Supporting Information for

CO_2-Responsive Graft Copolymers: Synthesis and Characterization

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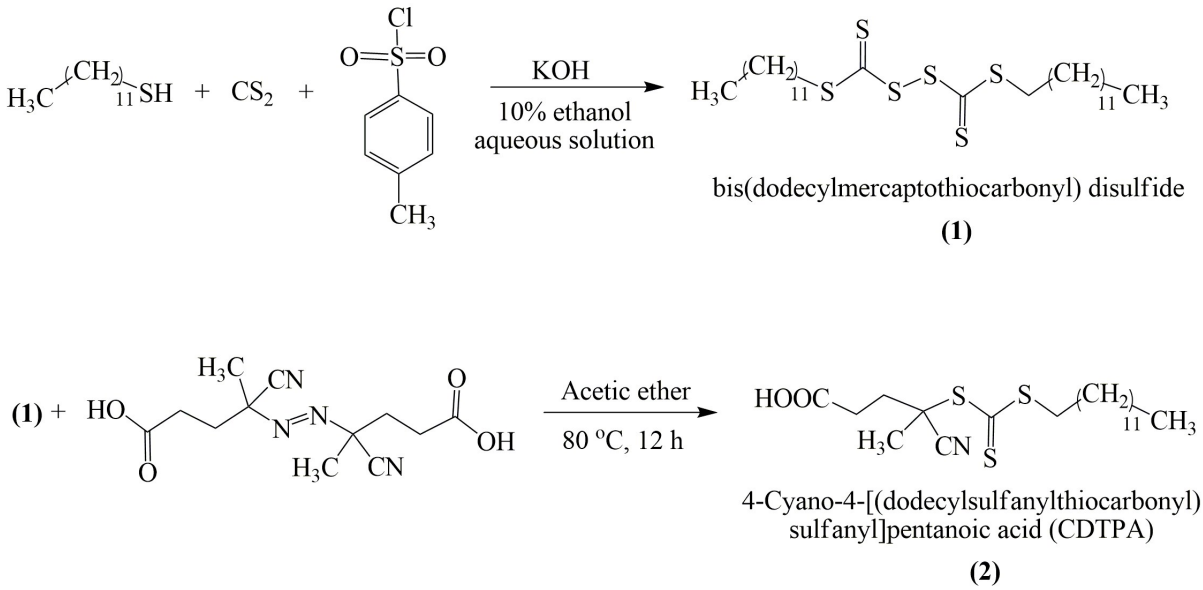
Experimental Section

Synthesis of 4-Cyano-4-[(dodecylsulfanylthiocarbonyl)sulfanyl]pentanoic acid (CDTPA): CDTPA was synthesized following literature report. The synthetic scheme is outlined below.[1]



Scheme S1 The synthetic route to 4-Cyano-4-[(dodecylsulfanylthiocarbonyl)sulfanyl]pentanoic acid (CDTPA)

Synthesis of compound 1: In the first step, the intermediate compound 1 was prepared as follows: 1-dodecanethiol (19.12 g, 0.094 mol) was dissolved in 80 mL of 10 % ethanol aqueous solution in a single neck round-bottom flask. Then potassium hydroxide (KOH) (6.36 g 0.11 mol) was added into the solution with vigorous stirring. After KOH was completely dissolved, carbon disulfide (7.17 g, 0.095 mol) was added dropwise into the mixture over 30 min and stirred at RT for 3 h. Then, p-toluensulfonyl chloride (8.78 g, 0.048 mol) in 20 mL of dichloromethane (DCM) was slowly added into the mixture under ice cold condition. The reaction was stopped after stirring at RT for 5 h. The mixture was extracted with 30 mL of DCM four times. The organic phases were combined together and, washed with saturated sodium bicarbonate solution three times and DI water two times, respectively. The obtained organic solution was dried over anhydrous sodium sulfate. After filtering out the solid, the excess solvent was removed under rotary evaporator to get 25 g of dark yellow solid as intermediate-

bis(dodecylmercaptothiocarbonyl) disulfide (compound 1) (Yield: 93%). ^{1}H-NMR (300 MHz, $CDCl_3$): 3.31ppm (t, 4H, -S-C**H$_2$**-CH_2-$(CH_2)_9$-), 1.70 ppm (t, 4H, -S-CH_2-C**H$_2$**-$(CH_2)_9$-), 1.28 ppm (s, 36H, -S-CH_2-CH_2-(C**H$_2$**)$_9$-) and 0.89 ppm (t, 6H, -$(CH_2)_{11}$C**H$_3$**).

