Supporting Information

RAFT-mediated, Visible Light-initiated Single Unit Monomer Insertion and Its Application in the Synthesis of Sequence-defined Polymers

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Materials

Methyl acrylate (MA, 99%), *n*-butyl acrylate (BA, 99%), 2-hydroxyethyl acrylate (HEA, 98%), 4-hydroxybutyl acrylate (HBA, 98%), benzyl acrylate (BnA, 98%), *N, N*-dimethyl acrylamide (DMA, 99%), 3-(trimethylsilyl)propargyl alcohol (99%), *N,N'*-dicyclohexylcarbodiimide (DCC, 99%), and 4-(dimethylamino)pyridine (DMAP, ⩾99%) and 2,3,4,5,6-pentafluorostyrene (PFSt, 99%) were purchased from Sigma-Aldrich and passed through alumium oxide to remove inihibitor prior to use. *N*-isopropylacrylamide (NIPAM, 97%) was purchased from Sigma-Aldrich and recrystallized in cyclohexane prior to use. Thiolactone acrylamide (TlaAm) was synthesized according to previous literature.[1] Tris(2-phenylpyridine)iridium(III) ($Ir(ppy)_3$, 99%) was purchased from Sigma-Aldrich and prepared to stock solution (1.0 mg/mL) in DMSO and stored under dark. 4-Cyano-4-[(dodecylsulfanylthiocarbonyl)sulfanyl]pentanoic acid (CDTPA, 97%) was purchased from Boron Molecular and used as received.

Instruments

Gel permeation chromatography (GPC) was performed using tetrahydrofuran (THF) as the eluent. The GPC system was a Shimadzu modular system comprising an auto injector, a Phenomenex 5.0 μm bead-size guard column (50 × 7.5 mm) followed by two MIX C columns provided by Polymer Lab for THF system, and a

differential refractive-index (RI) detector and a UV detector. The system was calibrated with narrow molecular weight distribution poly(styrene) (PSt) standards with molecular weights of 200 to 10^6 g mol^{-1}.

Nuclear Magnetic Resonance (NMR) spectroscopy was carried out on a Bruker Advance III with SampleXpress operating at 300 MHz using $CDCl_3$ as solvent and tetramethylsilane (TMS) as a reference. The data obtained was reported as chemical shift (δ) measured in ppm downfield from TMS.

On-line Fourier Transform Near-Infrared (FTNIR) was used for determination of monomer conversion by mapping the decrement of the vinylic C-H stretching overtone of the monomer at 6100~6220 cm^{-1}. A Bruker IFS 66/S Fourier transform spectrometer equipped with a tungsten halogen lamp, a CaF_2 beam splitter and liquid nitrogen cooled InSb detector was used. Each spectrum composed of 8 scans with a resolution of 4 cm^{-1} was collected in the spectral region between 7000-4000 cm^{-1} by manually placing the sample into the holder at predetermined intervals. The total collection time per spectrum was about 10 seconds and analysis was carried out with OPUS software.

Single unit addition was carried out in the 20 mL glass vessel where the reaction mixtures are irradiated by RS Component PACK LAMP LED lights (5 W). The distance of the samples to light bulb was 6 cm. The lights used were green LED light (λ_{max} = 530 nm, 0.6 mW/cm^2).

General procedures for single unit monomer insertion to CDTPA

In the synthesis of single unit monomer adduct CDTPA-MA, CDTPA (200 mg, 0.49 mmol), MA (0.67 mL, 7.4 mmol) and DMSO (6.0 mL) were placed into a 20 mL glass vial sealed with a rubber septum. The reaction mixture was degassed for 20 minutes with nitrogen. The reaction was then irradiated under green light at room temperature for 24 h. The reaction was stopped by removed from the light source. The reaction mixture was washed using saturated saline and extracted by ethyl acetate. After collecting the organic phase, the solution was blown by nitrogen to remove all the volatile moieties. The crude product was purified by silica gel chromatography using mixture of acetic acid and dichloromethane (DCM) (0.5%, v/v) as the eluent. After removing all the solvents by rotary evaporator, the single unit monomer adduct of CDTPA-MA was obtained as viscous yellow oil.

All the single unit monomer adducts based on other monomers were synthesized and purified in similar way.

Chain extension from CDTPA-MA using PET-RAFT polymerization of BA

CDTPA-MA (10 mg, 0.02 mmol), BA (134 mg, 1.04 mmol), $Ir(ppy)_3$ (0.006 mg, 9×10^{-6} mmol) and DMSO (0.45 mL) were placed into a 4 mL vial sealed with a rubber septum. The reaction was degassed for 20 minutes with nitrogen. The mixture was then irradiated under blue light at room temperature. Samples were withdrawn periodically for NMR and GPC analysis. The polymerization was stopped by removal from light following by blown using nitrogen to remove DMSO. The residual polymer was redissolved in THF, and then precipitated by addition into hexane. The dissolution/precipitation procedure was repeated 3 more times. The polymer was obtained as viscous liquid.

Synthesis of alkyne CDTPA

CDTPA (1.0 g, 2.48 mmol), 3-(trimethylsilyl)propargyl alcohol (0.47 g, 3.67 mmol), DCC (0.56 g, 2.72 mmol) and DMAP (5 mg, 0.04 mmol) were dissolved in THF (15 mL). The reaction was conducted at room temperature for 15 h. Then the reaction was filtered to remove the white solid and purified by column with DCM/hexane (1:5, v/v) as mobile phase. The product was obtained as yellow oil with 78% yield. The characterizations were in good accord with previous report in the literature.[2]

^{1}H NMR (300 MHz, $CDCl_3$)/ppm: 4.73 (s, 1H, $C\underline{H}_2O$), 3.35 (t, 2H, $C\underline{H}_2S$), 2.69 (d, 2H, $C\underline{H}_2CO$), 2.56 (m, 1H, $C\underline{H}C(CH_3)S$), 2.43 (m, 1H, $C\underline{H}C(CH_3)S$), 1.89 (s, 3H, $C(CN)C\underline{H}_3$), 1.71 (m, 2H, $SCH_2C\underline{H}_2$), 1.49- 1.18 (m, 18H, $SCH_2CH_2(C\underline{H}_2)_9$), 0.90 (t, 3H, $CH_2C\underline{H}_3$), 0.21 (s, 9H, $Si(C\underline{H}_3)_3$.

Synthesis of alkyne modified CDTPA-MA (M_1)

Alkyne CDTPA (200 mg, 0.39 mmol), MA (665 mg, 7.7 mmol), DMSO (6 mL) were placed into a 20 mL glass vial sealed with a rubber septum. The reaction mixture was degassed for 20 minutes with nitrogen. The reaction was then irradiated under green light at room temperature for 24 h. The reaction was stopped by removed from the light source. The reaction mixture was washed using saturated saline and extracted by ethyl acetate. After collecting the organic phase, the solution was blown by nitrogen to remove all the

volatile moieties. The crude product was purified by silica column using mixture of hexane and DCM (1/1, v/v) as the eluent. After removing all the eluent by rotary evaporator, the product was obtained as yellow oil with yield of 77%.

Synthesis of dimer M_1M_2

M_1 (0.57 g, 0.95 mmol), propylamine (117 μL, 1.43 mmol), HEA (220 μL, 1.90 mmol), TEA (13 μL, 0.095 mmol) and acetonitrile (5 mL) were placed into 20 mL vial and reacted for 3 h under room temperature. After removal of all the volatile moieties, the crude product was purified by silica column with gradient ethyl acetate/hexane as solvent (1/4 to 1/2, v/v). The product was obtained as colourless oil with yield of 95%.

Synthesis of M_1M_2-CDTPA

M_1M_2 (450 mg, 0.95 mmol), CDTPA (623 mg, 1.54 mmol), DCC (330 mg, 1.60 mmol), DMAP (5.0 mg) were dissolved in THF (15 mL) and reacted for 15 h. The reaction was filtered to remove the white solid and subjected for purification by silica column with ethyl acetate/hexane (1/4 to 1/2, v/v). The product was obtained as yellow oil with yield of 81%.

Synthesis of $M_1M_2M_3$

M_1M_2-CDTPA (0.53 g, 0.65 mmol), DMA (1.11 g, 11.2 mmol) and DMSO (8 mL) were placed into a 20 mL glass vial sealed with a rubber septum. The reaction mixture was degassed for 20 minutes with nitrogen. The reaction was then irradiated under green light at room temperature for 22 h. The reaction was stopped by removed from the light source. The reaction mixture was washed using saturated saline and extracted by ethyl acetate. After collecting the organic phase, the solution was blown by nitrogen to remove all the volatile moieties. The crude product was purified by silica column using a mixture of ethyl acetate and hexane (1/5 to 1/1, v/v) as the eluent. After removing all the eluent by rotary evaporator, the product was obtained as yellow oil with yield of 77.8%.

