

Supporting Information

Pseudo-tricolor Typed Nanobelt and Array Simultaneously Endowed with Conductive Anisotropy, Magnetism and White Fluorescence

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Chemicals: Aniline (ANI), (1S)-(+)-10-camphorsulfonic acid (CSA), CHCl_3 , *N,N*-dimethylformamide (DMF), methylmethacrylate (MMA), ammonium persulfate (APS), benzoylperoxide (BPO), anthracene, coumarin-6, Eu_2O_3 (99.99 %), 2-thenoyl trifluoroacetone (HTTA), triphenylphosphine oxide (TPPO), concentrated nitric acid (HNO_3), NaOH, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, $\text{Co}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, ammonium hydroxide and absolute alcohol were purchased from Beijing Chemical Works. All of the chemicals were analytically pure and directly used as received without further purification. Deionized water was made in our lab.

Synthesis of $\text{Eu}(\text{TTA})_3(\text{TPPO})_2$: 1.7596 g of Eu_2O_3 was dissolved in 20 mL of concentrated HNO_3 in a beaker, and the mixture was magnetically stirred, heated to 120 °C for nitration to obtain $\text{Eu}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$. After cooling down to room temperature, 20 mL of absolute ethanol was added into the beaker to obtain the ethanol solution of $\text{Eu}(\text{NO}_3)_3$. 6.6670 g of HTTA and 5.5680 g of TPPO were simultaneously dissolved in 200 mL of absolute ethanol, and then the ethanol solution of $\text{Eu}(\text{NO}_3)_3$ was added into the above mixed solution until white precipitate was formed, then the pH of the mixed solution was adjusted to 6-6.5 with concentrated ammonium hydroxide. The obtained admixture was continuously stirred at 60 °C for 3 h, and then the heating was stopped, followed by continuous stirring at room temperature for 12 h. Afterwards, the admixture was centrifuged and washed with deionized water and absolute ethanol for 3 times, respectively. Finally, the obtained substance was dried at 50 °C in a drying oven for 12 h to obtain $\text{Eu}(\text{TTA})_3(\text{TPPO})_2$.

Preparation of PMMA: PMMA was prepared by oxidative polymerization of MMA. MMA (100 mL) and BPO (0.1000 g) were added into a three-necked flask with a reflux device, and the mixture was magnetically stirred at 90-95 °C. When the viscosity of the mixture reached the viscosity just like that of glycerol, the heating was stopped and cooled down to room temperature to get gel-like liquid. Then the gel-like liquid was put into a test tube. The test tube was kept at room temperature for 10 days. Finally, it was put into the vacuum oven, and the gel-like liquid was then solidified. The temperature in the oven was raised to 110 °C for 2 h to terminate the reaction. The molecular weight of PMMA was tested and

calculated to be about 300, 000 according to the viscosity.

Preparation of CoFe₂O₄ NPs: CoFe₂O₄ NPs were prepared by coprecipitation method. A solution containing 0.72 mol of NaOH solution was slowly added into the mixed solution of 0.09 mol of FeCl₃·6H₂O and 0.045 mol of Co(NO₃)₃·6H₂O, and then the mixture was placed in a water bath, heated to 80 °C and stirred for 2 h. With the addition of NaOH aqueous solution to the above mixed solution, the color of the solution was gradually deepened due to the formation of black precipitates. The black precipitate was collected by magnetic separation, washed with deionized water and ethanol for three times, and then dried in a vacuum drying oven at 60 °C for 12 h to obtain CoFe₂O₄ NPs.