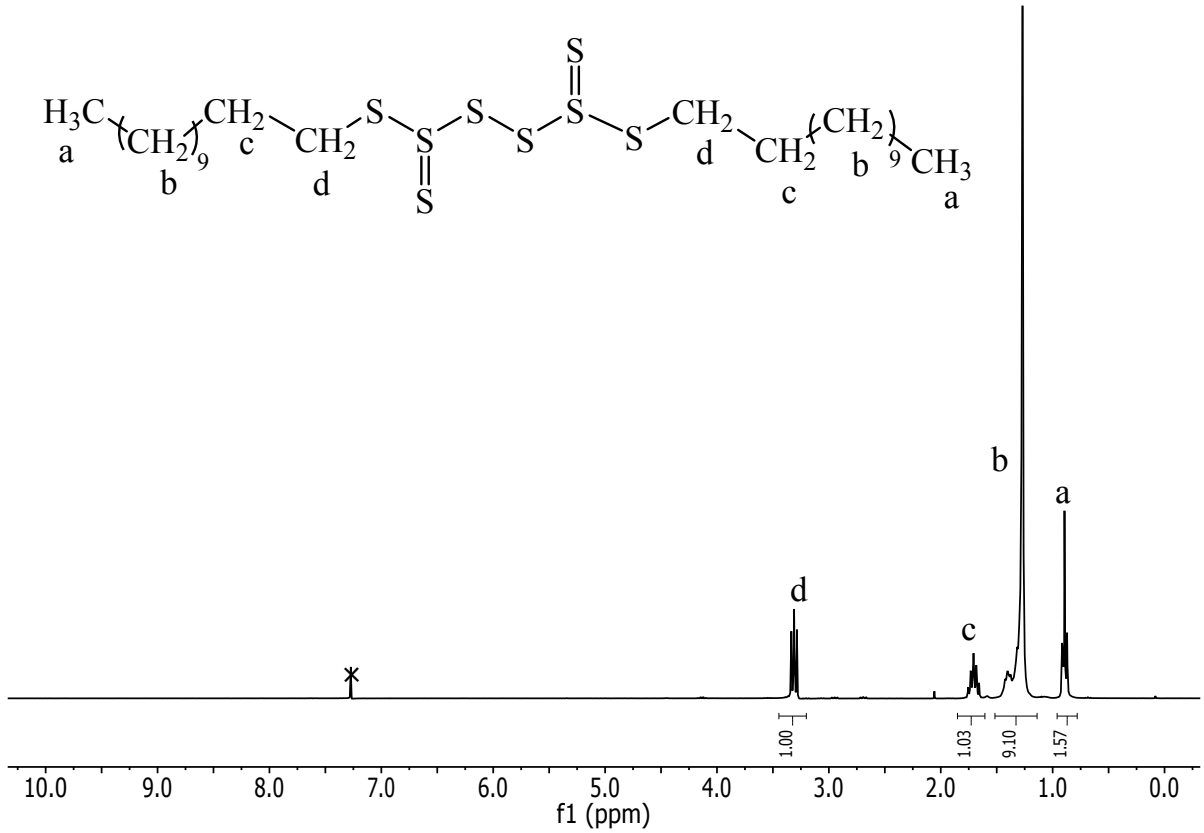


Fig. S1 ^{1}H-NMR spectrum of bis(dodecylmercaptothiocarbonyl) disulfide in $CDCl_3$, "×" denotes solvent peak.

Synthesis of compound 2: In this step, compound 1 (24 g, 0.043 mol) was dissolved in 200 mL of ethyl acetate and 4,4'-azobis(4-cyanovaleric acid) (13.9 g, 0.047 mol) was added to it. The mixture was stirred at 80 ^{o}C for 12 h. Subsequently, excess solvent was removed and crude product was purified by column chromatography using silica gel as stationary phase and ethyl acetate/ hexane (4 : 1, v : v) as eluent. The pure product (compound 2) was obtained as yellow solid (21.8 g, yield: 76 %). ^{1}H-NMR (300 MHz, $CDCl_3$): 3.36 ppm (t, 2H, -S-C**H$_2$**-), 2.69 ppm (t, 2H, HOOC-CH_2-C**H$_2$**-), 2.44 ppm (m, 2H, HOOC-C**H$_2$**-CH_2-), 1.89 ppm (s, 3H, -S(CN)C(C**H$_3$**)), 1.73 ppm (q, 2H, -S-CH_2-C**H$_2$**-), 1.27 ppm (s, 18H, -(C**H$_2$**)$_9$$CH_3$) and 0.89 ppm (t, 3H, -$(CH_2)_9$C**H$_3$**).

