Supporting Information

Well-Defined Selenium-Containing Aliphatic Polycarbonates *via* Lipase-Catalyzed Ring-Opening Polymerization of Selenic Macrocyclic Carbonate Monomer

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EXPERIMENTAL METHODS

Materials: All reagents were available as analytical-grade products from Sigma-Aldrich, Aladdin or Shanghai Chemical Reagents Company and used as received unless otherwise noted. Polyethylene glycol (PEG, M_n=2000) and polyethylene glycol monomethyl ether (mPEG, M_n=2000) were purified by azeotropic distillation with toluene and removing solvent under reduced pressure. Lipase CA: Novozym 435 from Candida antarctica was dried under vacuum over phosphorus pentoxide (P_2O_5) for 48 h. Anhydrous toluene was obtained by treating regular solvent with sodium for 36 h to remove the moisture followed by distillation.

Synthesis of di(1-hydroxyethylene) selenide: Sodium borohydride (22 g, 0.58 mol) was dissolved in deionized water (160 mL). Then, Se powder (7.2g, 0.09 mol) was added to react for one hour, followed adding 2-bromoethanol (24 g, 0.19 mol) in 230 mL THF under Ar flow. The system was stirred at 50 ^{o}C overnight and then was extracted with dichloromethane (3×200 mL). The organic layers were combined, dried, and concentrated for column chromatography with a 1:2 (Volume ratio) mixture of CH_2Cl_2 and ethyl acetate as eluent. The product was obtained as light yellow liquid with a yield of about 50%.

^{1}H NMR (400 MHz, $CDCl_3$, δ, ppm): 3.83 (t, J=6.0 Hz, 4H), 2.81 (t, J=6.0 Hz, 4H).

^{13}C NMR (400 MHz, $CDCl_3$, δ, ppm): 61.87, 27.47.

Synthesis of M_{Se}: Di(1-hydroxyethylene) selenide (1 g, 5.92 mmol) and diphenyl carbonate(1.9 g, 8.9 mmol) were dissolved in dried toluene (500-600 mL) under Ar flow. Afterwards, dried lipase CA (1.9 g) was added rapidly and the system was stirred at 70 ^{o}C for about 8 h. After the reaction, lipase CA was removed by filtration and the solvent was evaporated under reduced pressure. The crude reaction mixture was firstly washed with cold diethyl ether to clear away by-products and a few of oligomers. Finally, the monomer was purified by flash column chromatography using dichloromethane as eluent (35-45% yield).

^{1}H NMR (400 MHz, $CDCl_3$, δ, ppm): 4.46 (t, J=6.3 Hz, 8H), 2.92 (t, J=6.3 Hz, 8H).

^{13}C NMR (400 MHz, $CDCl_3$, δ, ppm): 154.75, 67.61, 22.30.

^{77}Se NMR(400 MHz, $CDCl_3$, δ, ppm): 137.0

FT-IR (v, cm^{-1}): 1752.5 (C=O).

HRMS (EI, m/z): M^+ Calculated for $C_{10}H_{16}O_6Se_2$, 391.9277; Found, 391.9278.

T_m=93 ^{o}C (DSC).

The typical enzymatic ROP of M_{Se}: A solution of initiator, benzyl alcohol in dried toluene with a concentration of 5×10^{-4} mmol μL^{-1} was prepared prior to polymerization. Typically, at 10 wt % of enzyme to monomer, **M_{Se}** (78 mg, 0.2 mmol) and lipase CA (8 mg) was added to a 5 mL vial equipped with a stir bar. Then, benzyl alcohol (20 μL, 0.01 mmol) and anhydrous toluene (~0.6 mL) were introduced *via* a gastight syringe to initiate polymerization. The polymerization was allowed to stir at 70 ^{o}C for 6 h. The resulting product was dissolved with ~1mL dichloromethane and the insoluble lipase CA was removed by filtration. The solution was precipitated into cold anhydrous diethyl ether and dried in vacuo to give transparent viscous polymers named as PSe with a yield about 80 %. The molecular weight (M_n) was obtained by comparing the peak integral ratio at 4.35 ppm or 2.85 ppm of the repeat units of polymers and 5.17 ppm of the initiator.