Preparation of Spinning Liquids for Fabricating [B+R]//[M@C]//[G] PNA: Four different types of spinning liquids were used for preparing the pseudo-tricolor typed nanobelt and array. The spinning liquid A for conductive region of the nanobelts was prepared as following. ANI, CSA and PMMA were dissolved into the mixed solvent of CHCl₃ (13.0000 g) and DMF (1.0000 g) under magnetic stirring (denoted as solution A-a). APS was added into the mixed solvent of CHCl₃ (1.0000 g) and DMF (3.0000 g) (named as solution A-b). Solution A-a and solution A-b were placed into an icebox at 0 °C for 20 min. Then the solution A-b was added dropwise into the solution A-a in an ice water bath and maintained for 3 h. At last, the final substance was kept at 0 °C for 24 h and thus PANI was obtained *via* the polymerization of aniline. The spinning liquid B for making the magnetic region was composed of CoFe₂O₄ NPs, PMMA, CHCl₃ and DMF. The as-prepared CoFe₂O₄ NPs were dispersed into the mixed solvent of CHCl₃ (14.0000 g) and DMF (4.0000 g) under ultrasonic for 25 min and then PMMA (1.0000 g) was added into the mixture. For fabricating blue-red luminescent region of the nanobelts, the spinning liquid C was prepared as following: 1.0000 g of PMMA, 0.1500 g of Eu(TTA)₃(TPPO)₂ and 0.0160 g of anthracene were dissolved into the mixed solvent of CHCl₃ (14.0000 g) and DMF (4.0000 g). For fabricating green luminescent region of the nanobelts, the spinning liquid D was prepared as below: 1.0000 g of PMMA and 0.0020 g of coumarin-6 were dissolved into the mixed solvent of CHCl₃ (14.0000 g) and DMF (4.0000 g) under magnetic stirring. The actual compositions of spinning liquids A and B were listed in Table S1 and S2.

Table S1 Compositions of the spinning liquid A.

Spinning liquid A	PANI:PMMA (wt %)	ANI (g)	CSA (g)	APS (g)	PMMA (g)	DMF (g)	CHCl ₃ (g)
S _{A-1}	30 %	0.3000	0.5100	0.9200	1.0000	4.0000	14.0000
S _{A-2}	50 %	0.5000	0.8700	1.4000	1.0000	4.0000	14.0000
S _{A-3}	70 %	0.7000	1.1100	1.8000	1.0000	4.0000	14.0000

Table S2 Compositions of the spinning liquid B.

Spinning liquid B	CoFe ₂ O ₄ :PMMA (Mass ratio)	CoFe ₂ O ₄ (g)	PMMA (g)	DMF (g)	CHCl ₃ (g)
S _{B-1}	0.3:1	0.3000	1.0000	4.0000	14.0000
S _{B-2}	0.5:1	0.5000	1.0000	4.0000	14.0000
S _{B-3}	1:1	1.0000	1.0000	4.0000	14.0000

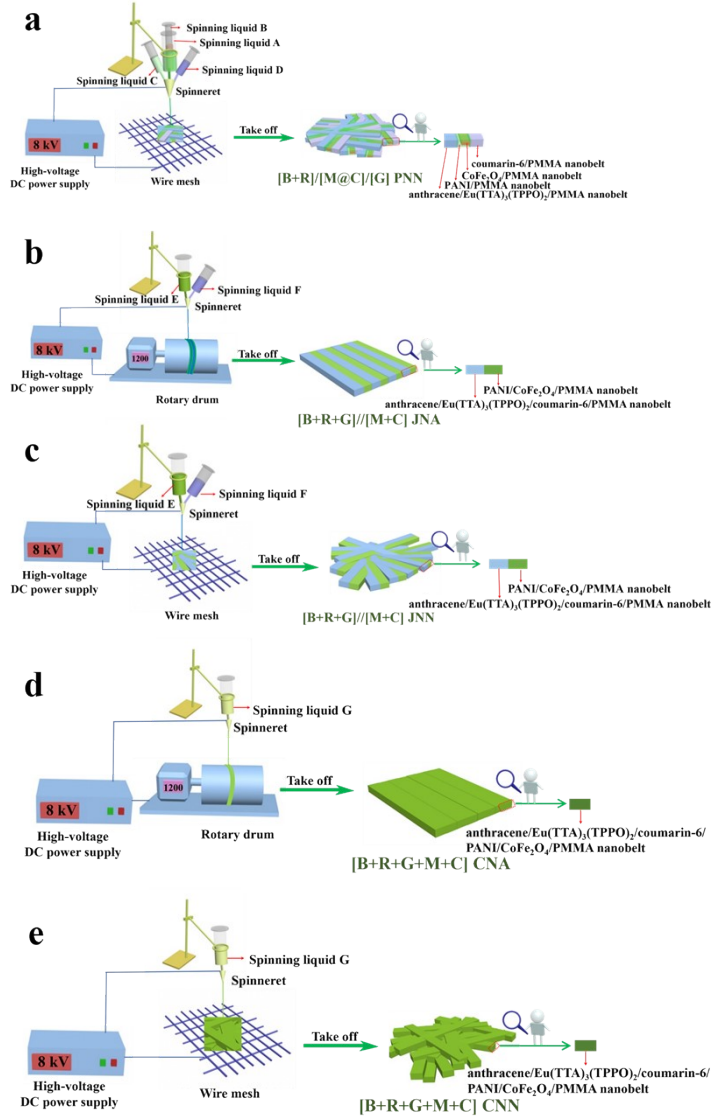


Fig. S1 Schematic diagrams of spinning devices and preparation process for five contrast samples.

