Electronic Supplementary Material (ESI) for Polymer Chemistry.

Bioinspired ultrasound-responsive fluorescent metal-ligand crosslinked polymer assemblies

Zhenhua Wang, Zhanhua Wang*, Hesheng Xia

State Key Lab of Polymer Materials Engineering, Polymer Research Institute, Sichuan University, Chengdu 610065, China
E-mail: zhwangpoly@scu.edu.cn

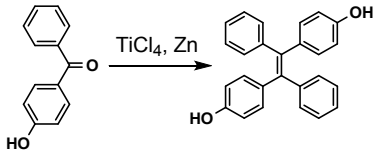
Materials

All chemicals were obtained from Maya agent corporation and used without any further purification. Except zinc dust was used after washing with dilute hydrogen chloride solution, acetone or ethanol.

Characterization

^{1}H NMR spectra were recorded at room temperature with a Bruker spectrometer operating at 400 MHz using $CDCl_3$ or DMSO-d6 as the solvent and tetramethylsilane as an internal reference. Dynamic light scattering (DLS) was performed on Zetasizer Nano S90. TEM was performed using a FEI Tecnai G2F20 S-TWIN transmission electron microscope, operating at an accelerating voltage of 200 kV. UV-Vis absorption and transmittance was recorded on the UV-Vis spectrophotometer (Agilent CARY 60). Steady-state fluorescence emission spectra of the micelle solutions were recorded on the 970CRT spectrophotometer (Shanghai Precision & Scientific Instrument Co., Ltd). The excitation wavelength was 340 nm.

Synthesis of dihydroxyl-Functionalized TPE (TPE-2OH)



A suspension of 4-hydroxybenzophenone (6.9 g, 35 mmol) and Zn dust (4.6 g, 90 mmol) in 150 mL THF was stirred for 1 h under a N_2 atmosphere. A suspension of $TiCl_4$ (3.9 mL, 35 mmol) was added dropwise to the suspension, and the reaction was allowed to proceed at 80 ˚C for 12 h. The reaction mixture was cooled to 25 ˚C and poured into a 10% aqueous K_2CO_3 solution (200 mL), and after vigorous stirring for 5 min, the dispersed insoluble material was removed by vacuum filtration using a Celite pad. The organic layer was separated, and the aqueous layer was extracted three times with ethyl acetate (300 mL). The organic fraction was dried over $MgSO_4$. The solvents were removed at reduced pressure to afford the crude product. The product was further purified by a silica gel column using ethyl acetate – hexane (1:1, v/v) as eluent.

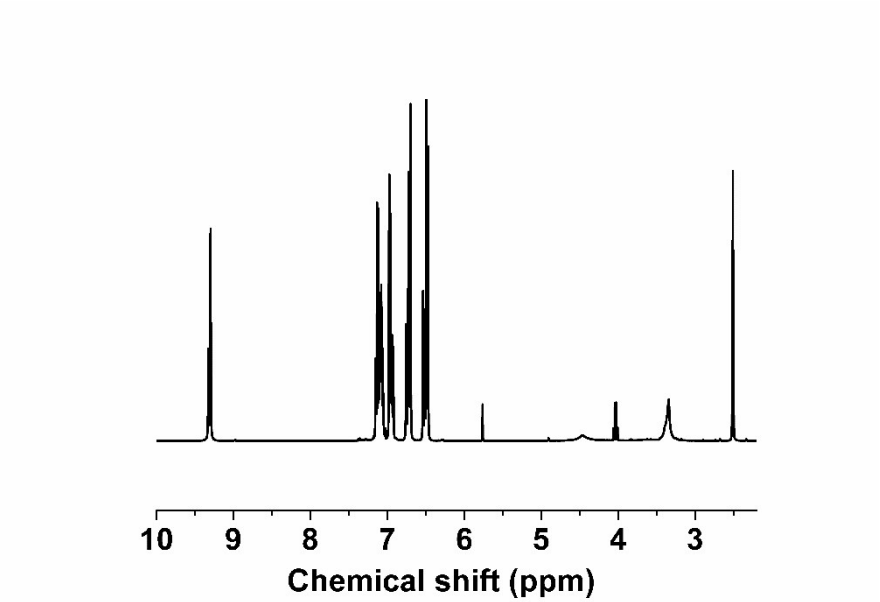
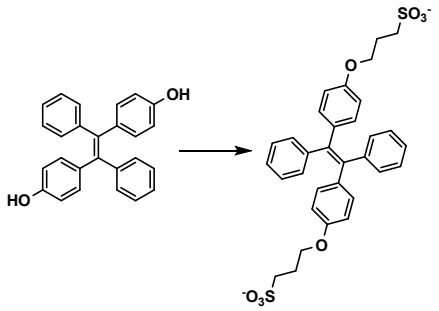