The PSe with different degree of polymerization (DP) and macroinitiator mediated ROP were carried out according to the same procedure.

The typical copolymerization of M_{Se} with trimethylene carbonate (TMC): The copolymerization was executed according to the similar procedure of homopolymerization. Typically, at 10 wt % of enzyme to monomer, **M_{Se}** (78 mg, 0.2 mmol), TMC (20 mg, 0.2 mmol) and lipase CA (10 mg) was added to a 5 mL vial equipped with a stir bar. Afterwards, benzyl alcohol (20 μL, 0.01 mmol) and anhydrous toluene (~0.8 mL) were introduced *via* a gastight syringe to initiate polymerization. After stirring at 70^{o}C for 24 h, the resulting product was dissolved with ~1 mL dichloromethane and the insoluble enzyme was removed by filtration. The solution was precipitated into cold anhydrous diethyl ether and dried in vacuo to give transparent viscous polymers named as PSe-*co*-PTMC with a yield about 84 %. Different copolymerization ratios can be obtained by adjusting the feed ratio of M_{Se} to TMC.

Polymerization kinetics experiment: In a 5 mL vial equipped with a stir bar, **M_{Se}** (78 mg, 0.2 mmol), benzyl alcohol (20 μL, 0.01 mmol) and lipase CA (8 mg) was added with the designed degree of polymerization (DP) of 20. Then, ~0.6 mL anhydrous toluene was added to initiate polymerization. The reaction mixture was allowed to stir at 70^{o}C and the solution (20 μL) was taken out from the reaction system at a determined time intervals for ^{1}H NMR spectroscopy analysis. Monomer conversion was calculated by comparing the area integral of the triplet at 4.46 ppm, corresponding to -CH_2SeCH_2- (8*H*) of monomer with that of the triplet at 4.35 ppm, corresponding to -CH_2SeCH_2- (8*H*) of polymer.

Characterization: NMR (^{1}H, ^{13}C, ^{77}Se) spectra were recorded on a Bruker Avance 400 spectrometer (400 MHz) and the data were analyzed with MestReNova software. Deuterated chloroform ($CDCl_3$) and tetramethylsilane (TMS) were used as the internal standard to record the chemical shifts. Diphenyl diselenide was employed as the reference to obtained ^{77}Se spectra. Fourier transform infrared spectrometer (FT-IR) was carried out on a Nicolet 5700 FT-IR spectrometer by KBr sample holder method. EI-mass spectrum was obtained on a Waters GCT Premier apparatus for detecting the structure of monomer and ionized debris. Gel permeation chromatograph (GPC) was performed using DMF as the eluent at a flow rate of 1.0 mL min^{-1} and polymethyl methacrylate (PMMA) as the standard to obtain the molecular weights and molecular-weight distributions. Multi-measurement gel permeation chromatography (GPC-LSL) was carried out on Waters515 with 658.0 nm laser wavelength using THF as the eluent at a flow rate of 1.0 mL min^{-1} to determine the weight-average molecular weight (M_w) and molecular-weight distributions. The melting point

(T_m) of monomer was determined with a US Dimond differential scanning calorimeter (DSC) under N_2 atmosphere, with a heating rate of 10 °C/min. Thermo-gravimetric analysis (TGA) was performed under N_2 atmosphere on STA409PC apparatus with a heating rate of 10 °C/min.