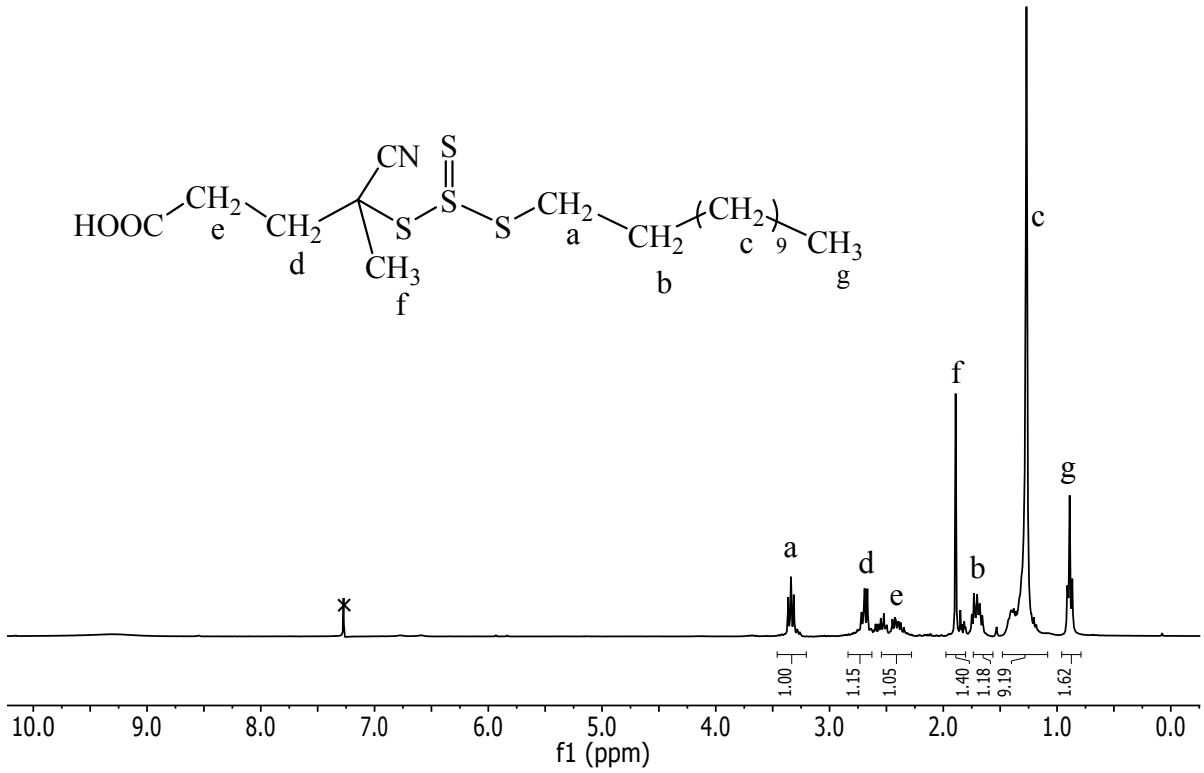
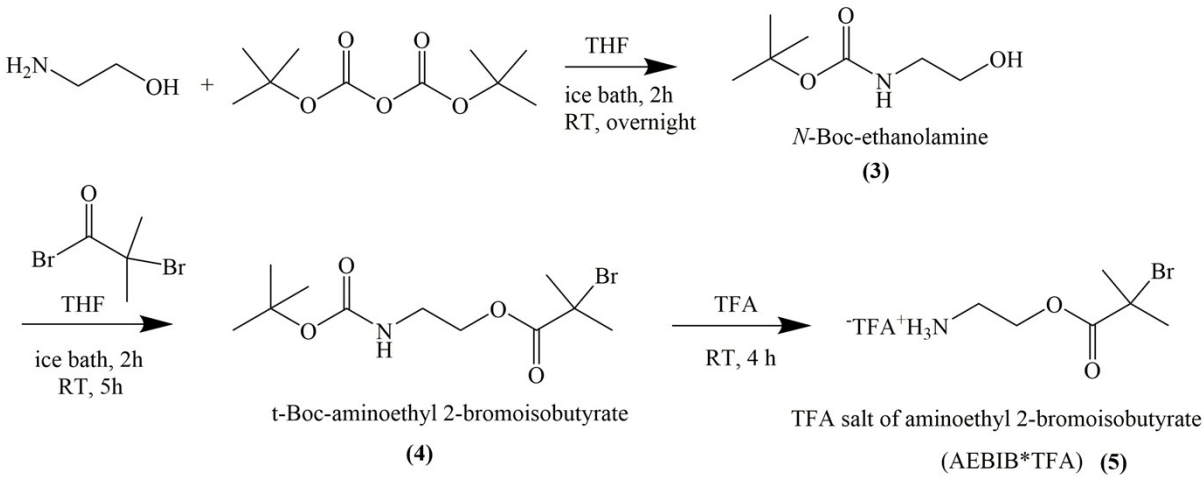


Fig. S2 ^{1}H-NMR spectrum of 4-Cyano-4-[(dodecylsulfanylthiocarbonyl)sulfanyl]pentanoic acid (CDTPA) in $CDCl_3$, "×" denotes solvent peak.



Scheme S2 The synthetic route to 2-aminoethyl 2-bromoisobutyrate. trifluoroacetic acid salt (AEBIB*TFA).