Table S3 Spinnerets, compositions of spinning liquids and collecting devices of the five contrast samples.

Samples	Homemade spinnerets	Compositions of spinning liquids and collecting devices
[B+R]/[M@C]/[G] PNN	Specially designed and assembled [uniaxial needle]/[coaxial needle]/[uniaxial needle] parallel spinneret	<p>Spinning liquid A: ANI, CSA, APS, PMMA, CHCl₃ and DMF</p> <p>Spinning liquid B: CoFe₂O₄ NPs, PMMA, CHCl₃ and DMF</p> <p>Spinning liquid C: anthracene, Eu(TTA)₃(TPPO)₂, PMMA, CHCl₃ and DMF</p> <p>Spinning liquid D: PMMA, CHCl₃ coumarin-6 and DMF</p> <p>Collecting device: wire mesh</p>

[B+R+G]/[M+C] JNA	Specially designed and assembled bi-axial parallel spinneret	Spinning liquid E: ANI, CSA , APS, CoFe ₂ O ₄ NPs, PMMA, CHCl ₃ and DMF Spinning liquid F: anthracene, Eu(TTA) ₃ (TPPO) ₂ , coumarin-6, PMMA, CHCl ₃ and DMF Collecting device: rotary drum
[B+R+G]/[M+C] JNN	Specially designed and assembled bi-axial parallel spinneret	Spinning liquid E: ANI, CSA, APS, CoFe ₂ O ₄ NPs, PMMA, CHCl ₃ and DMF Spinning liquid F: anthracene, Eu(TTA) ₃ (TPPO) ₂ , coumarin-6, PMMA, CHCl ₃ and DMF Collecting device: wire mesh
[B+R+G+M+C] CNA	Single spinneret	Spinning liquid G: ANI, CSA, APS, CoFe ₂ O ₄ NPs, anthracene, Eu(TTA) ₃ (TPPO) ₂ , coumarin-6, PMMA, CHCl ₃ and DMF Collecting device: rotary drum
[B+R+G+M+C] CNN	Single spinneret	Spinning liquid G: ANI, CSA, APS, CoFe ₂ O ₄ NPs, anthracene, Eu(TTA) ₃ (TPPO) ₂ , coumarin-6, PMMA, CHCl ₃ and DMF Collecting device: wire mesh

Preparation of Spinning Liquids for Contrast Samples: To emphasize the advantages of the array using pseudo-tricolor typed nanobelt as the building unit, five kinds of contrast samples were fabricated, including [anthracene/Eu(TTA)₃(TPPO)₂/PMMA]/[(CoFe₂O₄/PMMA) @(PANI/PMMA)] // [coumarin-6/PMMA] pseudo-tricolor typed nanobelts non-array (defined as [B+R]/[M@C]/[G] PNN for short), [anthracene/Eu(TTA)₃(TPPO)₂/coumarin-6/PMMA]// [CoFe₂O₄/PANI/PMMA] Janus nanobelts array (named as [B+R+G]/[M+C] JNA for short), [anthracene/Eu(TTA)₃(TPPO)₂/coumarin-6/PMMA]//[CoFe₂O₄/PANI/PMMA] Janus nanobelts non-array (denoted as [B+R+G]/[M+C] JNN for short), [anthracene/Eu(TTA)₃(TPPO)₂/ coumarin-6/CoFe₂O₄/PANI/PMMA] composite nanobelts array (named as [B+R+G+M+C] CNA for short), [anthracene/Eu(TTA)₃(TPPO)₂/coumarin-6/CoFe₂O₄/PANI/PMMA] composite nanobelts non-array (marked as [B+R+G+M+C] CNN for short).