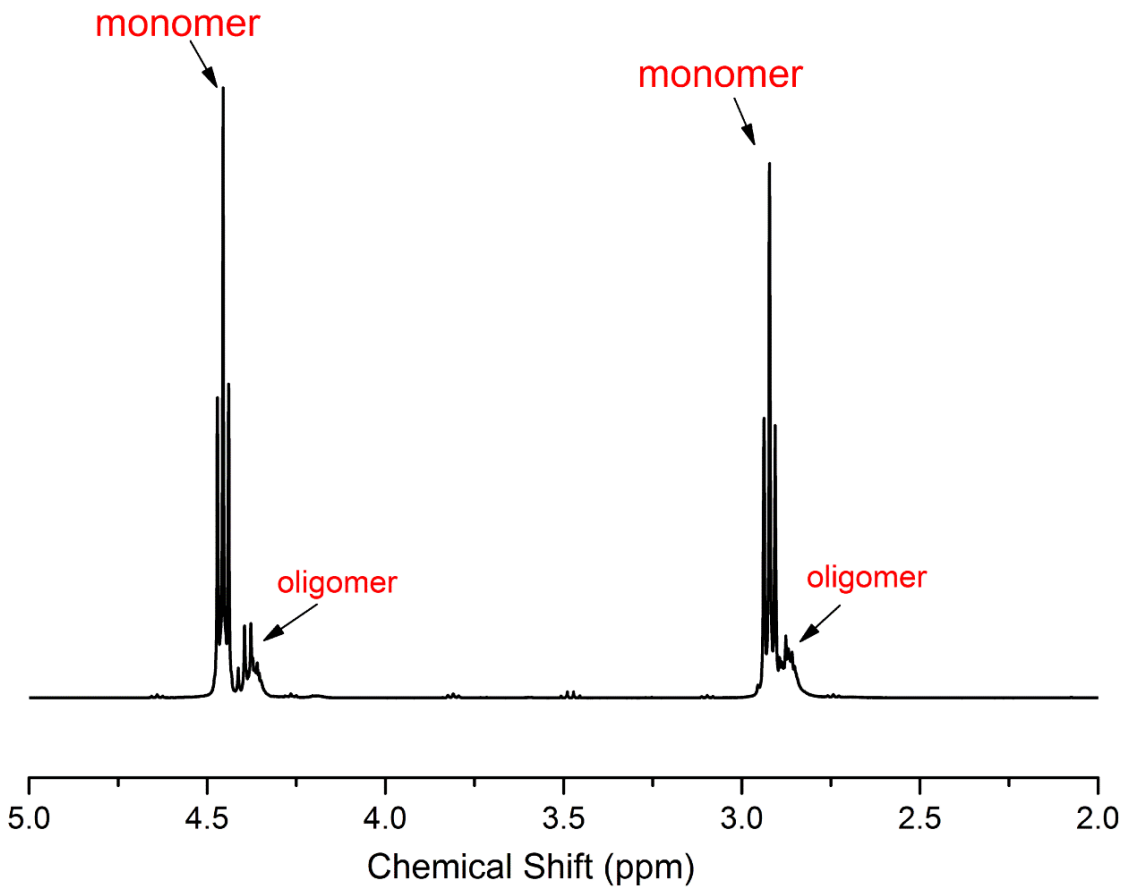


Figure S1. ^{1}H NMR spectrum of M_{Se} after the reaction, suggesting the inevitable generation of oligomer.

