Position of Biphenyl Group Turning the Structure and Photophysical Property of D-π-π-A Prototype Fluorescent Material

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Abstract
Three novel D-π-π-A prototype compounds, namely, (E)-2-(3-([1,1′-biphenyl]-2-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (2-BAM), (E)-2-(3-([1,1′-biphenyl]-3-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (3-BAM), and (E)-2-(3-([1,1′-biphenyl]-4-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (4-BAM) were synthesized. Furthermore, the structures and photophysical properties of three compounds were compared. Molecules of 2-BAM were packed into a 1D column structure with H-aggregation. However, both of 3-BAM and 4-BAM were packed into 3D layer structures with J-aggregation, respectively. Although all three compounds showed highly twisted molecular geometries, their respective molecular packing and intermolecular interactions were different. Because of the differences in electronic structures of molecules, three compounds displayed different emission behaviors in solid and dilute solution states. This study indicated that changing the position of biphenyl groups is an effective way for turning the structures and photophysical properties of such D-π-π-A prototype fluorescent materials.

Keywords Biphenyl · Structure · Photophysical property

Introduction

Due to the excellent characteristics and wide use in the fields of chemiluminescence, bioimaging, and lighting devices, a number of organic fluorescent materials have been synthesized and studied [1–5]. Most traditional organic fluorescent materials contain the structure of "donor (D)-conjugated bridge (π)-acceptor (A)". Previous studies have shown that, as for D-π-A prototype fluorescent materials, subtle variation of molecular structures would change their photophysical properties. Consequently, much research has been conducted in designing and synthesizing diverse classes of donor–acceptor (D-A) substituted π-conjugated derivatives (D-π-A), such as trephinelethene, 9, 10-divinylanthracene, distyrylbenzenes and cyanostilbene [6–10]. However, in order to further understand the structure–property relationship of organic fluorescent materials, studies on D-π-A prototype organic fluorescent materials are still isolated event. Therefore, there is a high demand for exploring new types of organic fluorescent materials.

Compared with D-π-A prototype organic fluorescent materials, by enlarging the π-conjugated linker, D-π-π-A prototype organic fluorescent materials possess broad and intense absorption in the visible spectral region, and applied in efficient solar cells, optical and electronic devices such as organic field-effect transistors (OFETs), organic light emitting diodes (OLEDs) and organic solar cells (OSCs). In this paper, we have designed and synthesized three novel D-π-π-A prototype organic fluorescent materials by changing the positions of biphenyl groups, namely, (E)-2-(3-([1,1′-biphenyl]-2-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (2-BAM), (E)-2-(3-([1,1′-biphenyl]-3-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (3-BAM), and (E)-2-(3-([1,1′-biphenyl]-4-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (4-BAM) (Scheme 1). Furthermore, their structures and photophysical properties were studied and compared. The results showed that changing the position of biphenyl groups would affect the structures and photophysical properties of such D-π-π-A prototype organic fluorescent materials, which is an effective way for turning structures and photophysical properties of organic fluorescent materials.
Experimental Section

General

Chemicals and solvents were purchased from Aldrich and Acros without further purification. The three compounds in this study were synthesized by the Knoevenagel reaction in a satisfactory yield [11]. The synthesis routes of three compounds were shown in Scheme 1. The $^1$H NMR and $^{13}$C NMR spectra of three compounds were taken at 303 K on a Agilent Technologies NMR spectrometer. Elemental analysis were performed using Flash EA 1112, CHNS-O instrument. The X-ray powder experiments were recorded on an 18 kW advance diffractometer (INCA Energy, Oxford Instruments). The differential calorimetry (DSC) was determined from 30 to 300 °C at 10 °C/min (Netzsch TG 209 apparatus). UV–vis absorption spectra were obtained on a TU-1901 spectrophotometer. Fluorescence spectra were taken on a RF-5000 spectrometer. The absolute photoluminescence quantum yield ($\Phi_{PL}$) was determined by HORIBA FluoroMax-4P fluorescence spectrometer using an integrating sphere.

Diffraction data for crystal were obtained with a Rigaku RAXISRAPID diffractometer. The structures were solved with direct methods using the SHELX program and refined with fullmatrix least-squares procedure [12]. All non-hydrogen atoms were refined anisotropically. Hydrogen atoms were inserted at idealized positions and refined by isotropic displacement. The DIAMOND program [13] and Mercury [14] were used to obtain the molecular graphics. The Multiwfn 3.7 program [15] was used to obtain the distributions of HOMO and LUMO.

