# Chiral Amplification in One-Dimensional Helical Nanostructures Self-Organized from Phenylethynyl Thiophene with Elaborated Long-Chain Dicarboxamides

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Supporting Information

**ABSTRACT:** A bis-phenylethynyl thiophene derivative functionalized with long-chain pyridyl biscarboxamides displayed unique helical morphology in the xerogel form via nicely complementary intermolecular interactions. The helical nanostructures visualized by TEM and AFM remarkably matched well with the computational results. Supramolecular chirality can be amplified by coassembly of a chiral conductor to bias the helical arrangement.



## ■ INTRODUCTION

Chirality plays a fundamental role in biological processes and has a profound influence on the chemistry and molecular interactions of living organisms.<sup>1</sup> Particular attention has been devoted to realization of the artificial hierarchical assemblies inspired from those intriguing self-organization of biological molecules into highly functional supramolecular chiral assemblies through noncovalent interactions.<sup>2</sup> Remarkable control of supramolecular chirality in nonbiological systems has been demonstrated with well-designed complementary building blocks by cooperative noncovalent interactions. Manipulation of chiral amplification is also important for many applications such as enantioselective catalysis, chiral separation, and sensing.<sup>3</sup>

Self-assembly of small molecules into one-dimensional nanostructures offers a number of potential applications in electronically and biologically active materials.<sup>4</sup> In this context, organogels represent promising candidates for creating such unique nanoscopic structures due to their ability of self-organization into highly ordered hierarchical nanomorphology.<sup>5</sup> Recently, we reported a unique building block featuring elaborated long-chain dicarboxamides, which easily turns the molecules incorporating such moieties into organogelators capable of effectively immobilizing a variety of organic solvents.<sup>6</sup> The perfectly matched intermolecular hydrogen-bonding and  $\pi$ -stacking interactions have been attributed to the highly efficient gelation ability of such rigid  $\pi$ -conjugated gelators. Herein, we report an interesting example of gelation-assisted preferential growth of one-dimensional helical nanostructures, and the supramolecular chirality of such assemblies can be further biased by coassembly of chiral and achiral gelators through the "sergeants-and-soldiers" approach.<sup>7</sup>

## RESULTS AND DISCUSSION

Three organogelators shown in Figure 1 were prepared by published methods and fully characterized.<sup>6</sup> TM12 was synthesized as a model compound to assess the photophysical properties of these organogelators. The different chain length in the gelators is expected to have little influence on the opticalties. The gelation ability is superior in some solvents with minimum gelation concentration as low as 0.5 mg/mL (see Table S1, Supporting Information). The sol-gel interconversion is fully thermoreversible by several cycles of heating and cooling. The organogels are remarkably stable, which can be stored for months except for gels based on PM-chiral, which slowly "melted" to viscous solution, and precipitation appeared in a few days. The longer alkyl chains in PM18 seem to provide stronger intermolecular interactions between the gelator molecules and the surrounding solvent molecules than its shorter congener PM-chiral, which resulted in their differences in terms of thermodynamic stability.

Temperature-dependent  ${}^{1}$ H NMR spectra were recorded for all three gelators (Figures S1–S3, Supporting Information). In general, the carboxamide N–H proton signal resonances in all

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**Figure 2.** TEM images of helical fibers of **PM18** ( $5.0 \times 10^{-5}$  M) self-assembly from a solution of toluene. The image at the right is a magnification of the image at the left side.

three gelators shifted to the upfield position, whereas the  $\beta$  proton resonances of pyridine and proton resonances of thiophene shifted to the downfield position with the temperature being raised from 298 to 338 K. The upfield shift of the carboxamide N–H proton signal and the downfield shift of the aromatic proton signals with increasing temperature suggest the weakening of intermolecular hydrogen-bonding and aromatic  $\pi-\pi$  interactions. The two doublet signal resonances from phenyl rings in **PM18** and **PM-chiral** also showed minor downfield shifts when temperature was raised from 298 to 338 K, also evidence of the weakening of aromatic  $\pi-\pi$  interactions. These results clearly demonstrated that the primary interactions responsible for molecular aggregation are due to the intermolecular hydrogen-bonding and favorable aromatic  $\pi-\pi$  interactions between the gelator molecules.