[B+R]/[M@C]/[G] PNN was fabricated by using spinning liquids S_{A-2}, S_{B-2}, S_C and S_D. The electrospinning process for preparing [B+R]/[M@C]/[G] PNN was similar to that for fabricating [B+R]/[M@C]/[G] PNA, but the collecting device was changed to a piece of wire mesh to replace the rotary drum. The spinning liquids for the [B+R+G]/[M+C] JNA and [B+R+G]/[M+C] JNN were fabricated by blending spinning liquids S_{A-2} and S_{B-2} at a volume ratio of 1:1 (named as spinning liquid E). Then, the spinning liquid S_C and spinning liquid S_D were mixed in isopyknic ratio to obtain spinning liquid

F. Spinning liquid E and spinning liquid F were applied to construct Janus nanobelts as building units to prepare [B+R+G]/[M+C] JNA and [B+R+G]/[M+C] JNN by parallel electrospinning technology. The rotary drum and the wire mesh as collecting devices were respectively used to collect [B+R+G]/[M+C] JNA and [B+R+G]/[M+C] JNN. The spinning liquids for the [B+R+G+M+C] CNA and [B+R+G+M+C] CNN were fabricated by blending spinning liquids S_{A-2} , S_{B-2} , S_C and S_D in isovolumetric ratio to acquire spinning liquid G. The rotary drum and the wire mesh were also used as collecting devices to collect [B+R+G+M+C] CNA and [B+R+G+M+C] CNN, respectively. The detailed preparative processes and conditions of the contrast samples were shown in the Fig. S1 and Table S3.

Characterization Methods

The as-prepared CoFe_2O_4 NPs and [B+R]/[M@C]/[G] PNA were identified *via* using X-ray diffractometer (XRD) with the model of D8 FOCUS and Cu $K\alpha$ radiation with scanning rate of $0.02^\circ \text{ s}^{-1}$ and angle ranging from 10° to 90° , which was made by Bruker Corporation, the operation current and voltage were maintained at 20 mA and 40 kV, respectively. The morphology and internal structure of the products were observed by a thermal field emission scanning electron microscope (SEM, JSM-7610F), optical microscope (OM, CVM500E) and fluorescence microscope (X-Cite Series 120Q and Axio Scope.A1). The accelerating voltage and vacuum degree of SEM were respectively maintained at 10 kV and 9.6×10^{-6} Pa. An energy dispersive spectrometer (EDS) produced by Oxford Instruments and attached to the SEM was used to analyze elemental compositions. The fluorescence properties of the samples were investigated by using a Hitachi fluorescence spectrophotometer F-7000, and the excitation and emission slits were respectively set to 2.5 nm and 2.5 nm. The electrical conductance was measured by an ECOPIA HMS-3000 Hall effect measurement system. Ubbelohde viscometer (PXWSN-265B) was used to measure the viscosity of PMMA. The magnetic measurements were carried out at room temperature under 10000 and -10000 Oe applied magnetic field by using a vibrating sample magnetometer (VSM, MPMS SQUID XL). A microcomputer controlled electronic universal testing machine (WDW-20kN) was applied to measure the stress and strain of the products. Software Nano Measurer was used to analyze the width of the nanobelt. The widths of 100 nanobelts were measured and the average width was obtained. The width distribution histogram of the obtained 100 nanobelts was drawn in the software Origin, and then the fitting curve was obtained by Gaussian fitting, and the variance was determined according to the fitting curve.

Morphology and Structure

The widths of nanobelts of contrastive [B+R]/[M@C]/[G] PNN, [B+R+G]/[M+C] JNA, [B+R+G]/[M+C] JNN, [B+R+G+M+C] CNA and [B+R+G+M+C] CNN are 6.72 ± 0.77 , 6.26 ± 0.85 , 6.39 ± 0.94 , 7.73 ± 0.71 and 6.87 ± 0.58 μm , respectively (Fig. S2a, S2b, S2c, S2d and S2e). The widths of the nanobelts of target sample and contrast samples are similar because the samples have identical compositions and contents.