Synthesis of TFA salt of 2-aminoethyl 2-bromoisobutyrate (AEBIB*TFA):

Synthesis of compound 3: *N*-Boc-ethanolamine was synthesized according to the reported procedure.[2] Ethanolamine (1.06 equiv, 5.59 g, 0.092 mol) was dissolved into 250 mL dried THF in 500 mL one neck round bottom flask. Then, ditert-butyldicarbonate (1 equiv, 18.85 g, 0.086) separately dissolved in 25 mL dried THF was added dropwise into ice cold

solution of ethanolamine solution for 0.5 h. After 2 h, the ice bath was removed and the reaction was continued at RT overnight. Then, the excess THF was removed under reduced pressure in the rotary evaporator and the crude product obtained was dissolved into 30 mL DCM and sequentially washed with 30 mL of saturated sodium bicarbonate ($NaHCO_3$) solution and DI water three times, respectively. Subsequently, the DCM phase was dried over sodium sulfate and solvent was removed by under reduced pressure in the rotary evaporator to obtain colorless oily product (8.4 g, yield: 66%). ^{1}H-NMR (300 MHz, $CDCl_3$): 3.65 ppm (t, 2H, -C**H$_2$**OH), 3.24 ppm (t, 2H, -C**H$_2$**NH-), 1.42 ppm (s, 9H, -NHBoc).

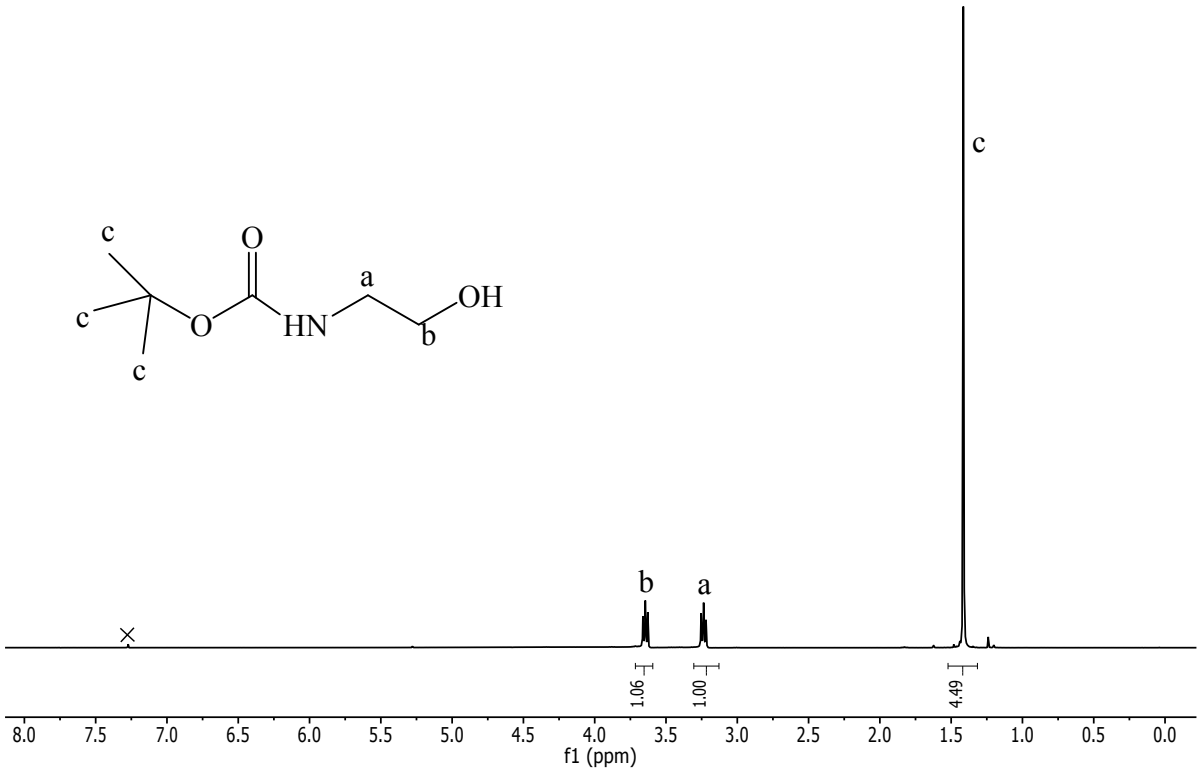


Fig. S3 ^{1}H-NMR spectrum of *N*-Boc-ethanolamine in $CDCl_3$, "×" denotes solvent peak.

Synthesis of compound 4: In this step, the *t*-Boc-aminoethyl 2-bromoisobutyrate also prepared following earlier report.[2] The *N*-Boc-ethanolamine (3) (1 equiv, 7.1 g, 0.044 mol) and 2,6-Lutidin (1.2 equiv, 5.7g, 0.053 mol) were dissolved in 100 mL of dried DCM and was cooled under ice bath. Then, 2-bromoisobutyryl bromide (1.06 equiv, 10.73 g, 0.047 mol) in 20 mL of DCM was added dropwise into the mixture for 0.5 h. After the reaction was stirred at RT for 4h, the precipitate was filtered off and the mixture was sequentially washed with saturated $NaHCO_3$ solution and DI water three times, respectively. The organic phase was dried over sodium sulfate. After removing excess DCM under reduced pressure, the crude product obtained was purified by column chromatography using silica gel as the stationary phase and DCM/ Ethyl acetate (4 : 1, v : v) as eluent to yield pale yellow liquid. Finally, the *t*-Boc-aminoethyl 2-bromoisobutyrate (compound 4) was obtained by crystallization in hexane (-20 ^{o}C) as white solid (9.58 g, Yield: 70 %). ^{1}H-NMR (300 MHz, $CDCl_3$): 1.45 ppm (s, 9H, -NHBoc), 1.95 ppm (s, 6H, -C(C**H$_3$**)$_2$Br), 3.46 ppm (q, 2H, -NHC**H$_2$**-), 4.25 ppm (t, 2H, -C**H$_2$**OCO-), 4.80 ppm (s, 1H, -N**H**-).