The absorption and fluorescence data along with fluorescence quantum yields of three gelators in optically dilute solution are summarized in Tables S2 and S3, Supporting Information. All three gelators display a series of absorption bands in the UV region and tailed into the near UV region (Figure S4, Supporting Information). The high-energy absorption band at ca. 334 nm for these compounds is assigned to a  $\pi - \pi^*$  transition mainly localized on the ethynylpyridine biscarboxamide moieties, whereas the low-energy absorption band at ca. 385 nm, which is absent in the spectrum of **TM12**, is assigned to the  $\pi - \pi^*$  transition mainly localized on the bisphenylethynyl thiophene.

All compounds show fairly weak fluorescence at room temperature solution with quantum yields less than 0.42% with typical fluorescence lifetimes in the subnanosecond scale.

The fluorescence intensities of these gelators are enhanced from solution to gel state (Figure S5, Supporting Information). The radiative rate constants in dilute solution and in the gel form are comparable for both **PM18** and **PM-chiral**, whereas the nonradiative rate constants display a 2-fold decrease in the gel form compared to the solution state (see Tables S2 and S3, Supporting Information). Upon formation of gel, the resulting ordered aggregates not only bathochromatically shifted the absorption to a longer wavelength compared to its molecularly dissolved counterparts but also expect to greatly reduce the conformational flexibility and, thus, slow down the nonradiative decay processes with enhanced fluorescence quantum yields.<sup>6b,8</sup>

TEM images for three gelators display interconnected networks of fibers with a diameter on the order of 20–50 nm and a length of several micrometers. The aspect ratios of the fibril assemblies are estimated to be ~2000. Careful scrutiny of the image of gelator **PM18** from a dilute solution of toluene ( $5.0 \times 10^{-5}$  M) in Figure 2 (see also Figure S9, Supporting Information, for a larger image of Figure 2) reveals an intriguing one-dimensional helical morphology with an average helical pitch of ~11 nm. The diameters of these helical stacks are estimated to be 10.4 nm, which is slightly longer than the extended molecular length calculated by molecular modeling (vide infra).







Figure 4. Schematic representation of the self-assembled organogelators into helical nanostructures, and effect of doping PM-chiral on the energy disparity of the enantiomeric helical formation.

The helical fibers observed in TEM for xerogels of **PM18** prepared from toluene solution are even more prominent under AFM studies. Figure 3 shows AFM images of the xerogels of **PM18** prepared from toluene on silicon oxide (see also Figures S10–S13, Supporting Information). The AFM images clearly display formation of entangled left-handed helical and right-handed helical fibers. The pitch distribution of these helical fibers ranges from ~11 to 120 nm depending on the gelator concentration. At a concentration of  $5.0 \times 10^{-5}$  M, the thinnest helical

pitch and diameter are estimated to be ~11 and 12 nm, respectively, with a typical length of 1.5  $\mu$ m. Longer and thicker helical fibers of **PM18** were observed in the AFM image at a concentration of  $6.0 \times 10^{-4}$  M. Attempts to acquire AFM images at  $1.0 \times 10^{-3}$  M or higher concentration were not successful but produced very blurry images. It is interesting to note that the AFM images of **PM-chiral** showed scattered helical fibers out of normal linear fibers (Figures S14 and S15, Supporting Information). The lack of a majority of helical fibers in the xerogel

of **PM-chiral** is likely due to the nature of the thermodynamic instability of **PM-chiral** aggregates during the solvent evaporation process when preparing the xerogels for AFM measurements.