Synthesis

Synthesis of (E)-2-((1,1'-biphenyl)-2-yl)-1-(9H-fluoren-2-yl) allyl-dene)malononitrile (2-BAM)

Initially, 2-acetylfuorene 1 (2.45 g, 11.75 mmol) was stirred with malononitrile (1.16 g, 17.625 mmol) in mixture of dichloromethane (20 mL) and methanol (10 mL), ammonium acetate (1.36 g, 17.625 mmol) was subsequently added. The mixture was stirred for 6 h at 40 °C. After removing the solvent, the resulting precipitate was separated with chromatography on silical gel (ethyl acetate/petroleum ether = 5/1) to afford pure compound 2 as a canary yellow solid (2.4 g, 80%). Anal. Calcd. (%): C, 84.77; H, 4.30; N, 10.93. Found: C, 84.71; H, 4.32; N, 10.97. $^1$H NMR (300 MHz, CDCl$_3$): δ 7.90 (m, 2H), 7.66 (s, 1H), 7.62 (m, 1H), 7.64 (t, 2H, 6 Hz), 7.44 (m, 2H), 4.00 (m, 2H), 2.72 (s, 3H). (Fig. S1, ESI†). $^{13}$C NMR (300 MHz, CDCl$_3$): 173.28, 145.39, 144.52, 142.73, 141.28, 139.77, 128.39, 127.24, 126.36, 125.84, 120.92, 118.42, 116.58, 77.49, 37.02, 25.76.

Compound 2 (0.24 g, 0.92 mmol) was stirred with biphenyl-2-carboxaldehyde (0.17 g, 0.92 mmol) in 2-propanol (15 mL). A catalytic amount of piperidine was added to the solution, and then the mixture was stirred for 3 h at 70 °C. After removing the solvent, the resulting precipitate was separated with chromatography on silical gel (dichloromethane/methanol = 4/1) to give pure 2-BAM as a yellow solid. Yield: 0.31 g (81%). Anal. Calcd. (%): C, 88.54; H, 4.80; N, 6.66. Found: C, 88.57; H, 4.82; N, 6.61. $^1$H NMR (300 MHz, CDCl$_3$): 6.780 (d, 1H, 3 Hz), 7.75 (d, 1H, 6 Hz), 7.58 (d, 1H, 3HZ), 7.48 (t, 2H, 18 Hz), 7.15 (t, 2H, 18 Hz).

Scheme 1 Synthetic route and chemical structures of three compounds
7.46 (m, 2H), 7.45 (s, 1H), 7.42 (t, 2H, 6 Hz), 7.39 (t, 1H, 3 Hz), 7.35 (m, 3H), 7.17 (m, 3H), 7.06 (d, 1H, 12 Hz), 3.84 (s, 2H) (Fig. S2, ESI†). $^{13}$C NMR (300 MHz, CDCl$_3$): δ 169.48, 145.72, 142.37, 141.69, 140.91, 136.73, 132.92, 131.77, 129.46, 128.28, 127.75, 126.58, 125.13, 124.96, 122.32, 121.69, 120.34, 116.68, 64.89, 37.38 ppm. IR (KBr pellet, cm$^{-1}$): 2285 (νC≡N), 1589 (νC=C), 1514 (νC-C), 1467 (νC-H), 1452 (νC-H), 835–696 (νAr-H) (Fig. S3, ESI†).