Figure S1 ^{1}H NMR spectrum of TPE-2OH in DMSO-d6

Synthesis of 9,10-bis[4-(3-sulfonatopropoxyl)-styryl]anthracene sodium salt (TPE-2SO_3Na)



A solution of TPE-2OH (0.88 g, 2.4 mmol) in 40 mL absolute ethanol was stirred under nitrogen. A mixture of NaOEt (0.46 g, 6.8 mmol) in 20 mL of ethanol was added dropwise and stirred. After the solution turned into orange-red, 1,3-propane sultone (0.56 g, 4.6 mmol) in 40 mL of ethanol was added slowly. The mixture was stirred for 12 h, and a white product was precipitated out from the solution. The product was collected by filtration and washed with ethanol and acetone twice. The white solid of TPE-2SO_3Na was dried in vacuum.

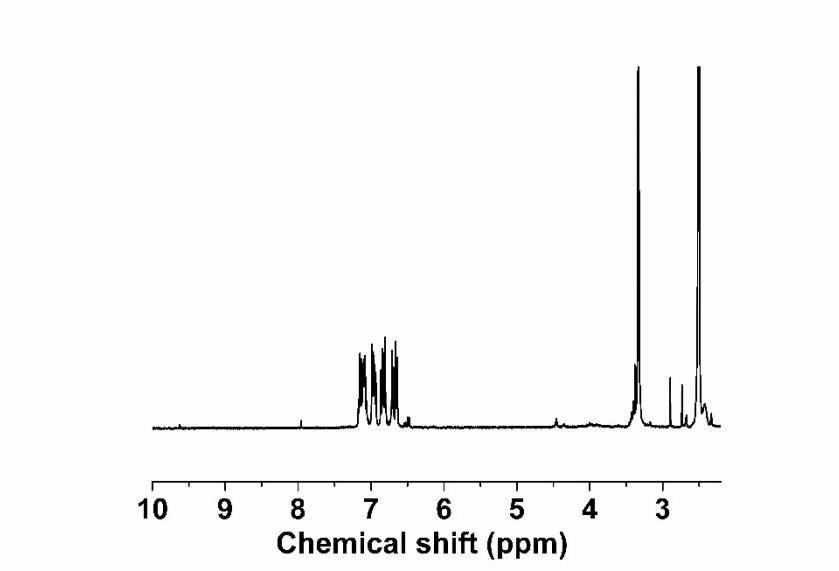
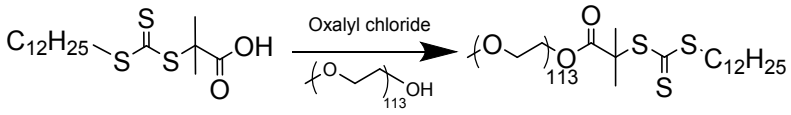


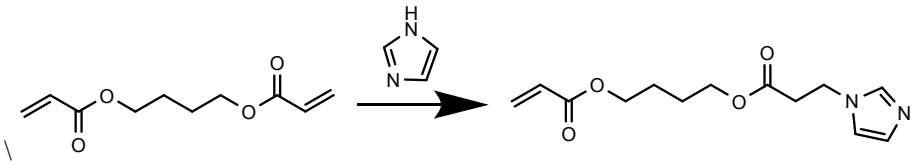
Figure S2 ^{1}H NMR spectrum of TPE-2SO_3^- in DMSO-d6

Synthesis of 4-(3-(1H-imidazol-1-yl)propanoyloxy)butyl acrylate.