Synthesis of $M_1M_2M_3M_4$

$M_1M_2M_3$ (450 mg, 0.47 mmol), 4-HBA (240 mg, 1.66 mmol), TEA (50 mg, 0.47 mmol), tri-n-butylphosphine (3 μL), acetonitrile (1 mL) and acetone (2 mL) were placed into 20 mL vial and reacted for 24 h under room temperature. After removal of all the volatile moieties by nitrogen, the crude was purified by silica column with gradient ethyl acetate/hexane as solvent (1/1 to 2/1, v/v). The product was obtained as colourless oil with yield of 92%.

Synthesis of $M_1M_2M_3M_4$-CDTPA

$M_1M_2M_3M_4$ (370 mg, 0.432 mmol), CDTPA (400 mg, 0.99 mmol), DCC (151 mg, 0.73 mmol) and DMAP (5 mg) were dissolved in THF (15 mL) and reacted for 24 h. The reaction was filtered to remove the white solid and subjected for purification by silica column with ethyl acetate/hexane (2/1, v/v). The product was obtained as yellow oil with yield of 73.5%.

Synthesis of $M_1M_2M_3M_4M_5$

$M_1M_2M_3M_4$-CDTPA (200 mg, 0.16 mmol), BnA (260 mg, 1.62 mmol) and DMSO (2.5 mL) were placed into a 20 mL glass vial sealed with a rubber septum. The reaction mixture was degassed for 20 minutes with nitrogen. The reaction was then irradiated under green light at room temperature for 24 h. The reaction was stopped by removed from the light source. The reaction mixture was washed using saturated saline and extracted by ethyl acetate. After collecting the organic phase, the solution was blown by nitrogen to remove all the volatile moieties. The crude product was purified by silica column using a mixture of ethyl acetate and hexane (1/1 to 3/1, v/v) as the eluent. After removing all the solvent by rotary evaporator, the product was obtained as yellow oil with yield of 53%.

Supporting data

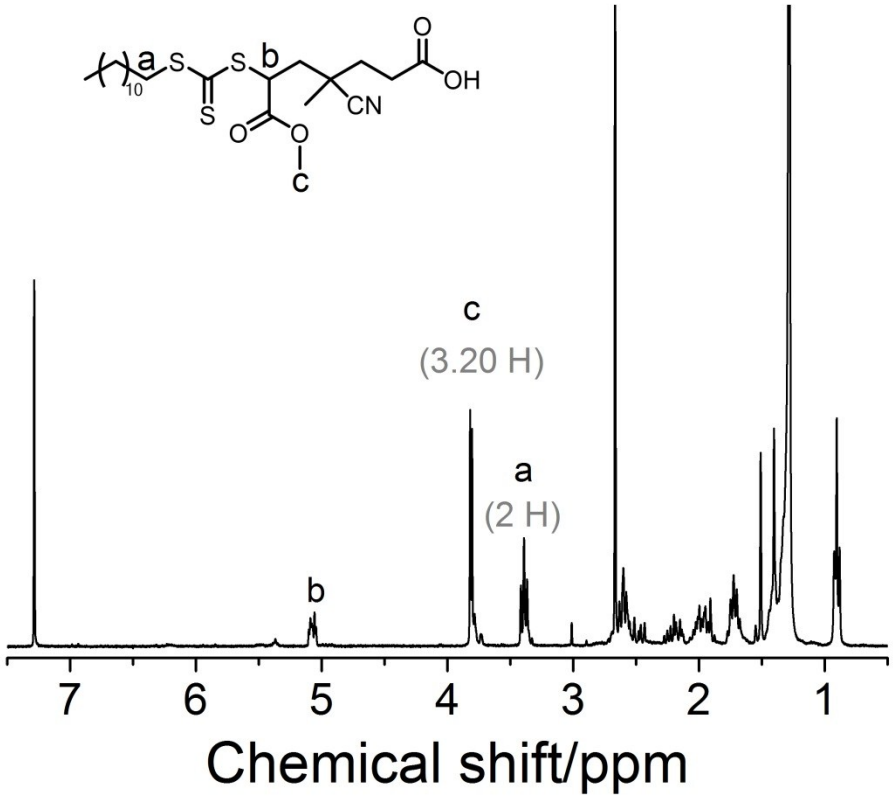

Figure S1 ^{1}H NMR spectrum ($CDCl_3$) of crude product obtained after 24 h reaction between MA and CDTPA under irradiation of green light.

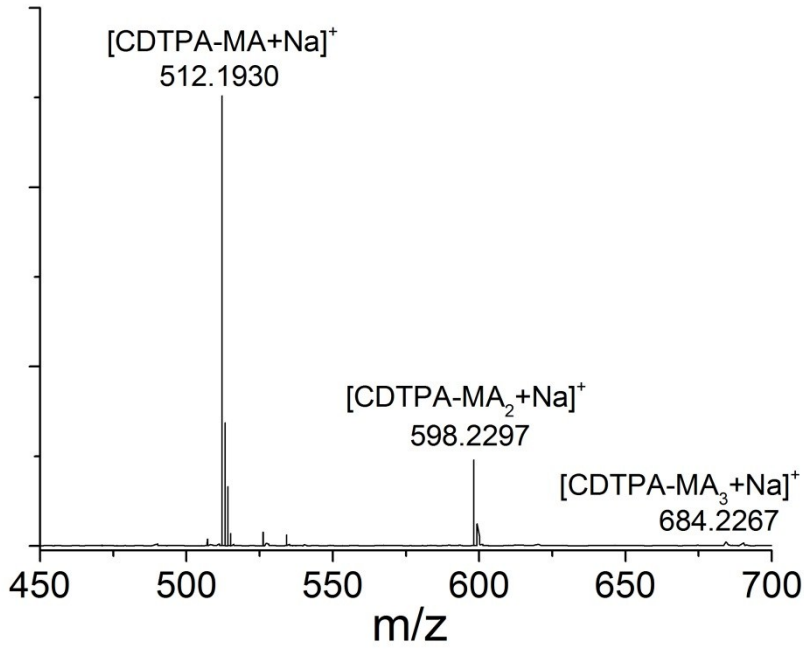

Figure S2 ESI-MS spectrum of crude product obtained after 24 h reaction between MA and CDTPA under irradiation of green light.

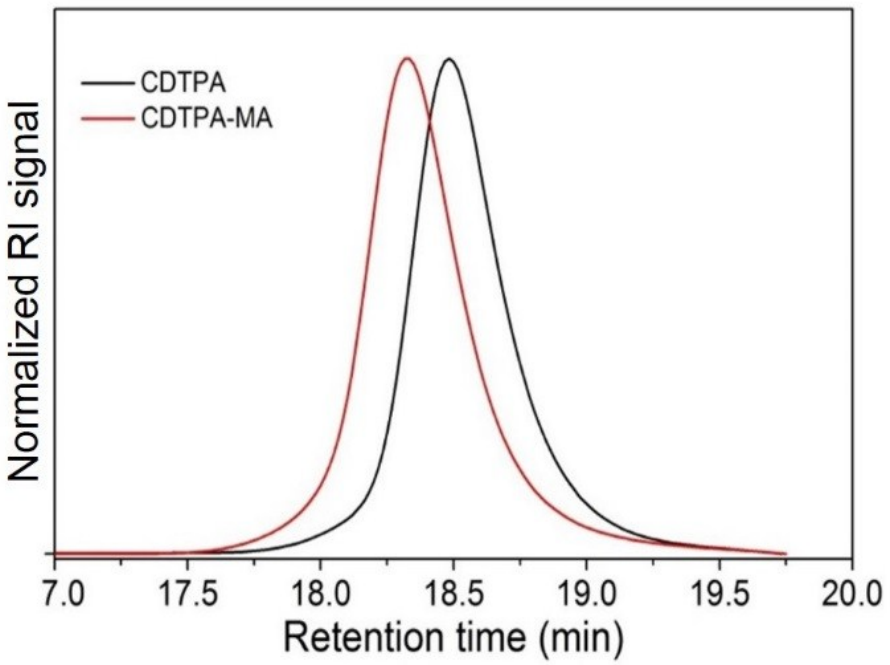

Figure S3. GPC traces of CDTPA and single unit monomer adduct CDTPA-MA.