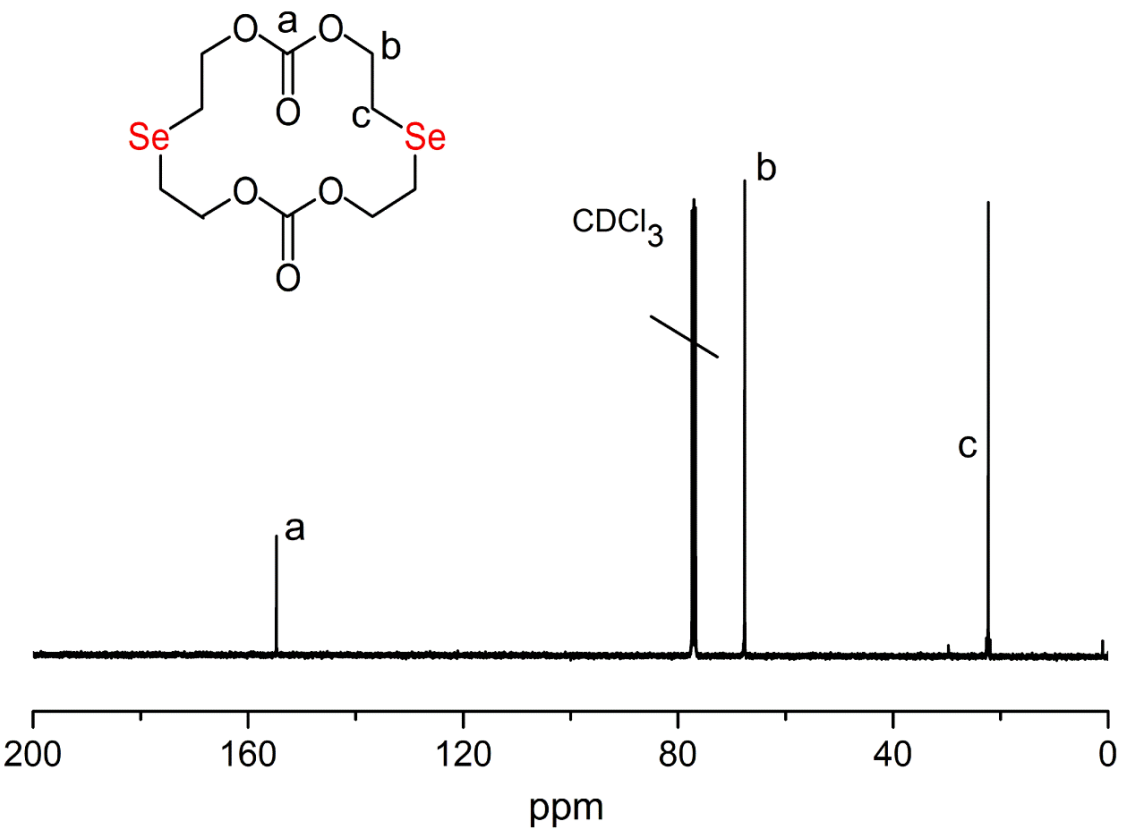


Figure S2. ^{13}C NMR spectrum of M_{Se} in $CDCl_3$.