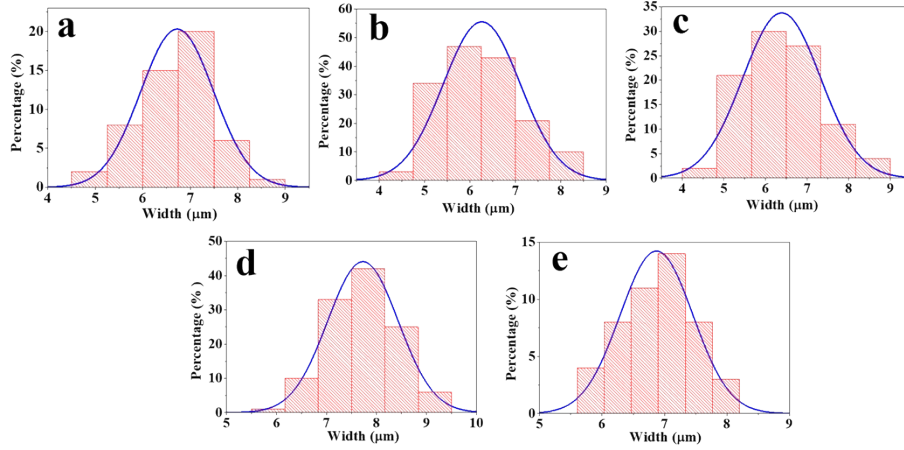


Fig. S2 Histograms of width distribution of nanobelts in contrastive [B+R]//[M@C]//[G] PNN (a), [B+R+G]//[M+C] JNA (b), [B+R+G]//[M+C] JNN (c), [B+R+G+M+C] CNA (d) and [B+R+G+M+C] CNN (e).

Electrical Conduction Analysis

Hall effect measurement system is used to measure the conductivity of the samples. Fig. S3 displays the sketch maps of the examination methods for the samples which are tailored to $1 \times 1 \text{ cm}^2$. For the array films, the conductance along the direction parallel to the nanobelt (i.e. the length direction) and perpendicular to the nanobelt (i.e. the width direction) are measured (Fig. S3 a and b). When the conductance along the length direction of the nanobelt (Xc direction) is tested, the length direction of the two tin sheets is perpendicular to the length direction of the nanobelt as shown in Fig. S3a. When the conductance along the width direction of the nanobelt (Yi direction) is tested, the length direction of the two tin sheets is parallel to the length direction of the nanobelt as shown in Fig. S3b. For non-array films, the conductance of the samples in two perpendicular directions are tested (Fig. S3c and d). During the test, we select any direction for testing, and then measure the direction perpendicular to the selected direction. When the selected any direction is tested, the length direction of the two tin sheets is perpendicular to the selected direction as shown in Fig. S3c. When the direction perpendicular to selected direction is tested, the length direction of the two tin sheets is parallel to the selected direction as shown in Fig. S3d. The two tin sheets ($1 \times 0.45 \text{ cm}^2$) are used as electrodes, and the tin sheets at the distance of 0.1 cm are adhered to films surface by conducting resin. Then the two stylets of the Hall effect measurement system are respectively pressed against the two tin sheets. The test is carried out at room temperature. A series of voltage and current values are obtained at the end of the test. The magnitude of voltage is kept at 10^1 - 10^5 V , and the magnitude of current is kept at 10^{-9} - 10^{-7} A . The average value of current and voltage are obtained, and the conductivity of the sample are calculated by the following formula:

$$k = (L \times I) / (U \times S)$$

where k is the conductivity of the sample, I and U are the average value of current and voltage. L and S respectively represent length and the cross-sectional area. The results are shown in the Table 2.