**Synthesis of (E)-2-(3-([1,1'-biphenyl]-3-yl)-1-(9H-fluoren-2-yl)allyl-diene)malononitrile (3-BAM)**

This compound was synthesized by the same procedure as described for 2-BAM except that biphenyl-3-carboxaldehyde was used instead of biphenyl-2-carboxaldehyde. Anal. Calcd. (%): C, 88.54; H, 4.80; N, 6.66. Found: C, 88.51; H, 4.78; N, 6.71. $^1$H NMR (300 MHz, CDCl$_3$): δ 7.99 (d, 1H, 6Hz), 7.91 (d, 1H, 6 Hz), 7.74 (m, 3H), 7.64 (m, 5H), 7.53 (d, 1H, 3 Hz), 7.47 (m, 6H), 7.03 (d, 1H, 12 Hz), 4.04 (s, 2H) (Fig. S4, ESI†). $^{13}$C NMR (300 MHz, CDCl$_3$): δ 168.31, 144.63, 141.82, 140.52, 139.78, 136.45, 131.92, 130.27, 129.15, 127.39, 126.18, 125.96, 124.47, 120.59, 116.28, 64.14, 37.22 ppm. IR (KBr pellet, cm$^{-1}$): 2218 (νC≡N), 1597 (νC=C), 1552 (νC=C), 1504(νC-H), 1409 (νC-H), 835–702 (νAr-H) (Fig. S7, ESI†).

**Photophysical Properties in Solid State**

As shown in Fig. 1, 2-BAM, 3-BAM, and 4-BAM displayed strong emissions with maximum PL peaks ($\lambda_{max}$) at 516, 522, and 567 nm, respectively (Fig. 1 and Table 3). Under illumination with a 365 nm UV lamp, Solids of 2-BAM and 3-BAM both emitted strong yellow green light, while 4-BAM emitted strong yellow light. Compared with the solid of 2-BAM, the emission wavelength of 3-BAM was slightly red-shifted. However, the emission wavelength of 4-BAM...
was red-shifted with 51 nm, compared with that of 2-BAM ($\lambda_{\text{max}}$, 516 and 567 nm for 2-BAM and 4-BAM, respectively, Table 3). From the solid emission behaviors of three compounds, it can be found that changing the positions of biphenyl group would lead to different photophysical property of such organic fluorescent compound.

Emission quantum yields ($\Phi_F$) and fluorescence lifetimes ($\tau_F$) were measured to further study their photophysical properties. 9,10-diphenylanthracene was used as a standard [$\Phi_F = 100\%$ in DCM] by excitation at 468 nm. All three compounds in this study and 9,10-diphenylanthracene were dissolved in DCM at $10^{-6}$ M and measured.

their absorptions at 468 nm. Thus obtained absorptions (Abs) and the integrated area (S) of the emission spectra obtained by excitation at 468 nm were used for the estimation of the fluorescence quantum yields. As summarized in Table 3, the emission quantum yields ($\Phi_F$) of three compounds were 31%, 53%, and 59% for 2-BAM, 3-BAM and 4-BAM, respectively. In addition, as summarized in Fig. 2 and Table 3, the fluorescence lifetimes ($\tau_F$) of three compounds were 4.90, 1.87, and 2.57 ns for 2-BAM, 3-BAM and 4-BAM, respectively. The differences in emission quantum yields ($\Phi_F$) and fluorescence lifetimes ($\tau_F$) should attributed to the different positions of biphenyl groups.

**Crystal Structures**

In order to investigate the structure–property relationship of three compounds, single crystals of the three compounds were obtained by the vapor diffusion method. Mixed solvents of dichloromethane and methanol were used for three compounds (dichloromethane/methanol; 3/1, 2/1, and 4/1 for 2-BAM, 3-BAM, and 4-BAM, respectively). Single crystals of three compounds were obtained by slow evaporation of the mixed solvents at room temperature for 4–5 days, respectively. Relevant crystallographic data of 2-BAM, 3-BAM, and 4-BAM are summarized in Table 1.

Crystal of 2-BAM have the space group $P\overline{1}$ with triclinic system, and its molecular illustration is shown in Fig. 3a. In the molecule of 2-BAM, the dihedral angle between the
fluorene and conjugated bridge (C\(\equiv\)C) moieties was 65.2°, and the dihedral angle between biphenyl and conjugated bridge (C\(\equiv\)C(CN))_2-conjugated bridge (C\(\equiv\)C) moieties was 9.6° (see Fig. 3b). In addition, the dihedral angle between the two phenyl rings was 44.8° (see Fig. 3b). These dihedral angles indicate that molecular geometry of 2-BAM in solid state was highly twist. As shown in Fig. 3c, molecule in 2-BAM slipped to the neighboring molecule, with a slip angle of 60.5° and a vertical distance of 3.49 Å, which indicates the H-aggregation of molecules. The main interactions among the neighboring molecules in 2-BAM were C-H…N interactions (Table 2), and molecules were packed into a 1D column structure (Fig. 3c). In addition, the centre distance \(d_{\text{centre}}\) between the neighboring molecules in 2-BAM was measured to be 4.0 Å, and vertical distance \(d_{\text{vertical}}\) between two fluorene moieties was 3.49 Å, indicating that there was relatively strong π…π stacking.