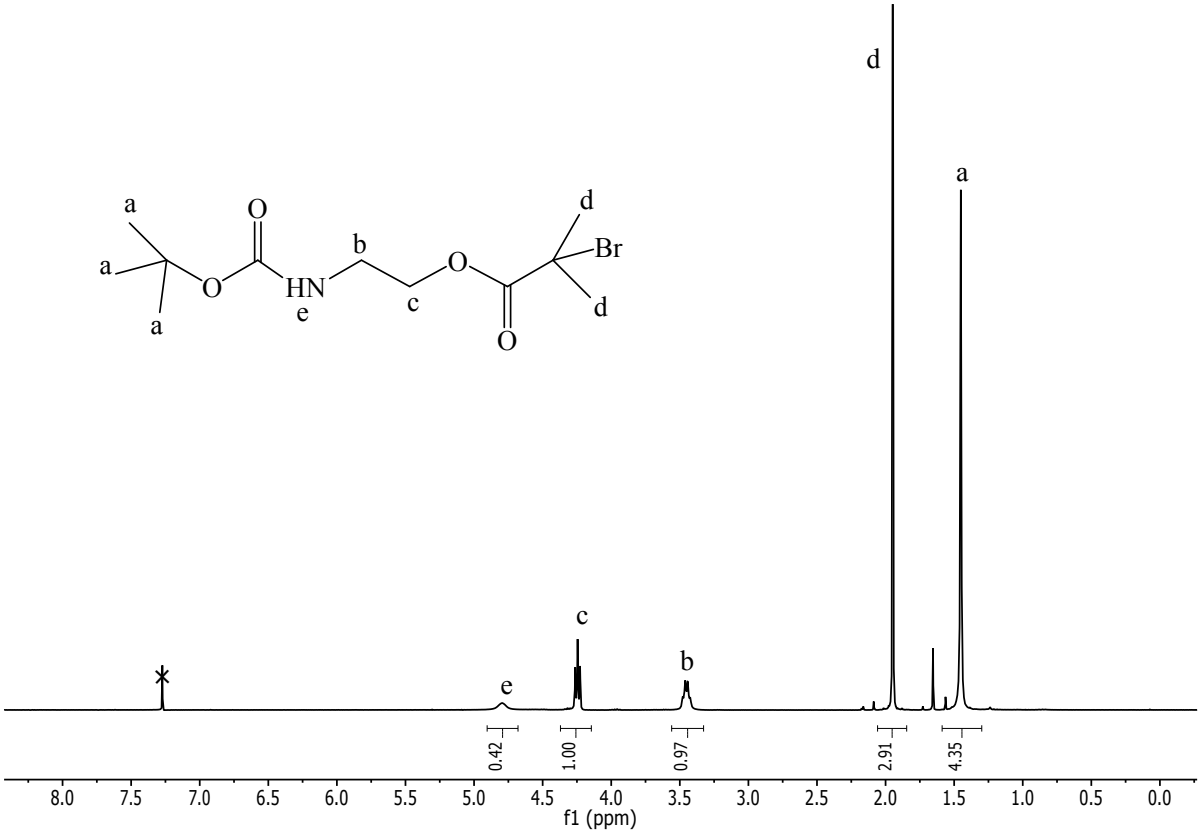


Fig. S4 ^{1}H-NMR spectrum of t-Boc-aminoethyl 2-bromoisobutyrate in $CDCl_3$, "×" denotes solvent peak.

Synthesis of compound 5: The amine ended initiator was prepared via a modified procedure based on previous reports.[3] *t*-Boc-aminoethyl 2-bromoisobutyrate (4) (8.0 g, 0.026 mol) was dissolved in 20 mL of trifluoroacidic acid (TFA). After vigorous stirring for 4 h, the excess TFA was removed by rotary evaporation. The TFA salt of 2-aminoethyl 2-bromoisobutyrate (AEBIB*TFA) (5) as white solid (7.8 g, yield: 93 %) by recrystallization of the crude product from diethyl ether by keeping the solution at -20 ^{o}C for two nights. ^{1}H-NMR (300 MHz, $CDCl_3$): 1.95 ppm (s, 6H, -C(C**H$_3$**)$_2$Br), 3.34 ppm (t, 2H, TFA$^-$NH$_3^+$C**H$_2$**-), 4.46 ppm (t, 2H, -C**H$_2$**OCO-) and 8.26 ppm (s, 1H, TFA$^-$N**H$_3^+$**CH$_2$-).