Oxalyl chloride (12.61 g, 100 mmol) was added to a solution of 2-(dodecylthiocarbonothioylthio)-2-methylpropanoic acid (3.65 g, 10 mmol) in chloroform (5 mL). The reaction was finished until no bubbles, and the residue solvent and extra oxalyl chloride was removed by vacuum. Then mPEG-5K (4 g, 8 mmol) was dissolved in 5 mL chloroform and added to the above flask. The reaction was stirred at room temperature overnight. The solution was precipitated from cold ether three times and the macroCTA (mPEG-CTA) was collected after filtration.

Synthesis of 4-(3-(1H-imidazol-1-yl)propanoyloxy)butyl acrylate (IMa)



To a flask purged with nitrogen, 1,4-butanediol diacrylate (19.8 mL, 44.1 mmol), 1-methylimidazole (0.84 mL, 10.55 mmol), and triethylamine (7.35 mL, 52.5 mmol) were dissolved in 45 mL CH_3CN:DMF mixture (5:4 v/v). A solution of imidazole (3.59 g, 52.5 mmol) in 9 mL of DMF was dropped to the stirred solution and the mixture was stirred overnight. After reaction, 20 mg 4-methoxyphenol inhibitor was added, then the solvent was removed via vacuum distillation. The residual light yellow oil was dissolved in 50 mL ethyl acetate and washed twice with 30 mL water and once with 30 mL brine. The organic layer was dried over Na_2SO_4 and concentrated in vacuum after filtration of drying agent. Crude mixture was purified by silica flash column chromatography using a gradient of petroleum ether and ethyl acetate (0-100% EtOAc) and then using EtOAc. The final colorless liquid was the product of IMa (9.39 g, 40%). TLC plates were stained using $KMnO_4$ to detect vinyl group.

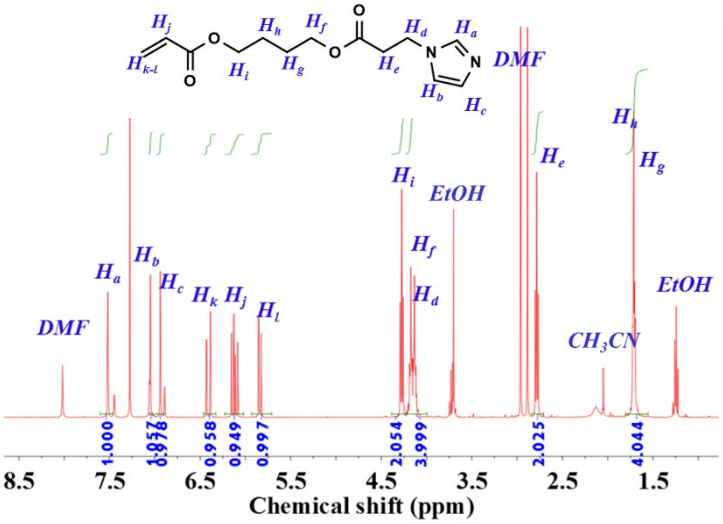
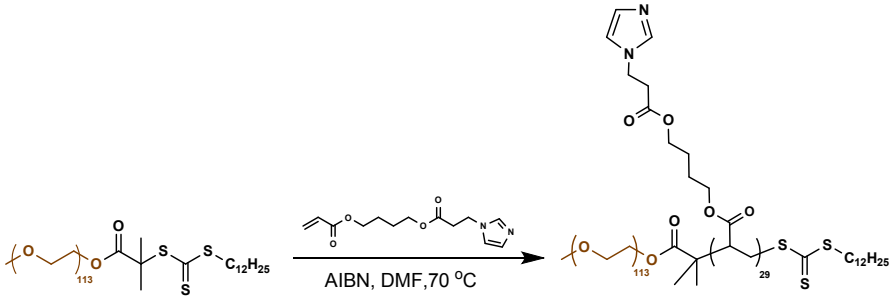