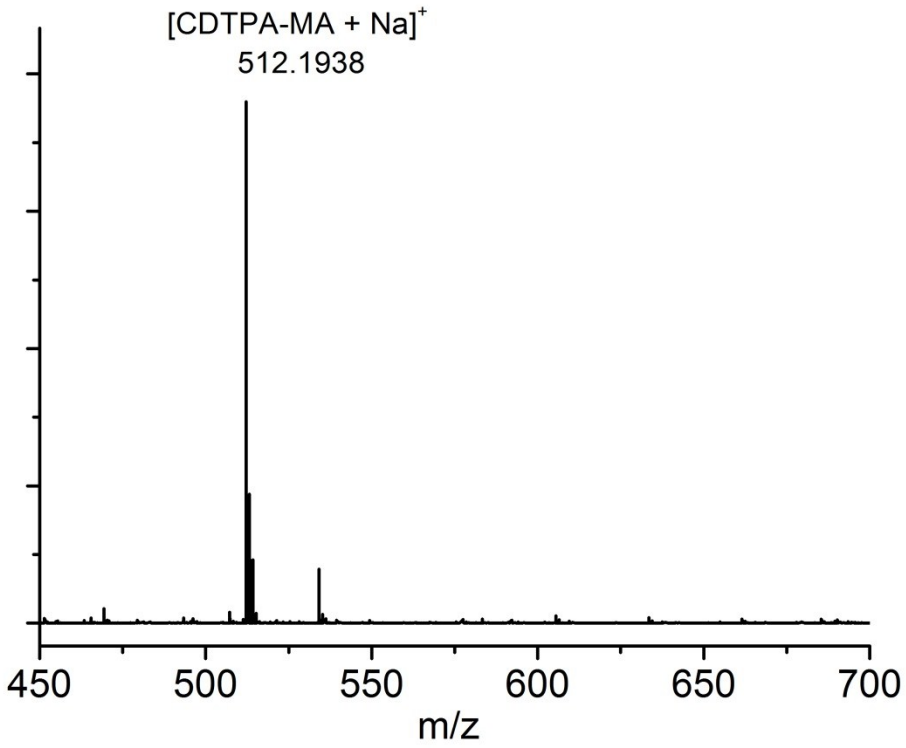

Figure S4 ESI-MS spectrum of purified single unit monomer adduct CDTPA-MA.

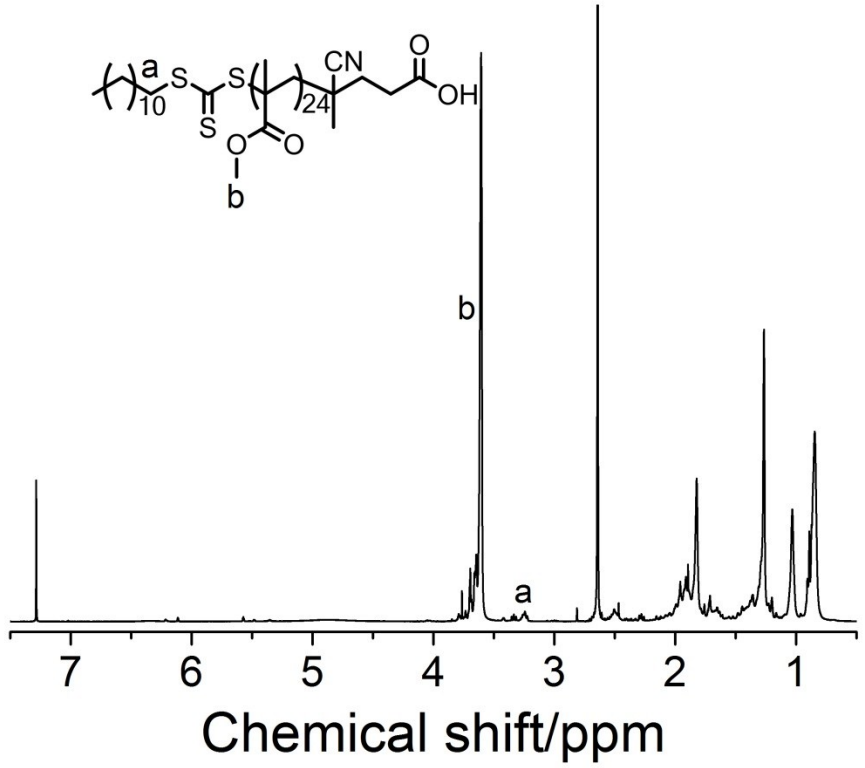

Figure S5 ^{1}H NMR spectrum ($CDCl_3$) of crude product obtained after 20 h reaction between MMA and CDTPA under irradiation of green light.

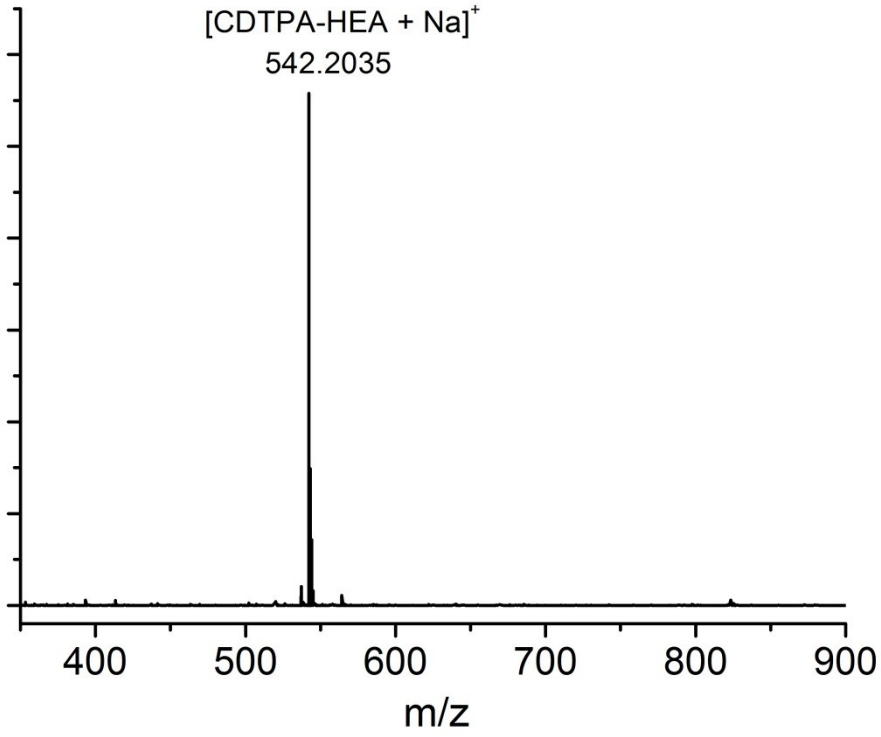

Figure S6 ESI-MS spectrum of purified single unit monomer adduct CDTPA-HEA.

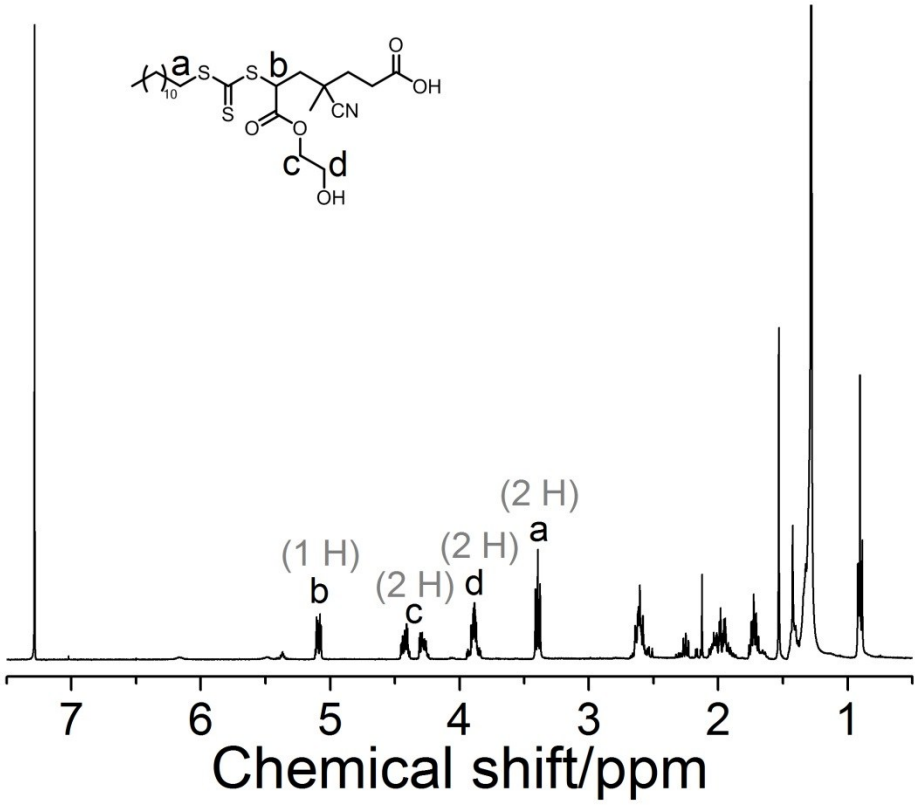

Figure S7 ^{1}H NMR spectrum ($CDCl_3$) of purified single unit monomer adduct CDTPA-HEA.