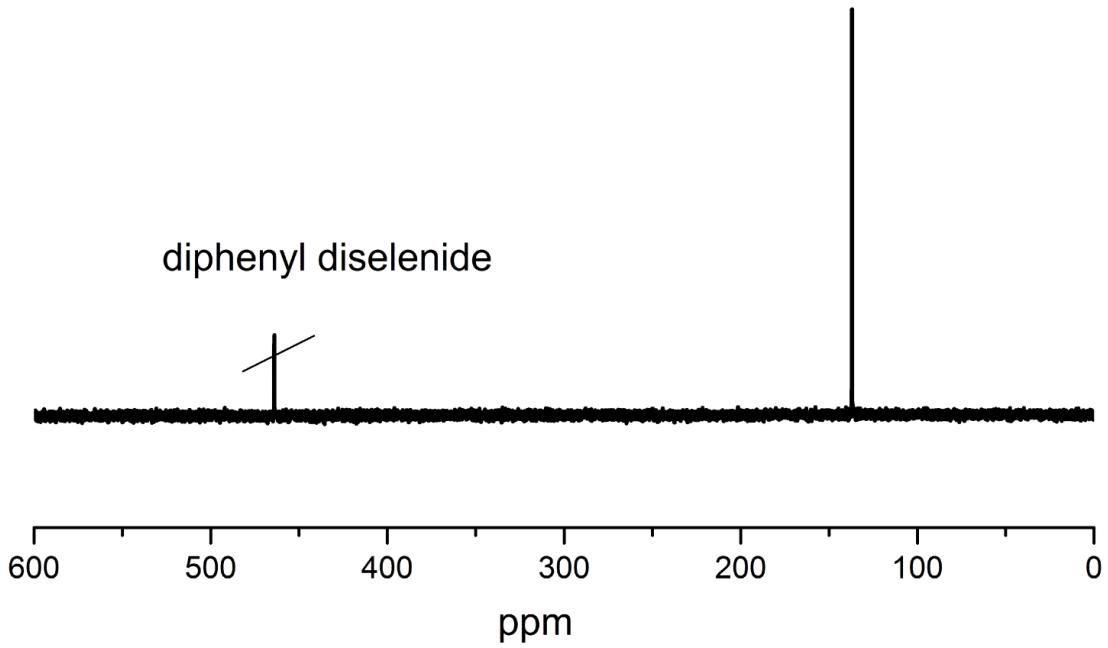


Figure S3. ^{77}Se NMR spectrum of M_{Se} in $CDCl_3$ using diphenyl diselenide at 464.1 ppm as the reference.

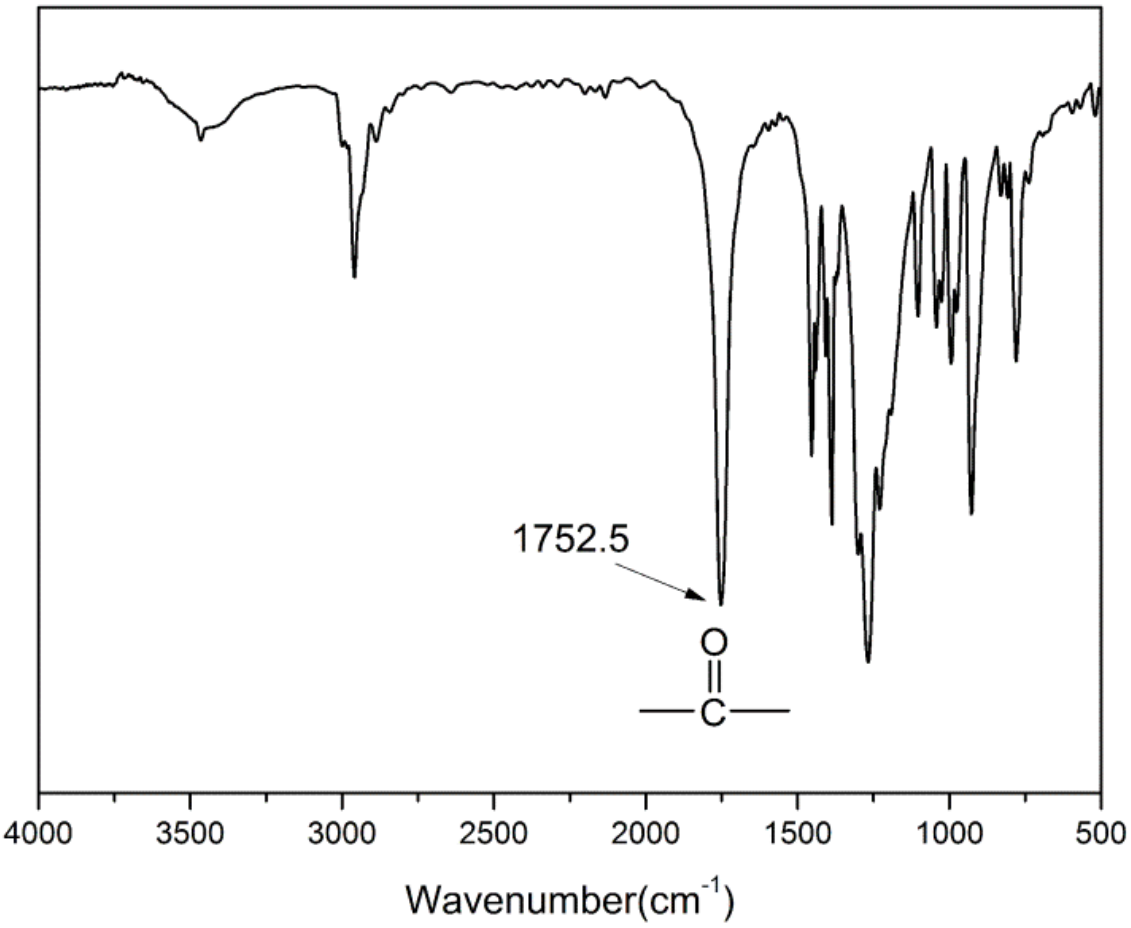


Figure S4. FT-IR spectrum of M_{Se}.