Similar to that of 2-BAM, the unit cell of 3-BAM also has the space group \(P\bar{1}\), belonging to triclinic system, and its molecular illustration is presented in Fig. 4a. In the molecule of 3-BAM, the dihedral angle between the fluorene and conjugated bridge (C\(\equiv\)C(CN))_2-conjugated bridge (C\(\equiv\)C) moieties was 58.6°, and the dihedral angle between biphenyl and conjugated bridge (C\(\equiv\)C(CN))_2-conjugated bridge (C\(\equiv\)C) moieties was 9.8° (see Fig. 4b). In addition, the dihedral angle between the two phenyl rings was 37.3°. These dihedral angles indicated that molecular geometry of 3-BAM in solid state was also highly twist. As shown in Fig. 4c, molecules in 3-BAM slipped to the neighboring molecule, with a slip angle of 13.3° and a vertical distance of 2.38 Å, indicating the J-aggregation of molecules. The main interactions between the neighboring molecules in 3-BAM were C-H…π and C-H…N interactions (Table 2), and molecules were packed into a 3D layer structure (Fig. 4d). In addition, the centre distance \(d_{\text{centre}}\) between the neighboring molecules in 3-BAM was measured to be 10.27 Å, and vertical distance \(d_{\text{vertical}}\) between two fluorene moieties was 2.38 Å (Fig. 4c), indicating that there was no overlap between the neighboring fluorene moieties, and no π…π interactions were formed in the crystal of 3-BAM.

The unit cell of 4-BAM was monoclinic, and the space group was \(C2/c\). The molecular illustration of 4-BAM was presented in Fig. 5a. In the molecule of 4-BAM, the dihedral angle between the fluorene and conjugated bridge (C\(\equiv\)C(CN))_2-conjugated bridge (C\(\equiv\)C) moieties was 67.8°, and the dihedral angle between biphenyl and conjugated bridge (C\(\equiv\)C(CN))_2-conjugated bridge (C\(\equiv\)C) moieties was 16.1° (see Fig. 5b). In addition, the dihedral angle between the two phenyl rings was 35.6° (see Fig. 5b). These dihedral angles indicated that molecular geometry of 4-BAM in solid state was also highly twist. As shown in Fig. 5c, molecules in 4-BAM slipped to the neighboring molecule, with a slip angle of 48.6° and a
vertical distance of 11.88 Å (see Fig. 5c), indicating the J-aggregation of molecules. The main interactions between the neighboring molecules in 4-BAM were C-H...π and C-H...N interactions (Table 2), and molecules were packed into a 3D layer structure (Fig. 5d). In addition, the centre distance $d_{centre}$ between the two neighboring molecules in 4-BAM was measured to be 15.90 Å, and vertical distance $d_{vertical}$ between two fluorene moieties was 11.88 Å, indicating that there was no overlap between the neighboring fluorene moieties, and no π...π interactions were formed in the crystal of 4-BAM.

From the crystal analysis of three compounds, it can be found that although all three compounds showed highly twisted geometries, their molecular packing and intermolecular interactions were different. Especially, their dihedral angles between the two phenyl rings were different (44.8°, 37.3° and 35.6° for 2-BAM, 3-BAM and 4-BAM, respectively), which indicates that changing the position of biphenyl group would affect the geometries of its own. Overall,

Table 2 Summary of intermolecular interactions in crystal structures of three compounds

| Compd | Interaction | d (Å) | A (°)  |
|-------|-------------|-------|-------|
| 2-BAM | C22-H22...N1 | 3.50a | 148.93 |
|       | C7-H7...N2  | 3.14a | 160.95 |
| 3-BAM | C9-H9...N1  | 3.36a | 122.11 |
|       | C18-H18...π1b | 3.16c | 120.81 |
|       | C26-H26...π1b | 3.21c | 122.85 |
| 4-BAM | C10-H10...N1 | 3.55a | 145.79 |
|       | C14-H14...π2d | 2.71c | 135.23 |