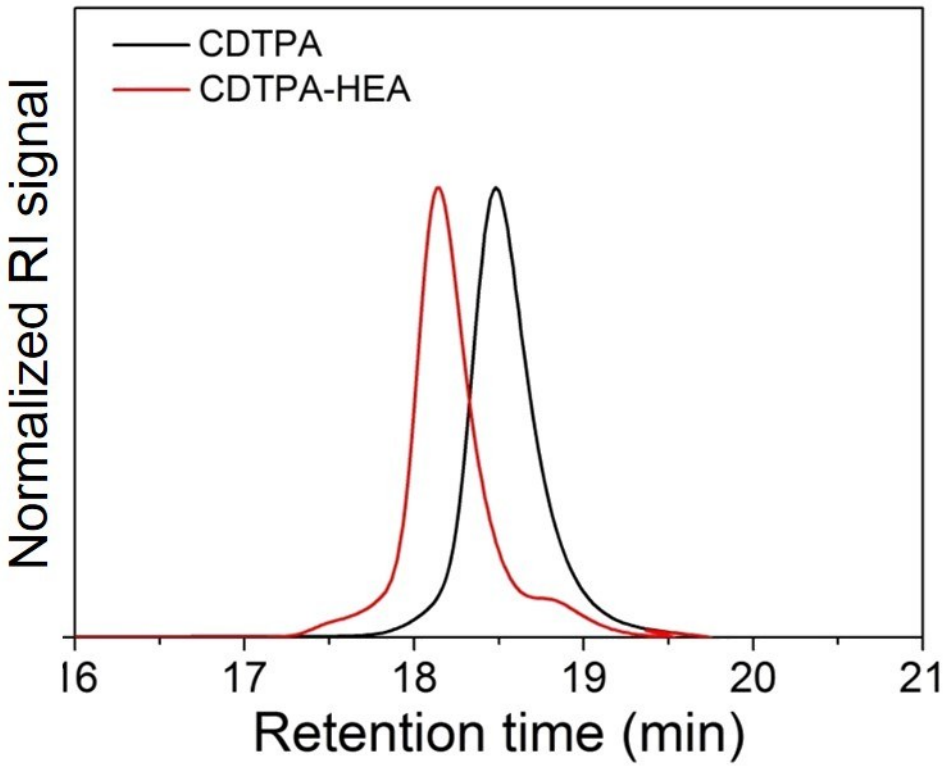

Figure S8 GPC traces of CDTPA and CDTPA-HEA.

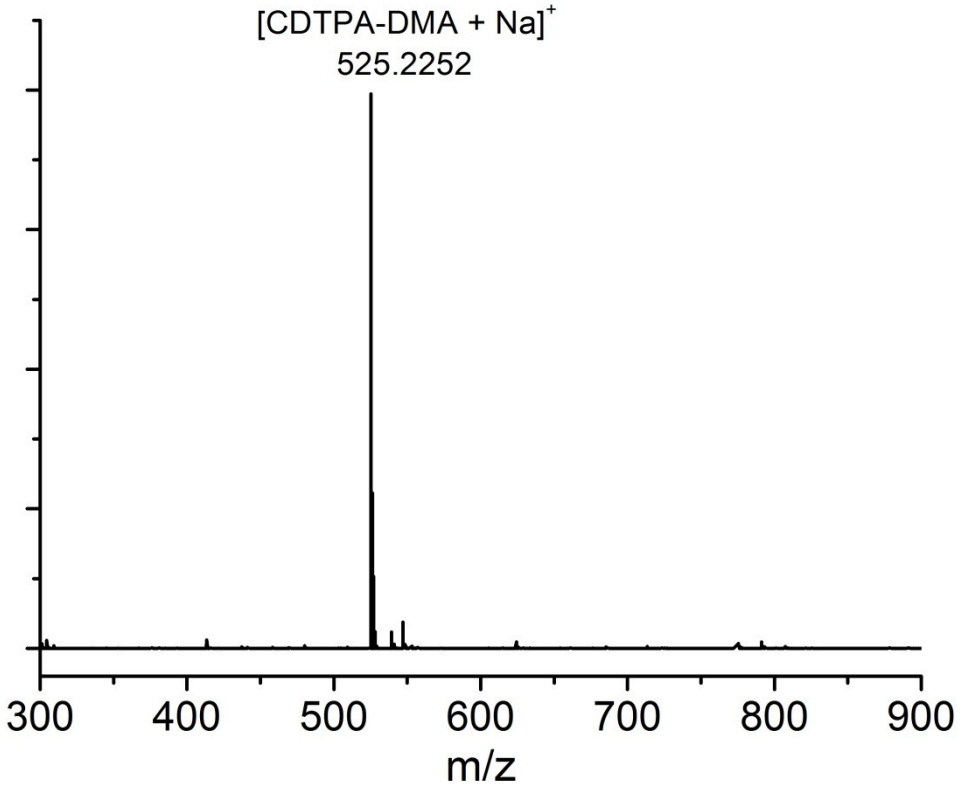

Figure S9 ESI-MS spectrum of purified single unit monomer adduct CDTPA-DMA.

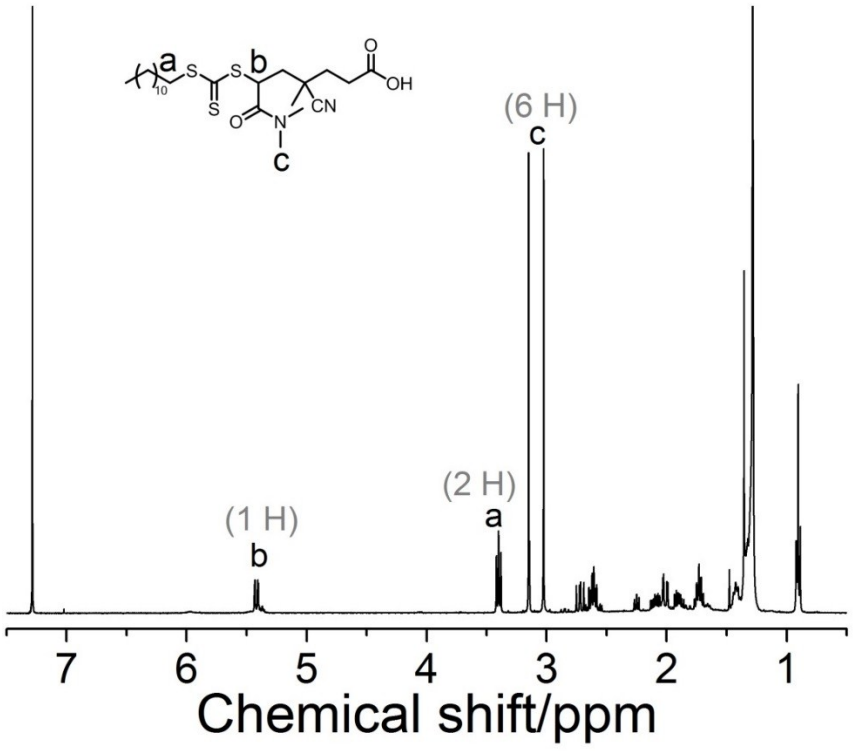

Figure S10 ^{1}H NMR spectrum ($CDCl_3$) of purified single unit monomer adduct CDTPA-DMA.