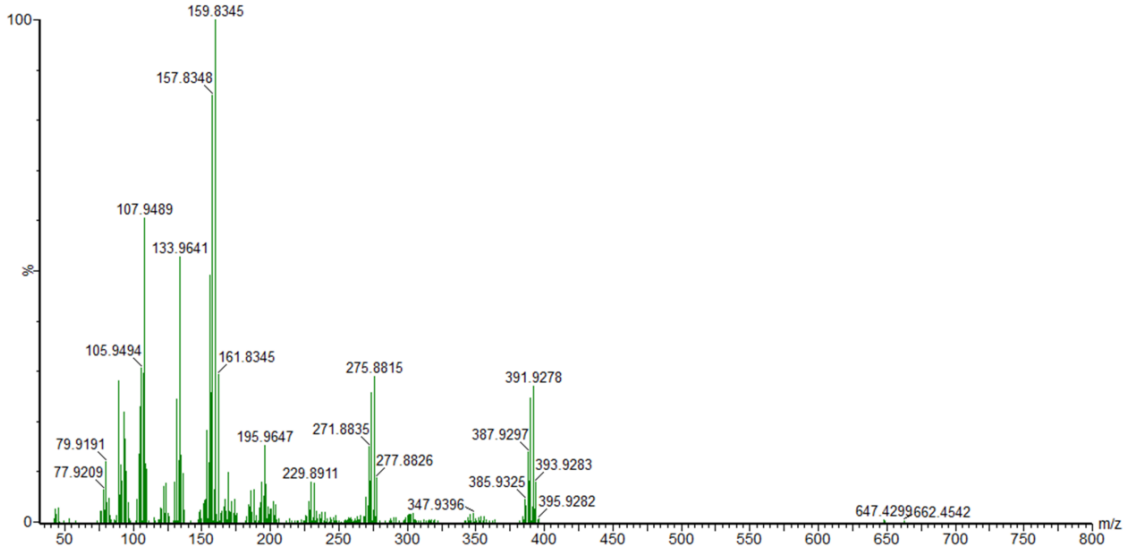


Figure S5. EI-MS spectrum of M_{Se} demonstrating the successful synthesis of M_{Se}.