a The distances were measured from the hydrogen atom the nitrogen atom
b $π_1$ corresponds to the phenyl ring made by the carbon atoms of C7-C12
c The distances were measured from the hydrogen atom to the center of phenyl ring
d $π_2$ corresponds to the phenyl ring made by the carbon atoms of C8-C13
Fig. 4 Perspective views of 3-BAM with the thermal ellipsoids set at 30% probability (a). Schematic molecular structures of 3-BAM in crystal. The fluorene moieties were shown in red. The conjugated bridge (C=C(CN)_2)-conjugated bridge (C=C) moieties were shown in blue. The phenyl rings linked to the conjugated bridge (C=C(CN)_2)-conjugated bridge (C=C) moieties were shown in light green. The phenyl rings on the other side of biphenyl moieties were shown in magenta (b). Packing diagram of 3-BAM via J-aggregation. The biphenyl moieties were shown in magenta (c). The layer structure of 3-BAM (d). Hydrogen atoms are omitted for clarity.

Fig. 5 Perspective views of 4-BAM with the thermal ellipsoids set at 30% probability (a). Schematic molecular structures of 4-BAM in crystal. The fluorene moieties were shown in red. The conjugated bridge (C=C(CN)_2)-conjugated bridge (C=C) moieties were shown in blue. The phenyl rings linked to the conjugated bridge (C=C(CN)_2)-conjugated bridge (C=C) moieties were shown in light green. The phenyl rings on the other side of biphenyl moieties were shown in magenta (b). Packing diagram of 4-BAM via J-aggregation. The biphenyl moieties were shown in magenta (c). The stacking image of 4-BAM (d). Hydrogen atoms are omitted for clarity.
the different molecular structures of three compounds indicated the influence induced by changing the position of biphenyl groups.

In order to study the influence induced by changing the positions of biphenyl groups, and further investigate the structure–property relationship of three compounds, the HOMOs and LUMOs of the three compounds in crystal were obtained by quantum computations at the molecular level according to the density functional method at the B3LYP/6-31G level. As shown in Fig. 6, as for 2-BAM and 3-BAM, their HOMO electrons were both distributed mainly on conjugated bridge (C=C(CN)2)-conjugated bridge (C=C) and fluorene moieties, respectively. However, the HOMO electrons of 4-BAM were distributed on the whole molecular backbone, which would lead to better conjugation character of molecules, thus giving rise to the red-shifted emission of 4-BAM, compared with that of 2-BAM and 3-BAM in solid state (λmax; 516, 522 and 567 nm for 2-BAM, 3-BAM, and 4-BAM, respectively, Table 3). Thus, it can be found from the theoretical calculations that, changing the position of biphenyl group would affect electron distributions of three compounds in solid state, endowing them with different emission behaviors.

The UV–vis Absorption of Three Compounds

The absorption spectra of three compounds in dichloromethane (DCM) were shown in Fig. 7. There are two main absorption bands in such D–π–π–A prototype compounds (see Fig. 7). As shown in Fig. 7, as for the three compounds, there was one similar absorption located at about 229 nm (229, 229, and 228 nm for 2-BAM, 3-BAM, and 4-BAM, respectively, Table 3), corresponding to the intramolecular charge transfer (ICT) process. However, the other absorptions located at about 365 nm were different (365, 369, and 385 nm for 2-BAM, 3-BAM, and 4-BAM, respectively), corresponding to the intramolecular charge transfer (ICT) process. However, the other absorptions located at about 365 nm were different (365, 369, and 385 nm for 2-BAM, 3-BAM, and 4-BAM, respectively, Table 3), which correspond to the π…π* transition. From the absorption spectra of three compounds, it can be found that the absorption band contributed to π…π* transition of 4-BAM was red-shifted compared with that of 2-BAM.

| Compd | Solution | Solid |
|-------|----------|-------|
|       | Abs(nm)  | PL(nm) | PL(nm) | ΦPl(%) | τf(ns) |
| 2-BAM | 365      | 518    | 516    | 31     | 4.90   |
| 3-BAM | 369      | 520    | 522    | 53     | 1.87   |
| 4-BAM | 385      | 547    | 567    | 59     | 2.57   |

Table 3 Photophysical properties of isomers in this study
and 3-BAM. Therefore, the similarities and differences of absorption spectra in dilute solution indicate the influence on the ground-state electron distributions of such fluorescent material induced by changing the positions of biphenyl groups.

