinction coefficient of the blend at 295 nm was the highest to display the highest PL intensity at 440 nm.

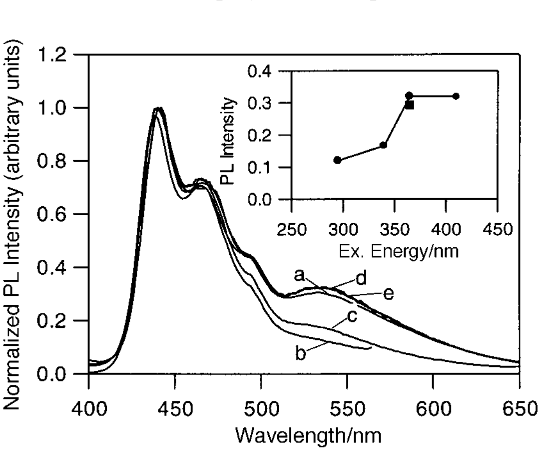


Fig. 5 Normalized PL spectra of PFPV (a) excited at 365 nm and PFVP–PVK (1 : 4) blend excited at 295 (b), 340 (c), 365 (d) and 410 nm (e), respectively. The inset shows normalized PL intensity of blend at 540 nm with different excitation energy. The PL intensity of PFPV is marked as squares.

A single-layered LED was fabricated by spin-casting the solution of the copolymer or the blend with PVK in chlorobenzene using ITO and Al as the anode and cathode, respectively. A broad EL emission with a maximum at 540 nm was unexpectedly observed when the copolymer was used as the emitting material as shown in Fig. 6. The EL spectrum is identical to the PL spectrum of the copolymer spin-cast from the solution not in chlorobenzene but in formic acid. PFPV was found to be one of the cases showing a PL spectrum different from its EL spectrum. The predominant formation of the excitons for the secondary emission in EL of the single component LED was attributed to the aggregate excitons or excimers when the primary excitons quenched at the Al electrode. Holes must have moved close to the polymer–electrode interface before electrons penetrated deep into the emitting layer indicating the hole mobility was too high compared to the electron mobility. The EL spectrum of the blend, however, shows the emission maximum at 440 nm and a shallow peak at 540 nm. The hole mobility seems to be reduced in the blend due to the presence of PVK, giving time for deep penetration of electrons from the cathode. It is observed that the primary EL emission centers in the blend are the same as those for PL emission. However, the secondary EL emission from the blend with PVK was not suppressed as much as the secondary PL emission. The EL quantum efficiency of the LED fabricated with the blend was in the range of 0.001%.

An attempt was made to use the copolymer as an electron transporting–hole blocking material since the pyridine unit was linked in the main chain of the molecule.[36] A fluorene-based statistical copolymer, P-3,[5] was blended with PFPV with various blending ratios. The AB spectrum of a blend is a superposition of the two spectra of each polymer. The PL spectra of the blends on photoexcitation at 365 nm were the same as that of P-3 indicating that there was energy transfer from PFPV to P-3 as shown in Fig. 7. The highest PL intensity as shown in the inset was observed when the blend ratio was 1 to 4 between P-3 and PFPV. The PL intensity was higher than that of the blend between PFPV and PVK (Fig. 4). When the PL spectra were normalized at the emission maximum, the PL spectra were nicely superposed with one another. It seems

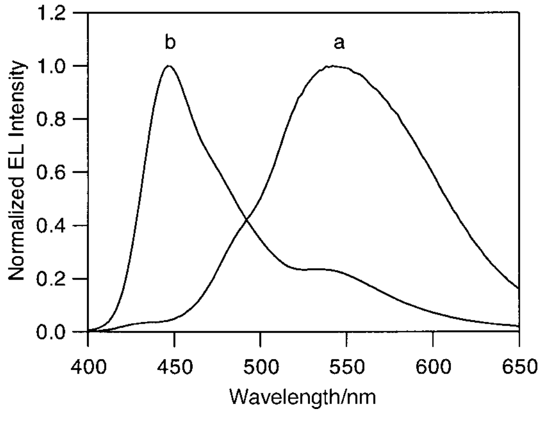


Fig. 6 Normalized EL spectra of PFPV (a) and PFPV–PVK (1 : 4) blend (b).

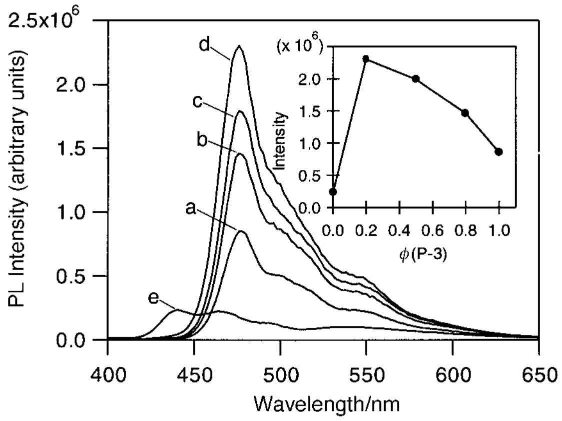


Fig. 7 PL spectra of (P-3)–PFPV blends with different ratios: 10/0 (a), 8/2 (b), 5/5 (c), 2/8 (d) and 0/10 (e). The inset shows the maximum PL intensity against the fraction of P-3 in blends.