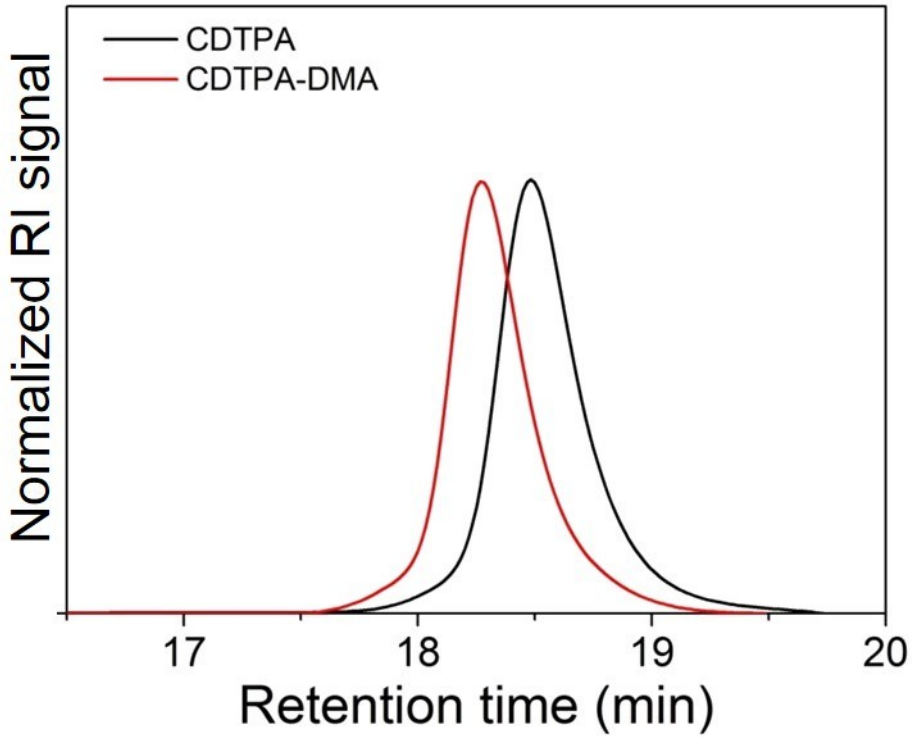

Figure S11 GPC (THF) traces of CDTPA and single unit monomer adduct CDTPA-DMA.

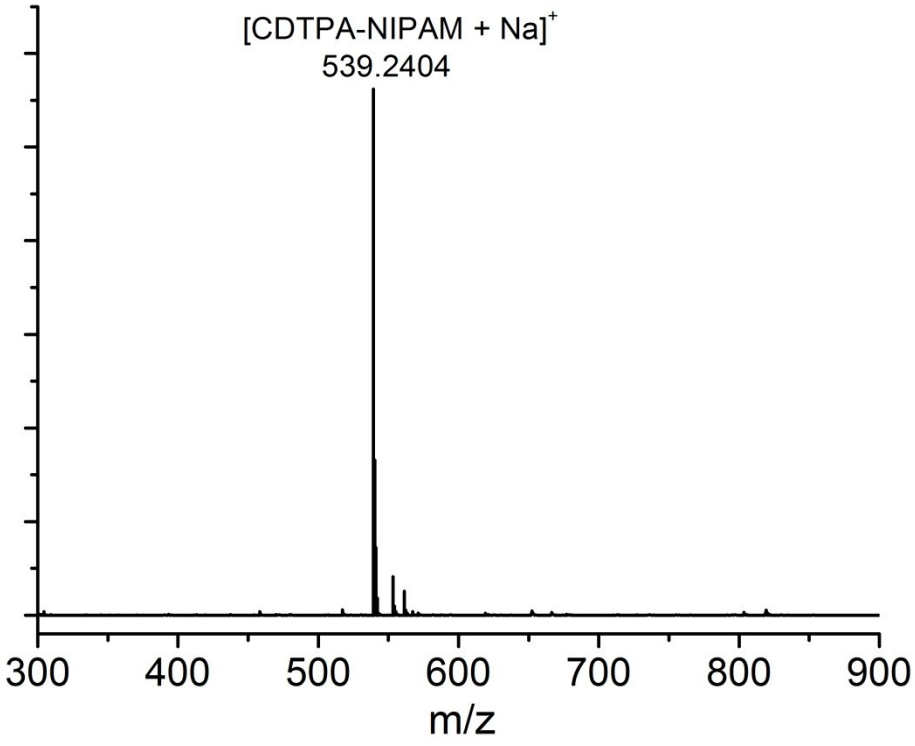

Figure S12 ESI-MS spectrum of purified single unit monomer adduct CDTPA-NIPAM.

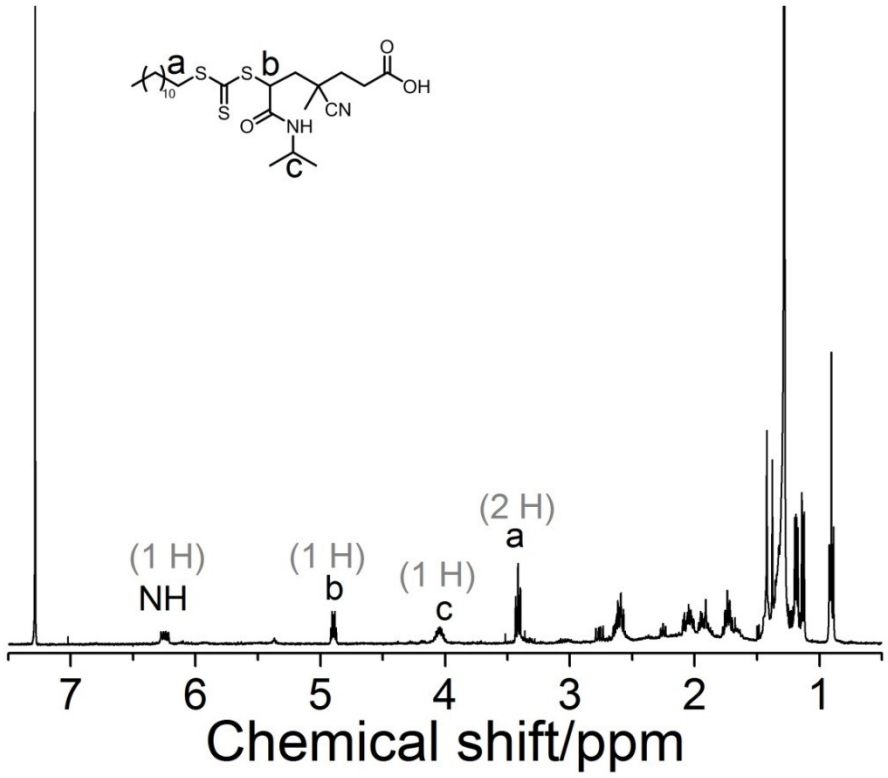

Figure S13 ^{1}H NMR spectrum ($CDCl_3$) of purified single unit monomer adduct CDTPA-NIPAM.

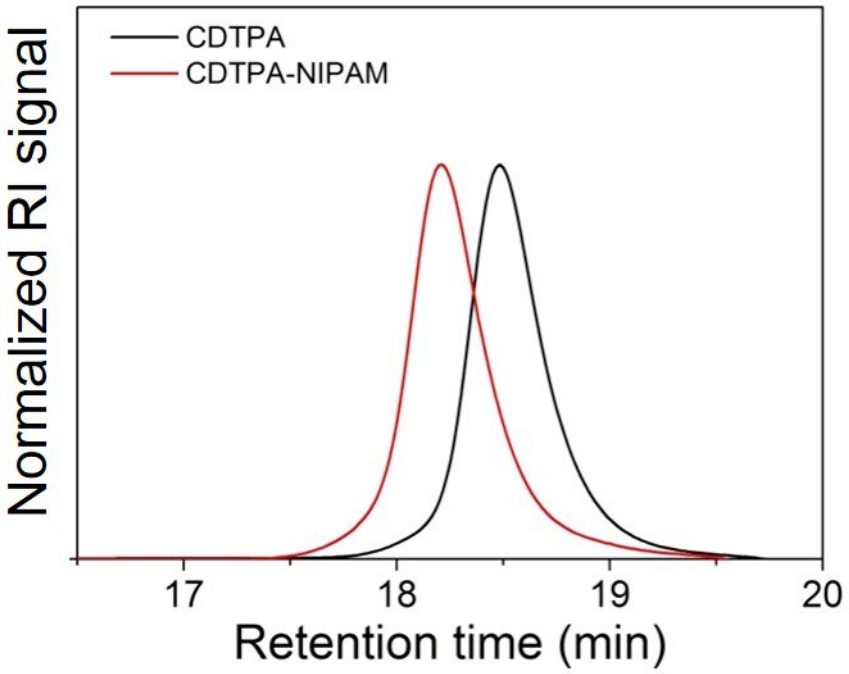

Figure S14 GPC traces of CDTPA and purified single unit monomer adduct CDTPA-NIPAM.