To unveil the nature of noncovalent interactions and supramolecular aggregation at these gelator systems, molecular mechanics and dynamics simulations were carried out using a Dreiding force field.<sup>9</sup> By taking advantage of the intramolecular hydrogen-bonding interactions between the amide N-Hs and the pyridine N atom, the pyridyl bis-carboxamide moiety adopts a rigid planar conformation and affords the corresponding twisted structures of an enantiomeric pair in PM18 (Figure S16, Supporting Information). This stereorequirement develops extraordinary features, leading to the enantiomeric stacking arrangements between the neighboring gelators with slightly clockwise- and counter-clockwise-oriented stackings. The optimized stackings are stabilized by the strong intermolecular hydrogen-bonding interactions of the amide N-Hs with the next adjacent amide carbonyl O atoms and  $\pi - \pi$  interactions. The optimized spacing and offset angle between the two adjacent gelator molecules are found to be 3.7 Å and 11°, respectively. As anticipated, the XRD patterns of toluene films of PM18 and PM**chiral** exhibit a diffuse reflection at d = 3.6 and 3.7 Å, respectively, indicative of noticeable  $\pi - \pi$  interactions in the gel state (see Figure S18, Supporting Information).

Figure 4 gives the nanocoil aggregate structures of PM18 in which the relevant structural parameters are closely matched with the TEM and AFM images with a diameter of around 10 nm and a pitch length of 11 nm consisting of 33 aggregated gelator molecules. Molecular dynamics simulations show that an equilibrium mixture exists between the left-handed and right-handed sense of PM18 assembly. It is interesting to note that a slight counter-clockwise-oriented stacking of the coassembly would be relatively more stable than the clockwise one by 8.5 and 14.5 kcal mol<sup>-1</sup> at a doping of 50% and 100% **PM-chiral**, respectively. The XRD pattern of PM18 showed a reflection peak corresponding to a *d* spacing of the aggregate of 32.2 Å (see Figure S18, Supporting Information), which is on the order of the calculated interdigitated alkoxyl chains with 31.9 Å. Both XRD patterns of PM18 and PM-chiral at the low-angle region displayed a peak at  $\sim$ 20 Å, which is attributed to the molecular dimension along the 2,5-bis-phenylethynyl thiophene framework.

PM-chiral showed no circular dichroism (CD) responses until the concentration was higher than 7.5  $\times$  10<sup>-5</sup> M with three negative CD bands appearing at 360, 412, and 438 nm (Figure S20, Supporting Information). The contribution of linear dichroism (LD) to the observed spectra is considered to be small because the recorded LD signals from the same samples were very weak and the intensities of CD bands were intact to the rotation of the sample by  $90^\circ$  in a plane normal to the incident light.<sup>10</sup> As expected, achiral **PM18** was CD silent, which indicates no net macromolecular chirality presented in these achiral supramolecular aggregates. Nonetheless, it is possible to bias the helicity of achiral units in the presence of chiral handles and strong noncovalent interactions between the monomeric units with an intrinsic conformational chirality of the assembly and careful matching of secondary interactions to obtain a welldefined chiral conformation in the aggregation process.<sup>1</sup> Indeed, the appearance of the CD signal of PM18 with a negative value was observed upon doping of PM-chiral over 5 mol %, which is indicative of formation of left-handed chiral helical aggregates (Figure 5).<sup>5a,11</sup> The negative and positive Cotton bands at a doping of PM-chiral over 20 mol % appeared at 362 and 338 nm,



**Figure 5.** CD spectra of **PM18** in toluene  $(1 \times 10^{-3} \text{ M})$  at 25 °C with different amounts of coassembled **PM-chiral**.