that the concentration ratios between the primary and secondary fluorophores in a given blend are fixed regardless of the blend ratios. If all or part of the fluorophores changed the morphology at the interface between the two polymers on blending, the fluorophore concentration ratios changed with changes of the blend ratios and the superposition of the PL spectra was unlikely. The fluorophores contributing to the PL emission should reside in the polymer bulk which was formed by phase separation on drying the solvent during spin-casting of the solution. Otherwise, when the intensity of the maximum peak was normalized, the intensity of other peaks should be enhanced or reduced to a certain degree on changing the interface contacts by changing the acceptor concentration. The pyridine-based copolymer with the emission maximum at 440 nm is an effective donor which shows no PL emission itself in the blend system.

Fig. 8 shows the normalized EL spectra of LEDs fabricated with blends between P-3 and PFPV, with the intention that PFPV would act as an electron injection and hole blocking material for P-3. The EL spectrum of the P-3 LED shows the emission maximum at 475 nm—the same as the PL maximum. The PFPV LED, however, shows the emission maximum at 540 nm, which is the secondary emission, with a weak shoulder at 440 nm for the primary exciton emission. The blend LEDs show both the maxima at 475 and 540 nm, and the intensity ratio between the two emission maxima depends on the concentration ratio in the blend. The radiative singlet excitons for EL were formed in both the polymers. It is apparent that excitons formed in PFPV failed to carry out the energy transfer but participated in the formation of the secondary singlet excitons.

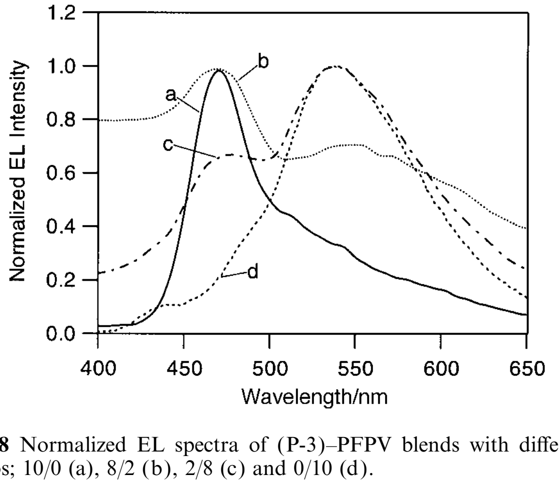


Fig. 8 Normalized EL spectra of (P-3)–PFPV blends with different ratios; 10/0 (a), 8/2 (b), 2/8 (c) and 0/10 (d).

A three-layered LED was fabricated with PVK as the hole transporting material (10 nm thick), P-3 as the light-emitting source (90 nm thick) and PFPV as the electron transporting layer (30 nm thick) employing sequential spin-casting on ITO, followed by thermal evaporation of Al. It is important to note that the sequential spin-casting of the PFPV solution in formic acid on the P-3 layer was possible to make a fine film whereas the poly(pyridine-2,5-diyl) solution in formic acid failed to make a fine film on the same layer. It is believed that a coulombic interaction between the fluorenedivinylene unit from both the polymers at the interface was sufficient to make a good layered film.

The EL spectrum of the LED shown in Fig. 9 exhibits two emission peaks at 475 and 540 nm indicating that both P-3 and PFPV emission centers functioned independently. The energy transfer between PFPV and P-3 observed on photoexcitation of the blend of the two polymers was not carried out in this system. It is apparent that the hole barrier with 0.3 eV erected by PFPV at the interface of P-3 (ionization potential of −5.4 eV) and PFPV is not high enough to block the holes injected into the PVK layer with the energy difference of 1.0 eV against ITO of −4.8 eV. The high-energy holes moved toward the cathode through P-3 and into the PFPV layer to couple with electrons injected from Al. Since the hole barrier at the (P-3)–PFPV interface is 0.3 eV and the PFPV layer thin, the neutral polaron excitons are formed in both layers. The excitons in PFPV carry insufficient energy to transfer it to P-3 but generate the aggregates or dimer structures to show the secondary emission at 540 nm.

It was learned that an LED with a thinner film of PFPV (10 nm thick) reduced substantially the secondary emission

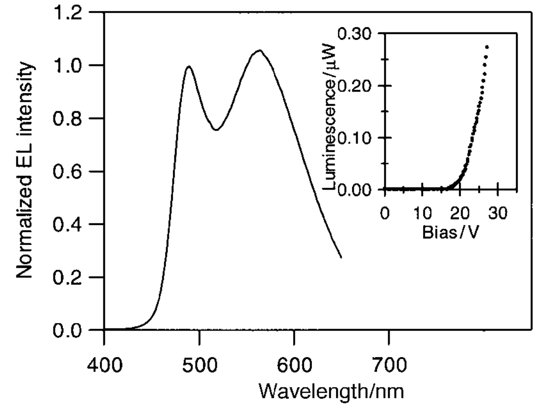


Fig. 9 Normalized EL spectrum of three-layered LED of ITO/PVK/P-3/PFPV/Al. The inset shows L–V curve.