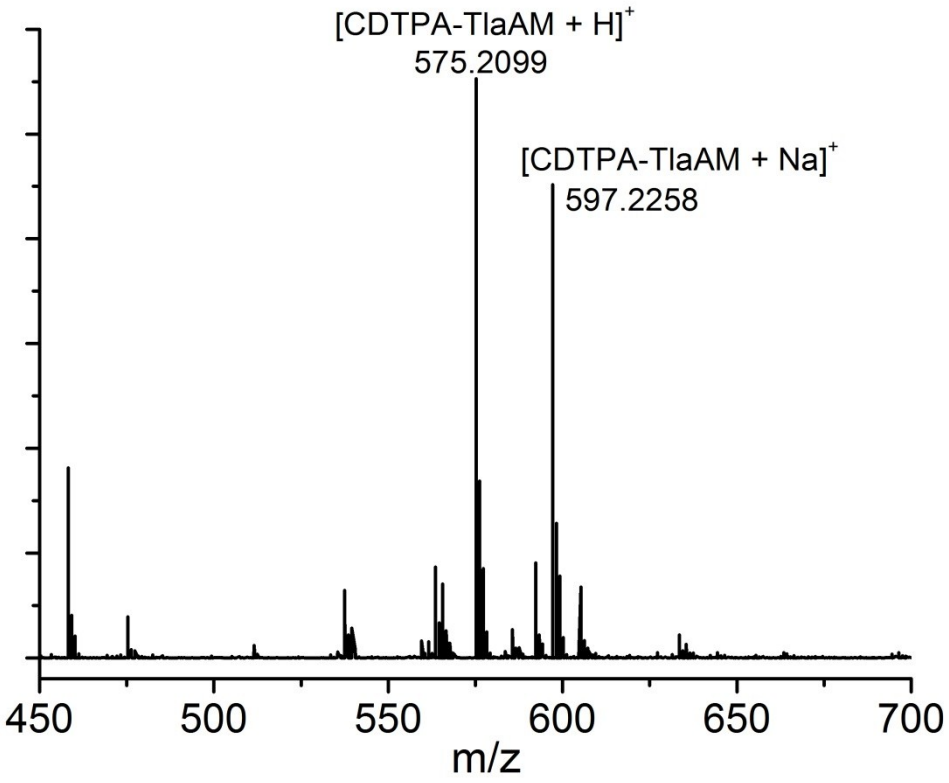

Figure S15 ESI-MS spectrum of purified single unit monomer adduct CDTPA-TlaAm.

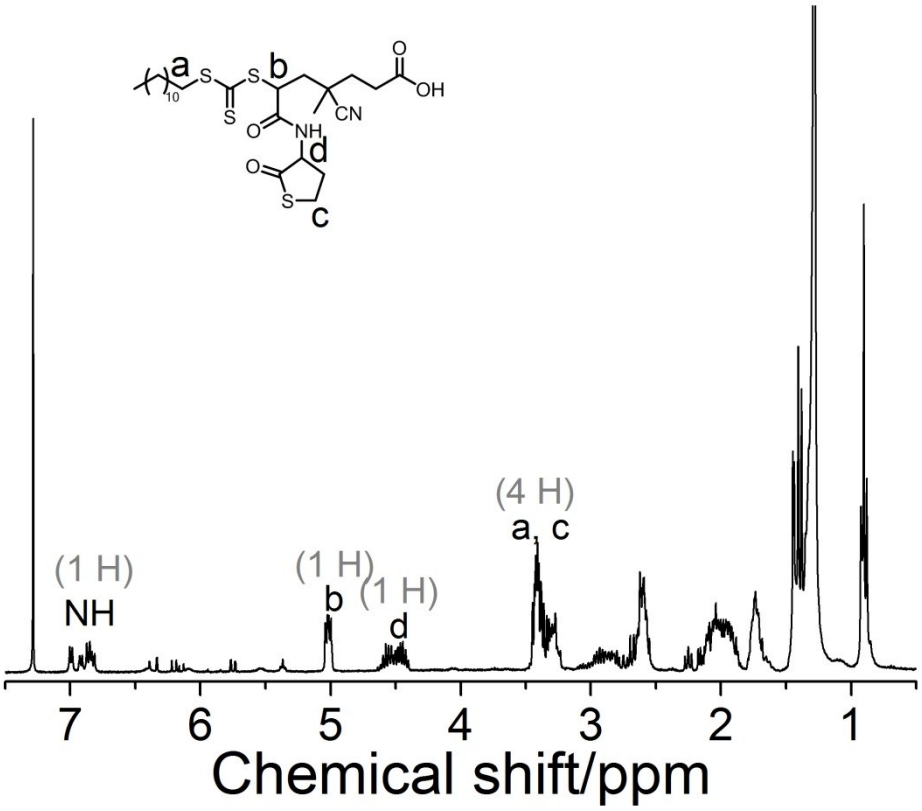

Figure S16 ^{1}H NMR spectrum ($CDCl_3$) of purified single unit monomer adduct CDTPA-TlaAm.

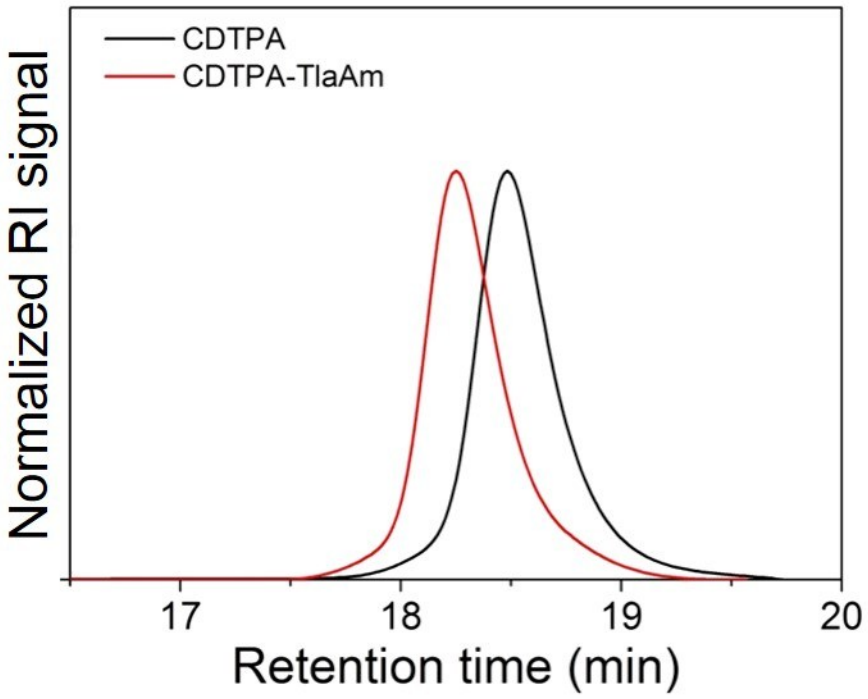

Figure S17 GPC traces of CDTPA and purified single unit monomer adduct CDTPA-TlaAm.

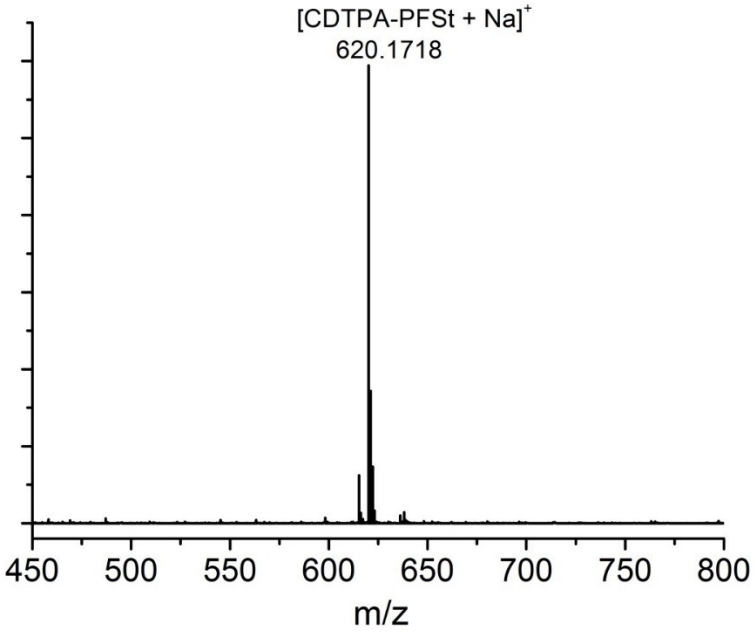

Figure S18 ESI-MS spectrum of purified single unit monomer adduct CDTPA-PFSt.