**The Photoluminescence (PL) Property in Solution**

The photoluminescence property of three compounds in DCM was also investigated. As shown in Fig. 8, the maximum PL peaks ($\lambda_{\text{max}}$) of 2-BAM, 3-BAM, and
4-BAM were 518, 520, and 547 nm, respectively (Table 3). Compared with that of 2-BAM and 3-BAM, the emission wavelength of 4-BAM in dilute solution was red-shifted. In order to further investigate structure–property relationship of three compounds in dilute solution, the HOMOs and LUMOs of three compounds in solution state were also

**Fig. 9** Calculated frontier molecular orbitals of three compounds in dilute solution. The LUMOs of three compounds were -2.74, -2.80 and -2.82 eV for 2-BAM, 3-BAM and 4-BAM, respectively. The HOMOs of three compounds were -6.12, -6.12 and -6.03 eV for 2-BAM, 3-BAM and 4-BAM, respectively. The HOMO–LUMO gaps of three compounds were 3.38, 3.32 and 3.21 eV for 2-BAM, 3-BAM and 4-BAM, respectively.

**Fig. 10** DSC profiles of three compounds

![Graph showing DSC profiles of 2-BAM, 3-BAM, and 4-BAM](chart)

- **Heat flow**
- **Temperature (°C)**

- **Legend:**
  - Red: 2-BAM
  - Green: 3-BAM
  - Blue: 4-BAM
obtained by quantum computations at the molecular level, according to the density functional method at the B3LYP/6-31G level. For 2-BAM and 3-BAM, their HOMO electrons were both distributed mainly on conjugated bridge (C = C(CN)2)-conjugated bridge (C = C) and fluorene moieties, respectively (see Fig. 9). However, the HOMO electrons of 4-BAM were distributed through the whole molecular backbone, which would lead to better molecular conjugation character, thus giving rise to the red-shifted emission of 4-BAM in solution, compared with that of 2-BAM and 3-BAM (λ_max; 518, 520 and 547 for 2-BAM, 3-BAM, and 4-BAM, respectively, Table 3).

**Thermodynamic Property**

Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) of three compounds were taken to study their thermodynamic stability (Fig. S8, ESI†). As Fig. 10 shows, 2-BAM, 3-BAM, and 4-BAM melt at 210.05, 216.81, and 219.27 °C, respectively, indicating that the three compounds all exhibit high thermal stability. In addition, the similar melting points of three compounds reveal that changing the position of biphenyl group would not affect melting points of such fluorescent material distinctly. However, this is not the case for their melting enthalpy (4.88, 73.98, and 82.36 J g⁻¹ for 2-BAM, 3-BAM, and 4-BAM, respectively).

**Conclusion**

In order to study the influence on the structure and property of D-π-π-A prototype organic fluorescent material induced by the changing the position of biphenyl group, three novel compounds, namely, (E)-2-(3-[1,1′-biphenyl]-2-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (2-BAM), (E)-2-(3-[1,1′-biphenyl]-3-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (3-BAM), (E)-2-(3-[1,1′-biphenyl]-4-yl)-1-(9H-fluoren-2-yl)allylidene)malononitrile (4-BAM) were synthesized. Furthermore, their structure–property relationship was investigated. Although three compounds all showed highly twisted geometries in crystals, their molecular packing and intermolecular interactions were different. Especially, changing the position of biphenyl groups would give rise to different geometries of its own. Because of the differences in electronic structures, the three compounds displayed different emission behaviors in solid and dilute solution. This study indicates that changing the positions of biphenyl groups is a useful way for turning the structure and property of D-π-π-A prototype fluorescent material.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s10895-022-02945-y.

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**Author Contributions** Dong-En Wu: conceptualization; investigation; methodology; formal analysis; writing-original draft. Qin-Yuan Yin: conceptualization; investigation; methodology; writing-review and editing; supervision. Qing-Hui Guo: writing-review and editing. All authors read and approved the final manuscript.

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**Data availability** All the data were given in the manuscript and supporting information files.

**Declarations**

**Ethical Approval** The submitted manuscript are prepared in compliance with the Ethics in Publishing Policy as described in the Guide for Authors, the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part.

**Consent to Participate** All the co-authors consent to participate.

**Consent for Publication** All the co-authors consent to publish.

**Conflict of Interest** The authors declare that they have no conflict of interest.

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