Figure 6. Temperature dependence of the UV–vis (top) and CD (bottom) spectra of a toluene solution of PM18 ( $1 \times 10^{-3}$  M) and PM-chiral (5 mol %) coassembly at different temperatures.

respectively, with a zero crossing at 348 and 330 nm, which is close to the  $\pi - \pi^*$  transition of the thiophene ethynylpyridyl dicarboxamide chromophore in the gel state. Thus, the observed CD spectra suggest that the left-handed helical arrangement is circularly polarized along the transition moments of the thiophene ethynylpyridyl dicarboxamide chromophores. The CD intensities at 362 nm are plotted against the doping concentration of PM-chiral (Figure S21, Supporting Information), showing a steady increase of CD signal upon increasing the amount of PM-chiral. The LD spectra were separately recorded under the same experimental conditions (Figure S22, Supporting Information). The optical densities of the LD signals from these gel samples were very weak (<0.001), and thus, their contributions to the observed CD spectra were considered to be negligible.<sup>10</sup> The CD signals increased with doping amount of PM-chiral up to 30 mol % in the supramolecular assemblies with



anisotropy factor g values of  $-1.9 \times 10^{-3}$  and  $2.3 \times 10^{-4}$  at 362 and 338 nm, respectively.<sup>7b</sup> A similar pattern but weaker intensity of CD responses of **PM18** upon coassembling various amounts of **PM-chiral** was observed when the concentration of **PM18** was lowered to  $1 \times 10^{-4}$  M (Figure S23, Supporting Information).

Variable-temperature absorption spectra of coassembled **PM18** (1 × 10<sup>-3</sup> M) and **PM-chiral** (5 mol %) showed a clear transition from the molecularly isolated molecules to the self-assembly nanostructures upon decreasing temperature (Figure 6).<sup>12</sup> The temperature at  $\alpha_{agg} = 0.5$  is estimated to be 35 °C on the basis of temperature-dependent UV–vis absorption spectra of coassembled **PM18** (1 × 10<sup>-3</sup> M) and **PM-chiral** (5 mol %) (Figure S24, Supporting Information).<sup>5e</sup> The CD signal did not appear until the temperature was lower than 45 °C, which is slightly higher than the critical gelation temperature of 36 °C. The CD intensity increased with decreasing temperature due to the enhanced intermolecular interactions between gelator molecules with decreasing temperature. Heating the sample again resulted in a gradual disappearing of the CD signal, whereas the CD signal can be restored by cooling the sample, demonstrating the highly dynamic nature during the chiral conversion process.

### CONCLUSION

In summary, the xerogel of **PM18** displayed unique helical morphology via nicely complementary intermolecular hydrogenbonding and aromatic  $\pi - \pi$  stacking interactions. The helical nanostructures visualized by TEM and AFM matched with the theoretically calculated helical pitches and diameters. Thus, the hierarchical assembly of supramolecular helices can be realized at

the molecular level by microscopic techniques. The supramolecular chirality can be induced by coassembly of a chiral conductor **PM-chiral** and **PM18** to bias the helical arrangement via the "sergeant and soldiers" principle, which was confirmed by chiral amplification of CD Cotton signals. The degree of chiral amplification strongly depends on temperature. The intermolecular interactions are enhanced between the gelators with decreasing temperature and resulted in a favorable chiral amplification effect.

### EXPERIMENTAL SECTION

**Materials and Methods.** All chemicals are commercially available unless mentioned elsewhere. All reactions and manipulations were carried out under  $N_2$  with the use of standard inert atmosphere and Schlenk techniques. Solvents used for synthesis were dried by standard procedures and stored under nitrogen atmosphere. Reactions were monitored by TLC using aluminum plates precoated with a 0.25 mm layer of silica gel containing a fluorescent indicator. Starting materials, 3,4-diethynyl-2,5-bis(phenylethynyl)thiophene (4),<sup>6a</sup> 4-bromo- $N^2$ , $N^6$ bis(4-(dodecyloxy)phenyl)pyridine-2,6-dicarboxamide (7),<sup>6a</sup> and 3,4diethynylthiophene (17)<sup>13</sup> were synthesized according to published methods. The synthetic procedures are outlined in Schemes 1 and 2.