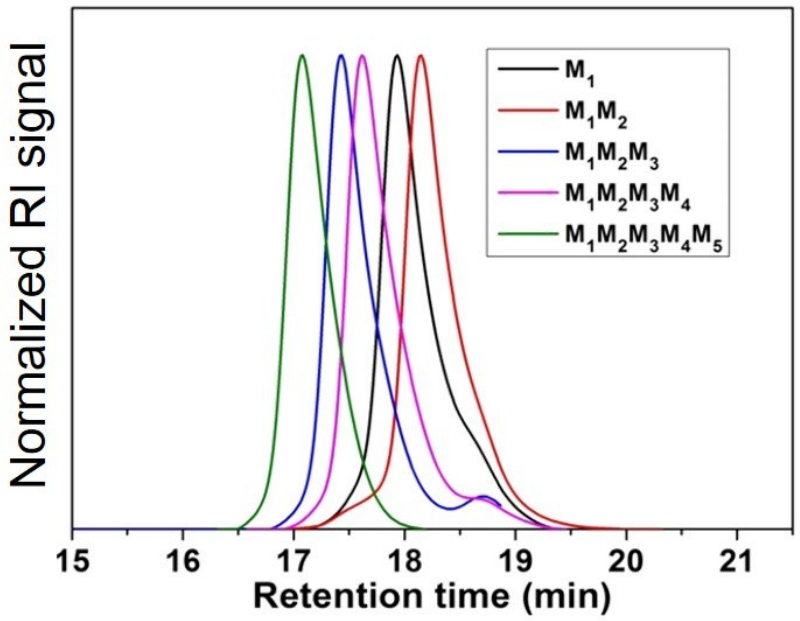

Figure S19. GPC traces of compounds $\mathbf{M_1}$ to $\mathbf{M_1M_2M_3M_4M_5}$.

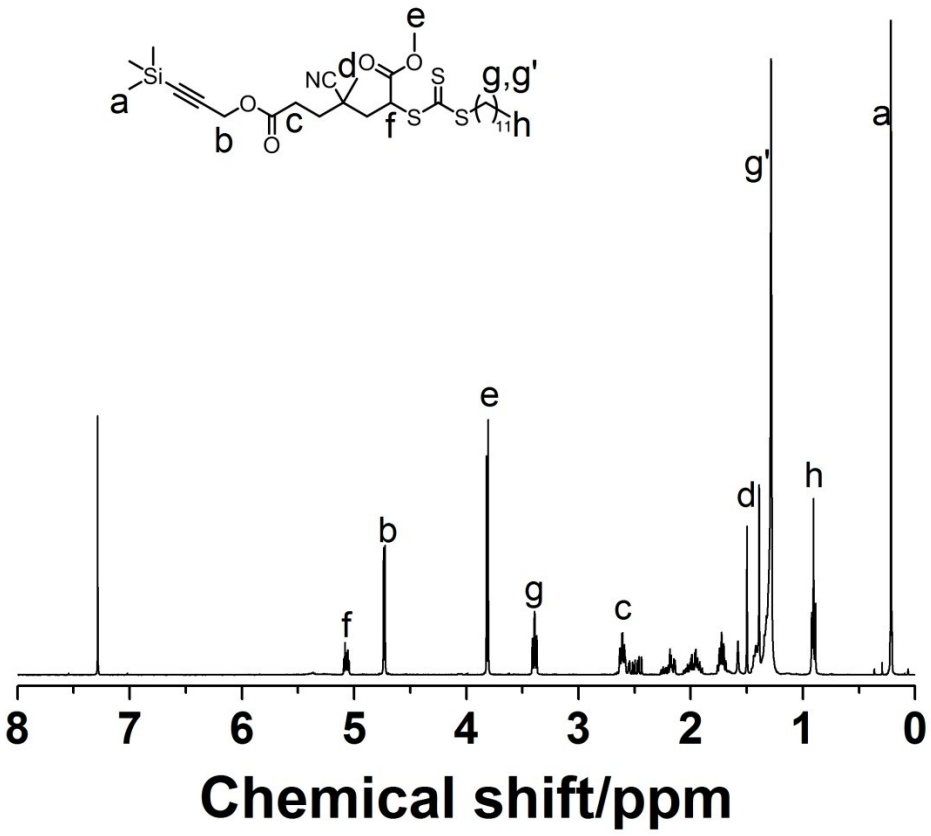

Figure S20 ^{1}H NMR spectrum ($CDCl_3$) of purified single unit monomer adduct $\mathbf{M_1}$.

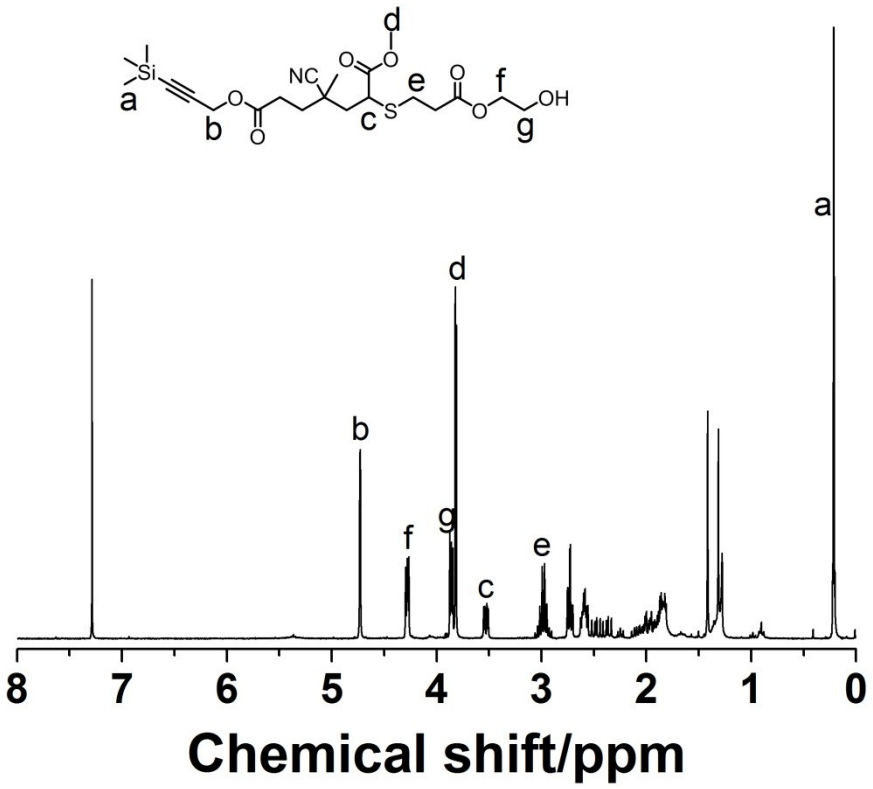

Figure S21 ^{1}H NMR spectrum ($CDCl_3$) of purified $\mathbf{M_1M_2}$.

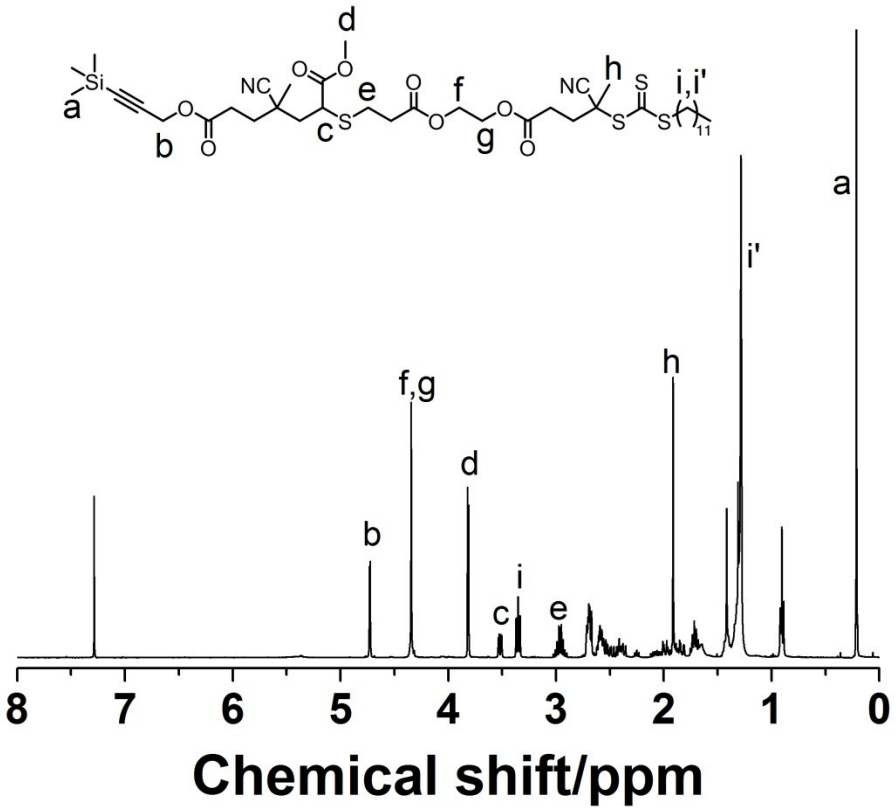

Figure S22 ^{1}H NMR spectrum ($CDCl_3$) of purified $\mathbf{M_1M_2}$**-CDTPA**.