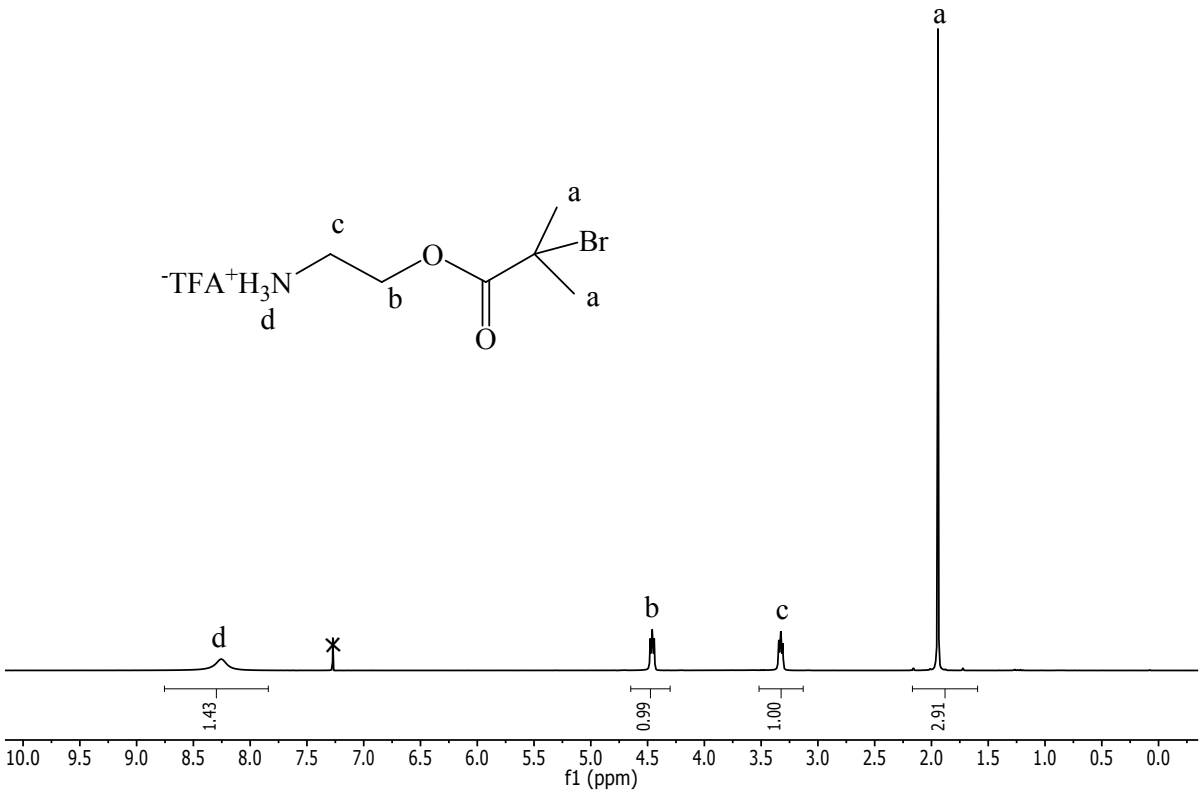


Fig. S5 ^{1}H-NMR spectrum of 2-aminoethyl 2-bromoisobutyrate. trifluoroacetic acid salt (AEBIB*TFA) in $CDCl_3$, "×" denotes solvent peak.

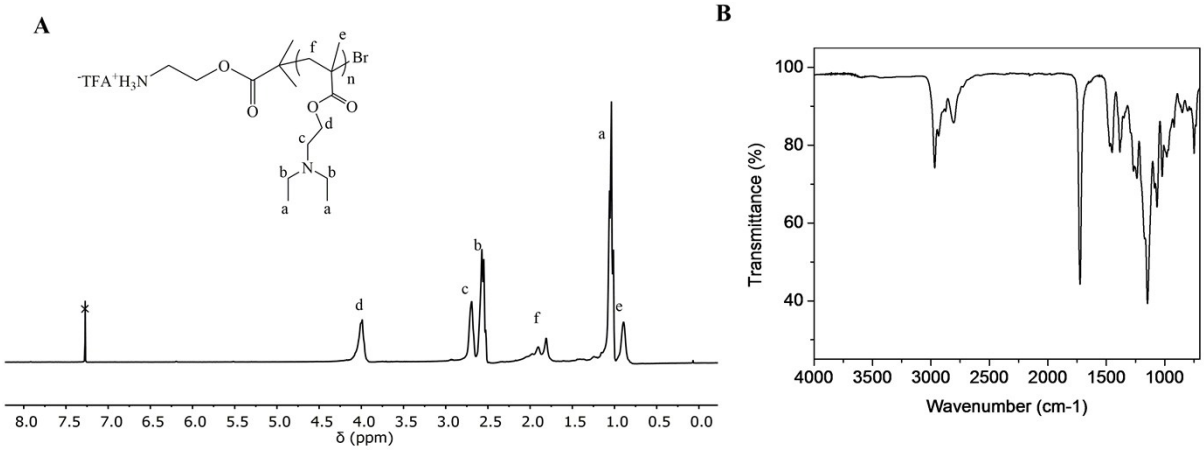


Fig. S6 ^{1}H NMR spectrum of PDEAEMA (P2) in $CDCl_3$, "×" denotes solvent peak (A) and FT-IR spectrum of PDEAEMA (P2) (B)