Figure S3 ^1H NMR spectrum of IMa in $CDCl_3$

Synthesis of PEG-b-PIMa

mPEG-CTA (0.132 g, 0.025 mmol), AIBN (1.0 mg, 6.25 μmol), IMa (1.33 g, 5 mmol) were dissolved in DMF (1 mL), the mixture was freeze-thawed three times and polymerized at 70◦ C for 24 h. after polymerization, the mixture was cooled and precipitated in ether/hexane (40 mL, 1:3). After filtration, the polymer was dissolved in CH_3CN and precipitated twice into stirring ether/hexane (40 mL, 1:3). The yellowish sticky polymer was collected by vacuum filtration and dried under vacuum.



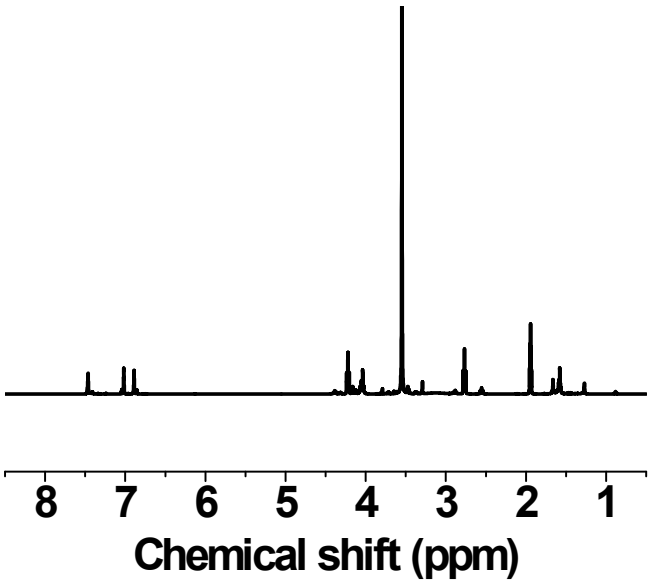


Figure S4 ^1H NMR spectrum of PEG-*b*-PIMa in CD_3CN

Preparation of FMCPA assemblies

A solution of PEG-b-PIMa in CH_3CN (5 mg/mL) was dropped into water (volume: 25 mL). During the evaporation of CH_3CN, the block polymer was gradually assembled into vesicle (0.5 mg/mL). Then the corresponding amount of zinc salts and TPE-$2SO_3$- were added stepwise to form the fluorescent metal-ligand crosslinked polymer assemblies. The pH of the systems with different amounts of zinc ions were in the range of 7.25 ± 0.30.

Ultrasound irradiation

Ultrasound experiments were performed on a cube with a 6 mm (diameter) titanium solid probe (Nanjing Xian'ou Instrument Co., Ltd). For a typical sonication experiment, the solution temperature was kept between 5˚C~10˚C using an ice bath and purged with N_2 for 15 min before ultrasound. Polymer assemblies with a concentration of 0.5 mg/mL in water were exposed to ultrasound (pulse time: 1 s).