Compound **8**. To a 500-mL flask containing 4-(octadecyloxy)aniline (1.66 g, 4.6 mmol) and 4-bromo-pyridine-2,6-dicarbonyl dichloride (0.59 g, 2.1 mmol) was added  $CH_2Cl_2$  (60 mL) and  $NEt_3$  (1.0 mL), and the resulting mixture was stirred at room temperature for 12 h. The solution was washed with water (100 mL  $\times$  3). The organic layer was collected and dried over MgSO<sub>4</sub>. The resulting residue was redissolved in THF and slowly precipitated with MeOH in a freezer to afford a white

solid (1.53 g, 78%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  9.29 (s, 2H), 8.58 (s, 2H), 7.60 (d, 4H, *J* = 8 Hz), 6.91 (d, 4H, *J* = 8 Hz), 3.94 (t, 4H, *J* = 6 Hz), 1.87–1.79 (m, 4H), 1.53–1.18 (m, 60H), 0.86 (t, 6H, *J* = 6.8 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  159.9, 156.7, 150.0, 136.8, 129.7, 128.7, 122.0, 114.9, 68.4, 31.9, 29.7, 29.6, 29.3, 26.0, 22.7, 14.1. HRFABMS *m*/*z* 932.5878 (calcd *m*/*z* 932.5880 for [M + H]<sup>+</sup>). Anal. Calcd for C<sub>55</sub>H<sub>86</sub>N<sub>3</sub>O<sub>4</sub>Br·H<sub>2</sub>O: C, 69.45; H, 9.32; N, 4.42. Found: C, 69.13; H, 9.21; N, 4.33.

Compound **S-9**. To a 500-mL flask containing (S)-4-(2-methylbutoxy)aniline (0.88 g, 4.9 mmol) and 4-bromo-pyridine-2,6-dicarbonyl dichloride (0.62 g, 2.2 mmol) was added CH<sub>2</sub>Cl<sub>2</sub> (60 mL) and NEt<sub>3</sub> (1.0 mL), and the resulting mixture was stirred at room temperature for 12 h. The solution was washed with water (100 mL × 3). The organic layer was collected and dried over MgSO<sub>4</sub>. The resulting residue was redissolved in THF and slowly precipitated with MeOH in a freezer to afford a white solid (0.98 g, 78%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  9.28 (s, 2H), 8.59 (s, 2H), 7.61 (d, 4H, *J* = 7 Hz), 6.92 (d, 4H, *J* = 7 Hz), 3.89–3.69 (m, 4H), 1.93–1.79 (m, 2H), 1.65–1.45 (m, 2H), 1.34–1.18 (m, 2H), 1.01 (d, 6H, *J* = 5.2 Hz), 0.95 (t, 6H, *J* = 5 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  159.7, 156.8, 150.0, 136.7, 129.6, 128.7, 121.9, 115.0, 73.2, 34.7, 26.1, 16.5, 11.3. HR-FAB MS *m*/*z* 568.1811 (calcd *m*/*z* 568.1811 for [M + H]<sup>+</sup>). Anal. Calcd for C<sub>29</sub>H<sub>34</sub>N<sub>3</sub>O<sub>4</sub>Br: C, 61.27; H, 6.03; N, 7.39. Found: C, 61.05; H, 6.03; N, 7.36.