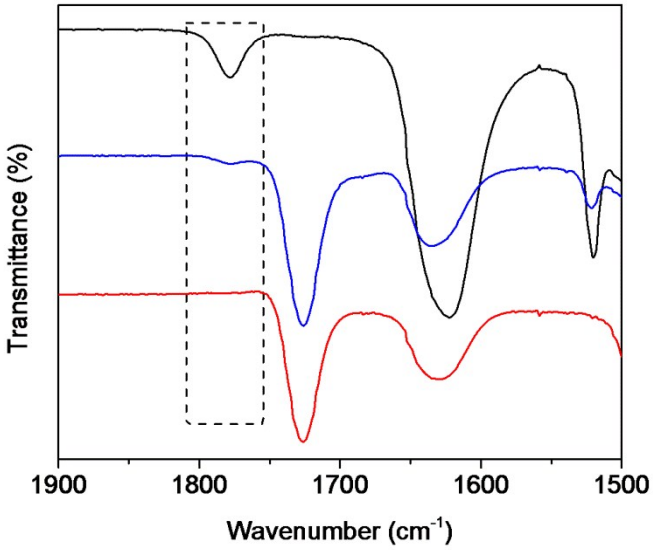


Fig. S7 The FT-IR spectra of transition of pentafluorophenyl ester during aminolysis of P(DMA-*co*-PFPA) (P1) at different time, 0 min (black line), 1.5 min (blue line), 5 min (red line).

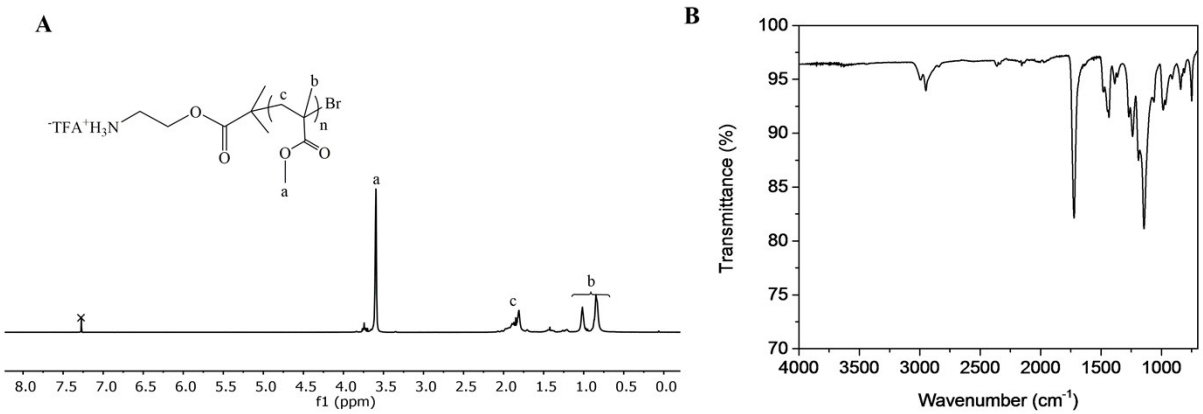


Fig. S8 ^{1}H NMR spectrum of PMMA (P3) in $CDCl_3$, "×" denotes solvent peak (A) and FT-IR spectrum of PMMA (P3) (B)

pK_a measurement and degree of protonation of tertiary amine groups in CO_2-resposnive graft copolymers

The pK_a of graft copolymers was determined as follows: 5 mL polymer solution (concentration: 0.5 mg/mL) was titrated with 0.001 mol/L hydrochloric acid and, the variable pH was successively monitored with the pH meter. The pH corresponding to the half the equivalence was determined as the pK_a value of corresponding polymer. As shown in Fig. S9, the volume of hydrochloric acid solution vs corresponding pH values of graft copolymer solutions were plotted. Then, the corresponding pK_a values of graft copolymers could be calculated with pK_a= 5.43 for P4 and pK_a= 5.35 for P5.