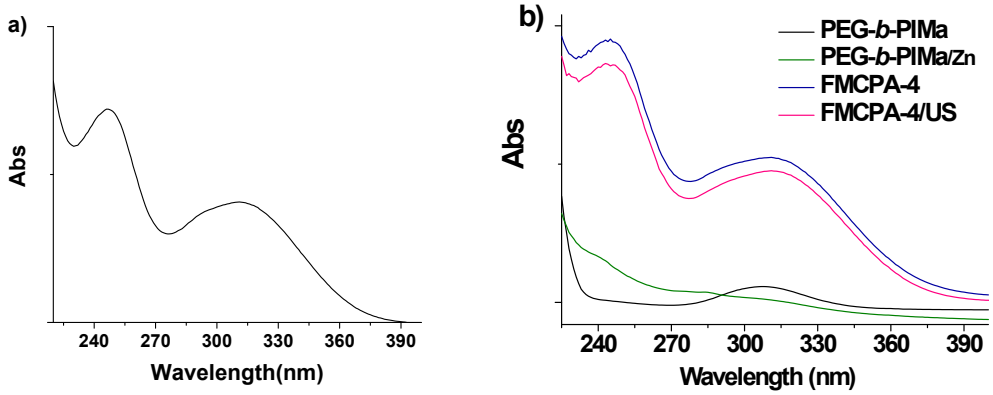


Figure S5 UV-Vis spectra of a) TPE-$2SO_3^-$. b) Polymer assemblies.

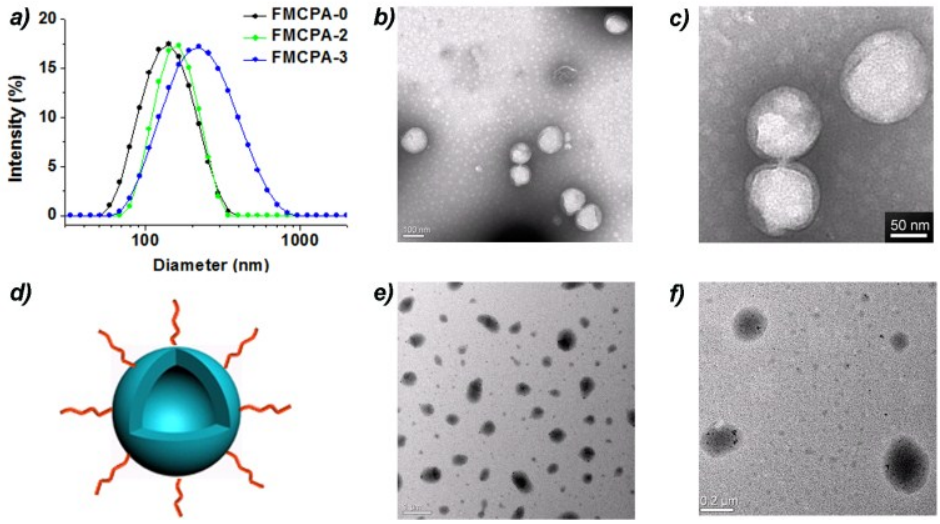


Figure S6 DLS data of FMCPA assemblies (a); TEM image of FMCPA-0 at lower (b) and higher magnification (c), Schematic illustration of fluorescent FMCPAs assembly (d); TEM image of FMCPA-3 assembly at lower (e) and at higher magnification (f)

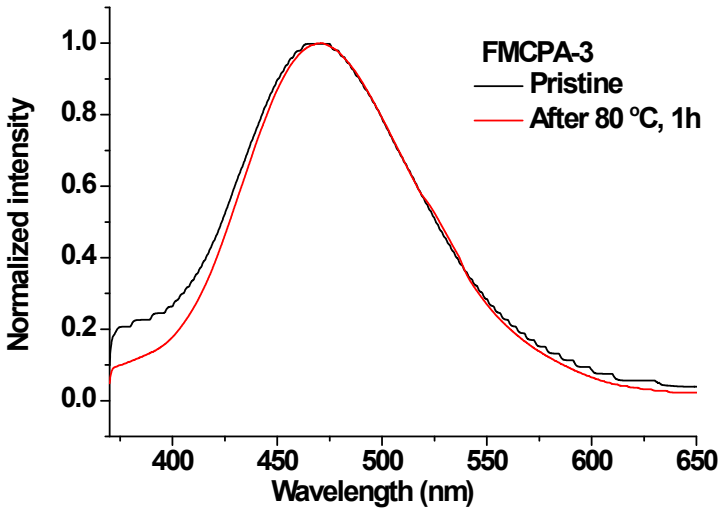


Figure S7 Fluorescence spectra of the FMCPA-3 before and after thermal treatment at 80 ˚C for 1 h, measured after cooling to room temperature.