PM18. Under an atmosphere of nitrogen, a 100-mL Schlenk flask equipped with a magnetic stir bar and a reflux condenser was charged with 4 (0.23 g, 0.7 mmol), 8 (1.4 g, 1.5 mmol), Pd(PPh<sub>3</sub>)<sub>4</sub> (81 mg, 0.07 mmol), CuI (13 mg, 0.07 mmol), and iPr<sub>2</sub>NH (50 mL). The mixture was refluxed for 24 h. After reaction, the volatile solvent was removed under reduced pressure. Subsequently, water (100 mL) was added and the brown suspension was extracted with  $CH_2Cl_2$  (100 mL  $\times$  3). The organic layer was collected, dried over MgSO<sub>4</sub>, filtered through a short neutral alumina column, and then evaporated to dryness. The resulting residue was redissolved in THF and slowly precipitated with CH<sub>3</sub>CN in a freezer to afford a yellow solid (0.47 g, 33%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  9.42 (s, 4H), 8.35 (s, 4H), 7.67–7.49 (m, 12H), 7.43–7.33 (m, 6H), 6.70 (d, 8H, J = 8.6 Hz), 3.82 (t, 8H, J = 6.5 Hz), 1.82 - 1.69 (m, 6H)8H), 1.51-1.17 (m, 120H), 0.86 (t, 12H, J = 6.5 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 160.6, 156.5, 149.7, 134.3, 132.0, 130.6, 129.4, 128.6, 127.9, 126.8, 121.7, 114.9, 100.7, 92.8, 89.3, 80.8, 73.4, 34.9, 29.7, 26.3, 16.5, 11.3. HR-MALDI MS m/z 2058.1670 (calcd m/z 2058.3638 for  $[M + Na]^+$ ). Anal. Calcd for  $C_{134}H_{182}N_6O_8S \cdot 6H_2O$ : C, 75.03; H, 9.12; N, 3.92; S, 1.49. Found: C, 75.03; H, 9.04; N, 3.90; S, 1.84.

PM-chiral. Under an atmosphere of nitrogen, a 100-mL Schlenk flask equipped with a magnetic stir bar and a reflux condenser was charged with 4 (0.23 g, 0.7 mmol), S-9 (0.85 g, 1.5 mmol), Pd(PPh<sub>3</sub>)<sub>4</sub> (81 mg, 0.07 mmol), CuI (13 mg, 0.07 mmol), and *i*Pr<sub>2</sub>NH (50 mL). The mixture was refluxed for 24 h. After reaction, the volatile solvent was removed under reduced pressure. Subsequently, water (100 mL) was added and the brown suspension was extracted with  $CH_2Cl_2$  (100 mL  $\times$  3). The organic layer was collected, dried over MgSO<sub>4</sub>, filtered through a short neutral alumina column, and then evaporated to dryness. The resulting residue was redissolved in THF and slowly precipitated with CH<sub>3</sub>CN in a freezer to afford a yellow solid (0.32 g, 35%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 9.43 (s, 4H), 8.41 (s, 4H), 7.72–7.49 (m, 12H), 7.46-7.33 (m, 6H), 6.75 (d, 8H, J = 8.4 Hz), 3.84-3.58 (m, 8H), 1.92-1.78 (m, 4H), 1.36-1.14 (m, 8H), 1.09-0.85 (m, 24H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  160.5, 156.2, 149.5, 134.2, 132.0, 130.4, 129.5, 128.6, 127.8, 126.7, 126.4, 121.6, 114.6, 100.6, 96.1, 92.7, 89.1, 80.7, 68.3, 32.6, 31.9, 29.7, 29.6, 29.4, 26.1, 22.7, 14.1. HR-MALDI MS m/z 1308.6215 (calcd m/z 1307.5680 for  $[M + H]^+$ ). Anal. Calcd for C82H78N6O8S·4H2O·CH3OH: C, 70.62; H, 6.43; N, 5.95; S, 2.27. Found: C, 70.96; H, 6.06; N, 5.91; S, 2.59.