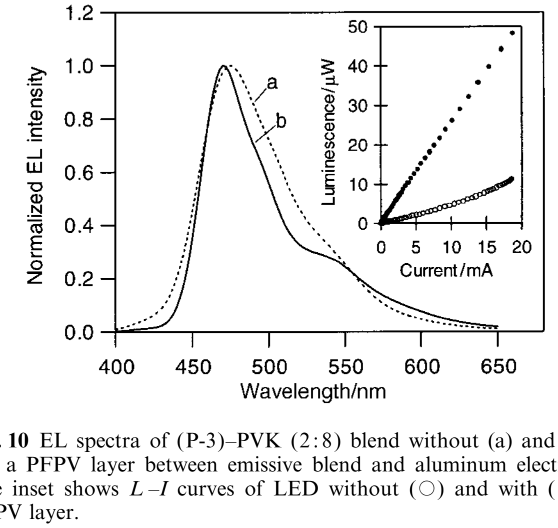


Fig. 10 EL spectra of (P-3)–PVK (2:8) blend without (a) and with (b) a PFPV layer between emissive blend and aluminum electrode. The inset shows L–I curves of LED without (○) and with (●) a PFPV layer.

intensity at 540 nm to narrow the spectrum with the emission maximum at 475 nm and a shoulder at 540 nm. This result indicates that PFPV is an electron transporting material to bring electrons into the P-3 layer although it failed to block holes at the interface but formed excitons in itself. The EL quantum efficiency, however, was lower than that of the LED with 30 nm thick PFPV. The reduction of intensity at 540 nm and the poor quantum efficiency must be attributed to the exciton quenching at the Al surface which was separated from the excitons by 100 Å or less. The inset in Fig. 9 shows the forward bias turn-on potential of around 15 V.

The strong secondary emission at 540 nm proved that a substantial number of holes moved in PFPV over the energy barrier of 0.3 eV. The holes injected into PVK over a high energy barrier of 1 eV passed through P-3 which had a HOMO level of -5.4 eV and a good hole transporting capability deduced from cyclic voltammetry. It is feasible that a strong space charge by holes was built up at the P-3–PFPV interface to pull electrons into the P-3 and at the same time holes moved into PFPV through the hole channel of the fluorenedivinylene units of PFPV.

We tried to reduce the hole flux in P-3 by blending it with PVK. A two layered LED sandwiching a (P-3)–PVK blend with the blending ratio of 2 : 8 as a hole transporting and light emitting layer and PFPV as an electron transporting layer between ITO and Al was fabricated to evaluate the EL performance as shown in Fig. 10. The EL emission spectrum shows the emission maximum at 475 nm with FWHM of 50 nm. The emission spectrum was superposed with that of the LED without the PFPV layer to show the spectrum was further narrowed. The inset in Fig. 10 demonstrates that the quantum efficiency of the LED with the PFPV layer is 0.1%, five times better than that without the layer. The high quantum efficiency proved that balancing the charge injections from the respective electrodes was improved and the emitting centers were confined in P-3. The holes must be blocked at the interface between P-3 and PFPV and electrons must be moved into the P-3 layer from PFPV but little holes into PFPV. The condition for the balanced charge injection may be formed due to controlled mobility of holes not to build up a strong space charge at the interface between the P-3 and PFPV layers.

Conclusion

An alternating copolymer consisting of a light emitting and electron transporting unit was synthesized by employing the Wittig reaction. Cyclic voltammetry proved that the copolymer preserved the electrochemical characteristics of each unit by performing both the reduction and oxidation processes from the neutral state. The PL spectrum of the PFPV film spin-cast from the solution in chlorobenzene showed an emission maximum at 440 nm. However, the EL spectrum had an emission maximum at 540 nm, the same as the PL maximum from the film spin-cast from solution in formic acid. The LED of a PVK–PFPV blend sandwiched between ITO and Al showed an emission maximum at 440 nm with a weak secondary peak at 540 nm. The LEDs were fabricated with PFPV–(P-3) blends to show two emission maxima at 440 and 540 nm of which the EL intensity ratio changed with the blending ratio. The LEDs with a layered structure obtained by sequentially spin-casting PVK, P-3 and PFPV on ITO, followed by evaporation of Al, also displayed two emission maxima at 440 and 540 nm but the intensity at 540 nm was reduced by reducing the PFPV thickness. An LED with a PVK–(P-3) blend as a hole transporting and light emitting layer and PFPV as an electron transporting layer sandwiched between ITO and Al displayed a strong emission spectrum with the maximum at 475 nm, FWHM of 50 nm and the quantum efficiency of 0.1%. PFPV was proved to be a good electron transporting and hole blocking copolymer.

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