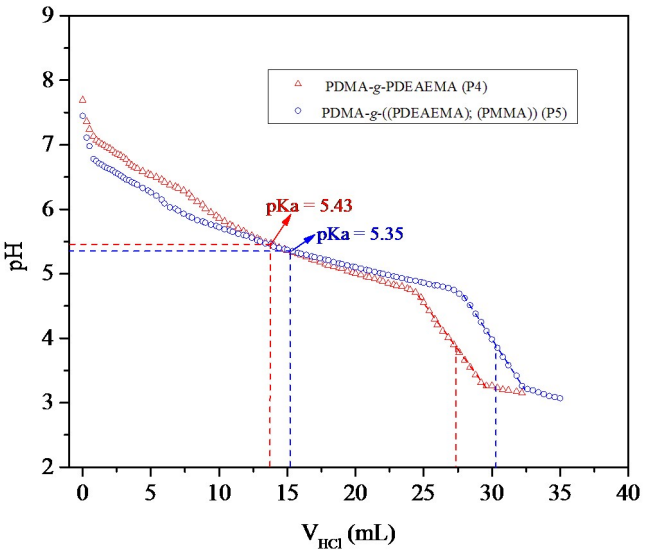


Fig. S9 Plotting curves of pH value *vs* volume of hydrochloric acid (concentration: 0.5 mg/mL of P4 and P5 vesicular solutions, 0.001 mol./L for hydrochloric acid)

After successful calculation of pK_a for P4 and P5, the degree of protonation of tertiary amine groups from PDEAEMA in P4 and P5 vesicular solutions after CO_2 and HCl treatment were calculated according to the following equations (1)-(4)[4]:

$$Ka = \frac{[PDEAEMA][H^+]}{[PDEAEMAH^+]} \quad (1)$$

$$\delta = \frac{[PDEAEMAH^+]}{[PDEAEMA]+[PDEAEMAH^+]} \quad (2)$$

$$pH = -\log[H^+] \quad (3)$$

$$\delta = \frac{1}{1+10^{pH-pKa}} \quad (4)$$

Upon purging CO_2 for 20 min, the pH value of P4 and P5 vesicular solution decreased from 7.62 to 5.56 and from 7.45 to 5.53. Based on the measured pK_a and the resulting pH values after purging CO_2 for 20 min of P4 and P5 solutions (concentration : 0.5 mg/mL), the degree of protonation δ values of tertiary amine groups from P4 and P5 aqueous solution were calculated as 42.6 % and 39.8 %, respectively, according to the equation 4. After reducing the pH of P4 and P5 vesicular solution (concentration : 0.5 mg/mL) to pH = 3 via adding 0.1 M HCl, δ of tertiary amine groups in P4 and P5 solution was measured to be approximately 99.9 %.

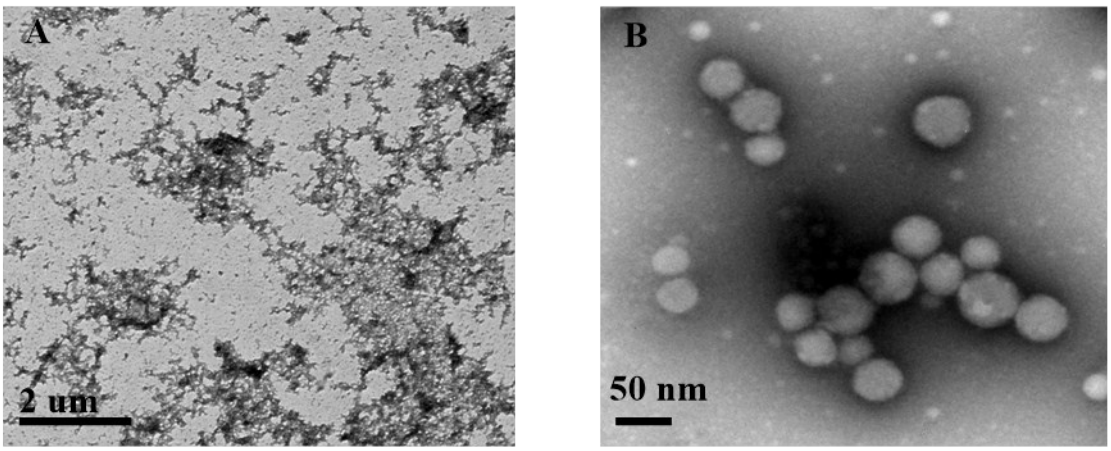


Fig. S10 The TEM images showing morphological transition of P4 (A) and P5 (B) vesicles after HCl treatment. The samples with concentration of 0.5 mg/mL were stained with 0.1 % phosphotungstic acid for TEM.

References

1 L. Fu, C. Sun and L. Yan, *ACS Appl. Mater. Interfaces*, 2015, **7**, 2104–2115.

2 H. Gao, J. Xiong, T. Cheng, J. Liu, L. Chu, J. Liu, R. Ma and L. Shi, *Biomacromolecules*, 2013, **14**, 460–467.

3 Z. Cao, Q. Yu, H. Xue, G. Cheng and S. Jiang, *Angew. Chemie*, 2010, **122**, 3859–3864.

4 H. Liu, Z. Guo, S. He, H. Yin, C. Fei and Y. Feng, *Polym. Chem.*, 2014, **5**, 4756–4763.