**TM12**. Under an atmosphere of nitrogen, a 100-mL Schlenk flask equipped with a magnetic stir bar and a reflux condenser was charged

with 17 (0.10 g, 0.76 mmol), 7 (1.21 g, 1.59 mmol), Pd(PPh<sub>3</sub>)<sub>4</sub> (53 mg, 0.10 mmol), CuI (7.7 mg, 0.10 mmol), iPr<sub>2</sub>NH (20 mL), and THF (30 mL). The mixture was stirred at 50 °C for 48 h. After reaction, the volatile solvent was removed under reduced pressure. Subsequently, water (100 mL) was added and the brown suspension was extracted with  $CH_2Cl_2$  (100 mL  $\times$  3). The organic layer was collected, dried over MgSO<sub>4</sub>, filtered through a short neutral alumina column, and then evaporated to dryness. The resulting residue was redissolved in THF and slowly precipitated with CH3CN in a freezer to afford a yellow solid (0.40 g, 35%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 9.56 (s, 4H), 8.17 (s, 4H), 7.65 - 7.47 (m, 10H), 6.59 (d, 8H, J = 8.4 Hz), 3.79 (t, 8H, J = 6.6 Hz), 1.84 - 1.62 (m, 8H), 1.49 - 1.02 (m, 72H), 0.87 (t, 12H, J = 6.6 Hz).NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  160.6, 155.9, 149.1, 133.7, 130.6, 130.0, 126.6, 123.7, 121.6, 114.3, 89.0, 88.9, 68.3, 67.9, 31.9, 30.9, 29.7, 29.6, 29.5, 29.4, 26.1, 25.6, 22.7, 14.1. HR-MALDI MS m/z 1499.9445 (calcd m/z 1499.9436 for  $[M + H]^+$ ). Anal. Calcd for  $C_{94}H_{126}N_6O_8S \cdot H_2O: C$ , 74.37; H, 8.50; N, 5.54; S, 2.11. Found: C, 74.49; H, 8.46; N, 5.64; S. 2.33.

Luminescence quantum yields in solution were calculated relative to diphenylanthracene in cyclohexane ( $\Phi = 0.95$ ).<sup>14</sup> Luminescence quantum yields were taken as the average of three separate determinations and were reproducible to within 10%. Corrected emission spectra were used for the quantum yield measurements. Luminescence quantum yields of toluene gels were measured at 293 K with an integrating sphere. Luminescence lifetimes were determined on a time-correlated pulsed single-photon-counting instrument.

Samples for transmission electron microscopy (TEM) images were prepared by drop casting the gelator solution in toluene on carboncoated copper grids (200 mesh), and the TEM images were obtained without staining. Samples for atomic force microscopy (AFM) measurements were analyzed by a magnetic tapping mode AFM. Silicon cantilevers with a force constant of 10-130 N/m and resonance frequency of 204-497 kHz were used for the AFM observations in air. The scan rate was varied from 0.3 to 1.0 Hz. Height and phase images were simultaneously obtained. The samples were prepared by drop casting of toluene solution of gelators on a freshly cleaned silicon wafer substrate and dried under vacuum for 24 h prior to imaging. Powder X-ray diffractions were measured with the films prepared by drop casting the gelator solution on a glass substrate and dried under vacuum using a Philips X'Pert PRO diffractometer with Ni-filtered Cu K $\alpha$  radiation.

The mole fraction of aggregate  $(\alpha_{agg}(T))$  was estimated by temperature-dependent UV–vis absorption spectra of coassembled **PM18** (1 ×  $10^{-3}$  M) and **PM-chiral** (5 mol %) using the equation shown below<sup>5e</sup>

$$\alpha_{\rm agg}(T) \approx (A(T) - A_{\rm mon})/(A_{\rm agg} - A_{\rm mon})$$

where  $\alpha_{agg}(T)$  is the mole fraction of aggregate at temperature *T* and  $A_{mon}$ , A(T), and  $A_{agg}$  are the absorbance at 400 nm for the monomer, the solution at temperature *T*, and the pure aggregate solution, respectively.

**Computational Analysis.** Molecular mechanics and dynamics simulations on the gelator molecules were performed using the Dreiding force field implemented in the Materials Studio package.<sup>15,16</sup> The detailed computational analysis is described in the Supporting Information.

## ASSOCIATED CONTENT

**Supporting Information.** Computational analysis, gelation properties, and optical spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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