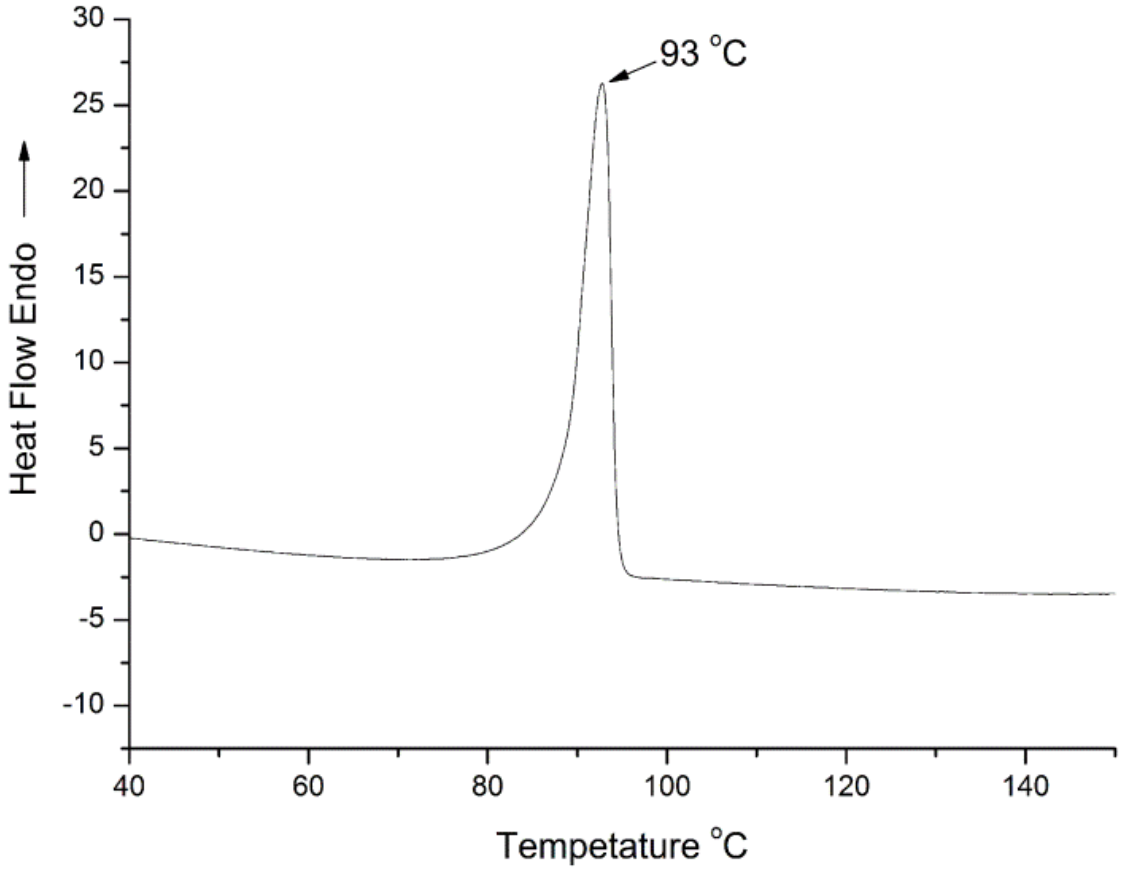


Figure S6. The melting point (T_m) of M_{Se} measured by DSC.