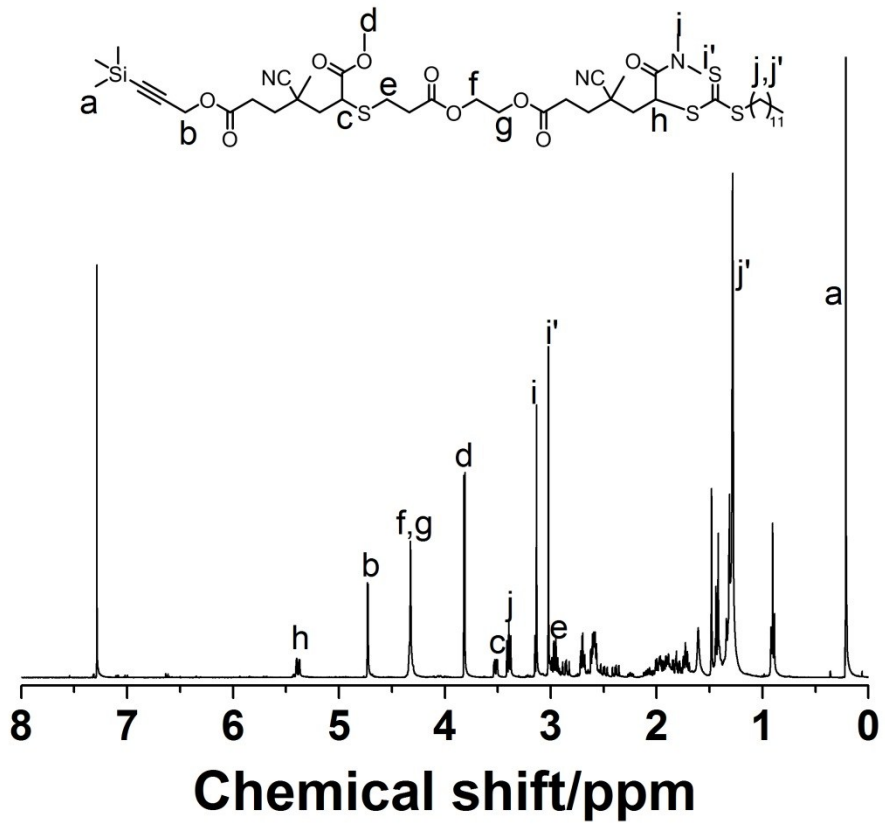

Figure S23 ^{1}H NMR spectrum ($CDCl_3$) of purified $\mathbf{M_1M_2M_3}$.

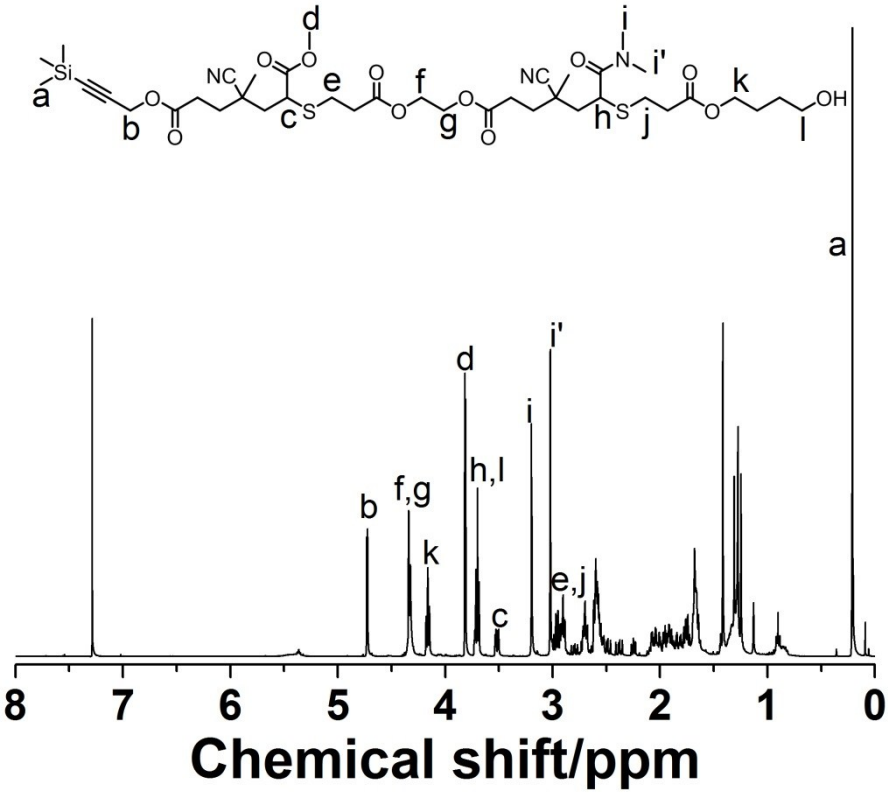

Figure S24 ^{1}H NMR spectrum ($CDCl_3$) of purified $\mathbf{M_1M_2M_3M_4}$.

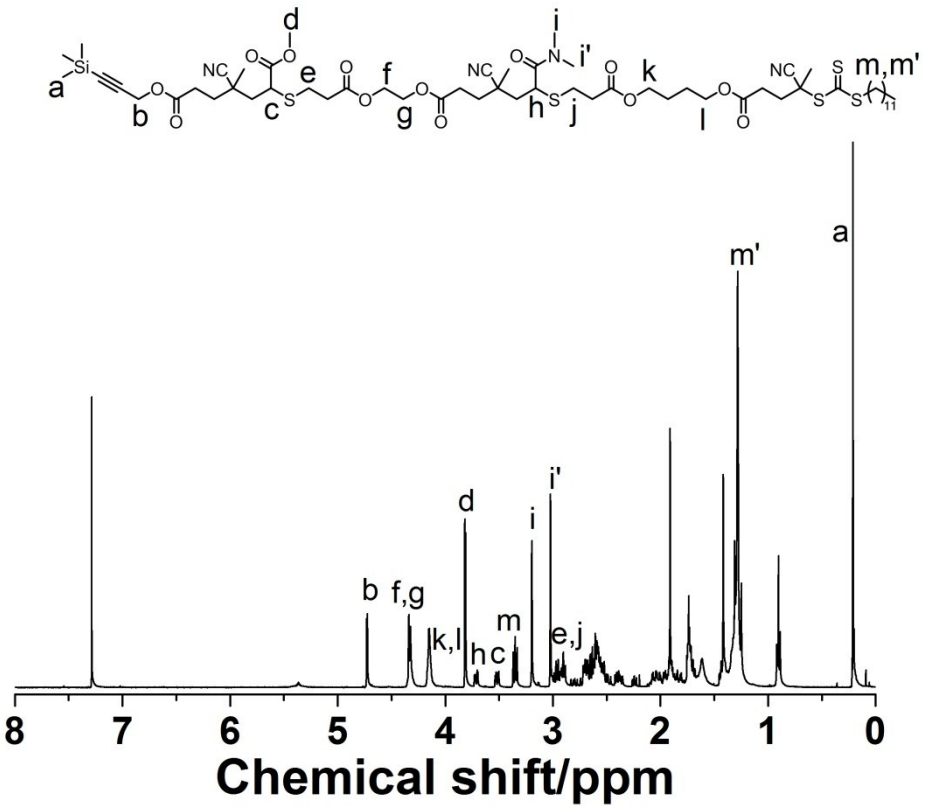

Figure S25 ^{1}H NMR spectrum ($CDCl_3$) of purified **$M_1M_2M_3M_4$-CDTPA**.

Additional References

1. S. Reinicke, P. Espeel, M. M. Stamenović and F. E. Du Prez, *ACS Macro Lett.*, 2013, **2**, 539-543.
2. K. Wang, H. Peng, K. J. Thurecht, S. Puttick and A. K. Whittaker, *Polymer Chemistry*, 2014, **5**, 1760-1771.