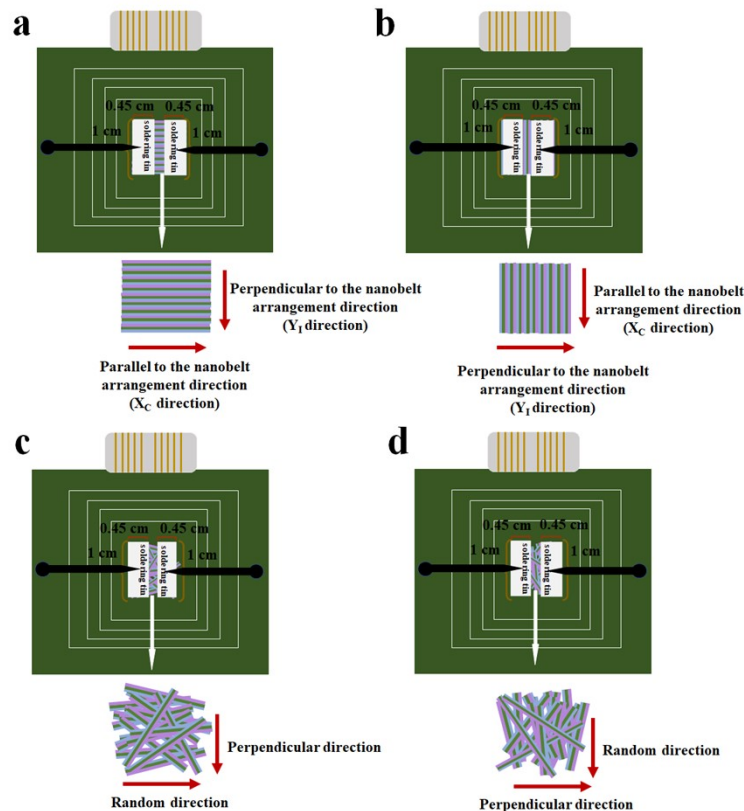


Fig. S3 Sketch maps of the test methods for electrical conduction along the direction parallel to the nanobelt (a) and perpendicular to the nanobelt (b) of the array film, and along the random direction (c) and perpendicular direction (d) of non-array film.

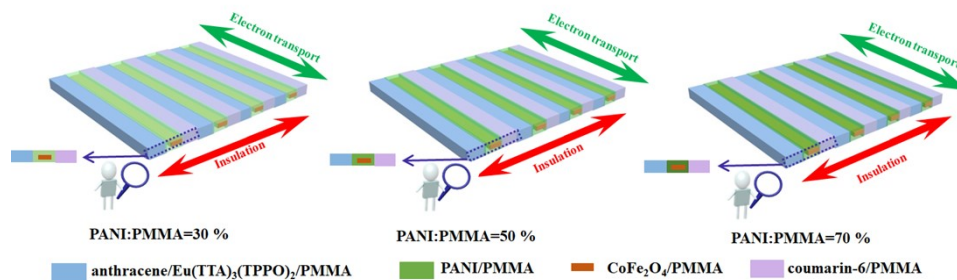


Fig. S4 Sketch maps of conductive directions of the [B+R]//[M@C]//[G] PNA with various percentages of PANI.

Fluorescent Performance

Fig. S5a-c exhibit the molecular structures of anthracene, coumarin-6 and $\text{Eu}(\text{TTA})_3(\text{TPPO})_2$. As demonstrated in the Fig. 11a, under the excitation of 365-nm ultraviolet light, the emission peaks of anthracene (403 and 426 nm) and coumarin-6 (490, 538 nm) are found. They belong to the dimer luminescence of anthracene and coumarin-6, respectively. The characteristic emission peaks of Eu^{3+} can be observed at 593 nm and 617 nm for $\text{Eu}(\text{TTA})_3(\text{TPPO})_2$, which can be attributed to the energy level transitions of $^5\text{D}_0 \rightarrow ^7\text{F}_1$ and $^5\text{D}_0 \rightarrow ^7\text{F}_2$ of Eu^{3+} , respectively.

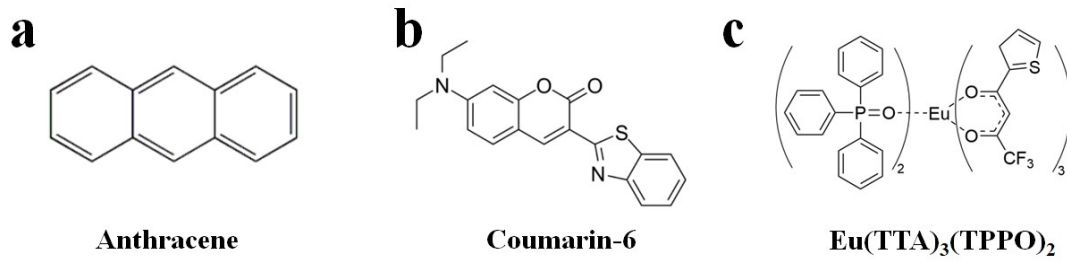


Fig. S5 Molecular structures of (a) anthracene, (b) coumarin-6 and (c) Eu(TTA)₃(TPPO)₂.