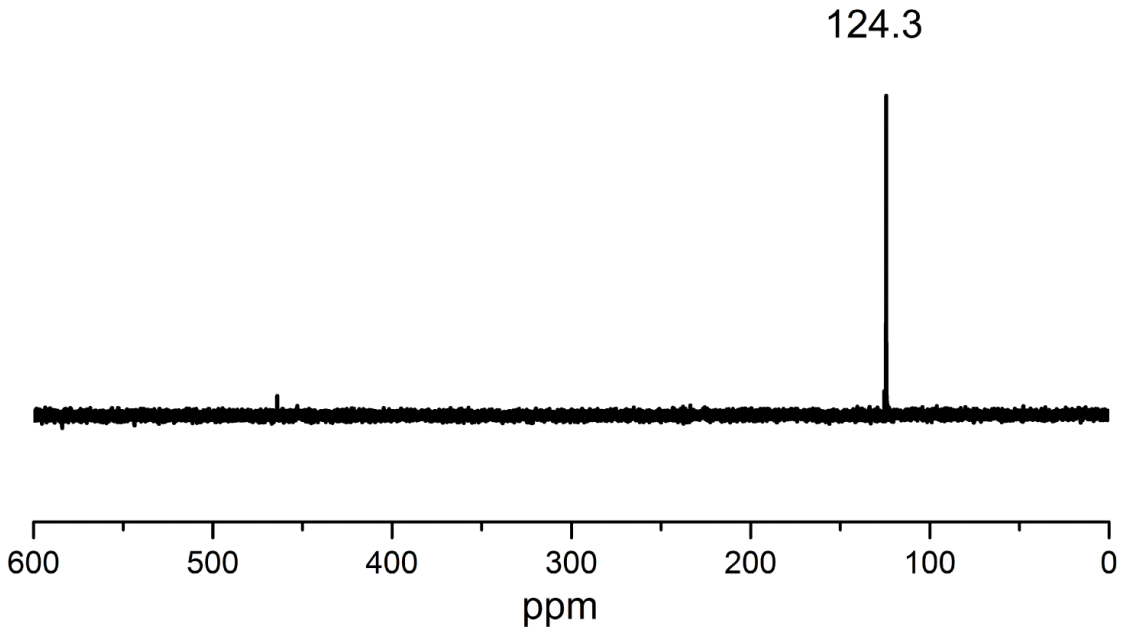


Figure S7. The ^{77}Se NMR spectrum of polymer (P_{Se}) in $CDCl_3$ using diphenyl diselenide at 464.1 ppm as the reference.

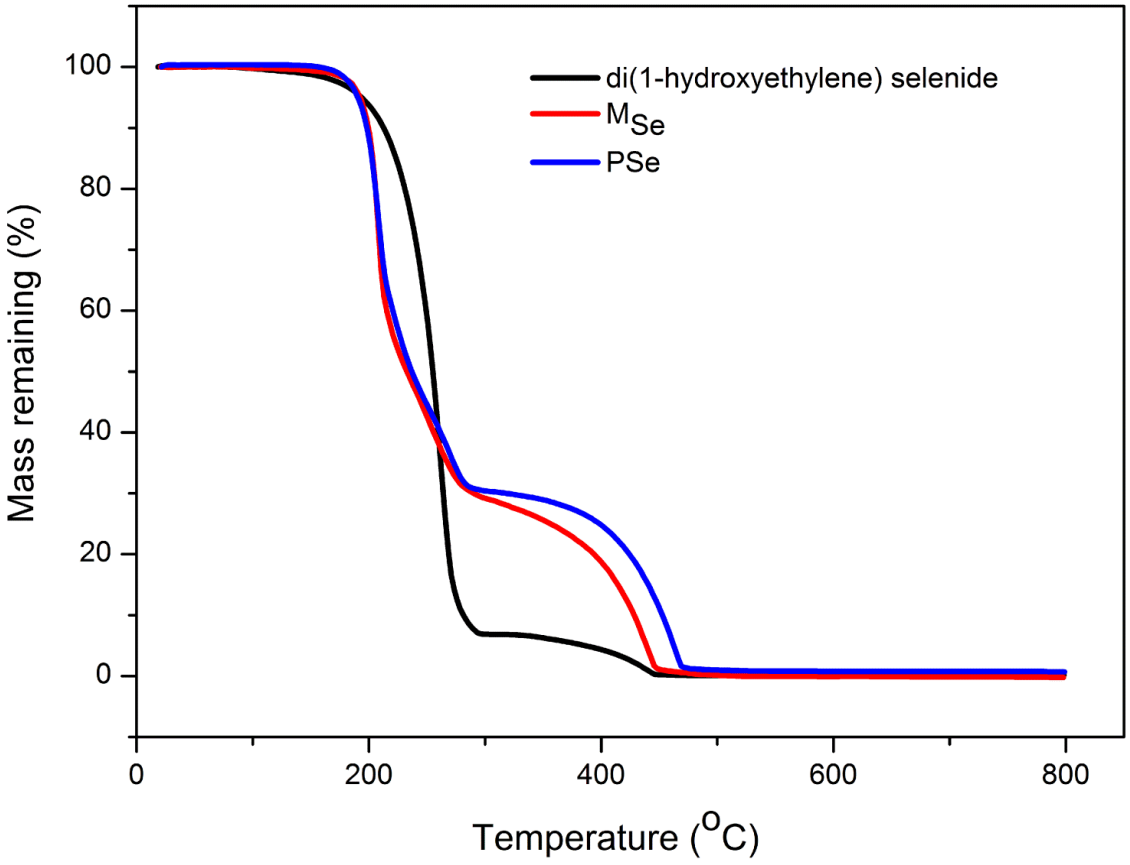


Figure S8. Thermo-gravimetric analysis of di(1-hydroxyethylene) selenide, M_{Se} and PSe.

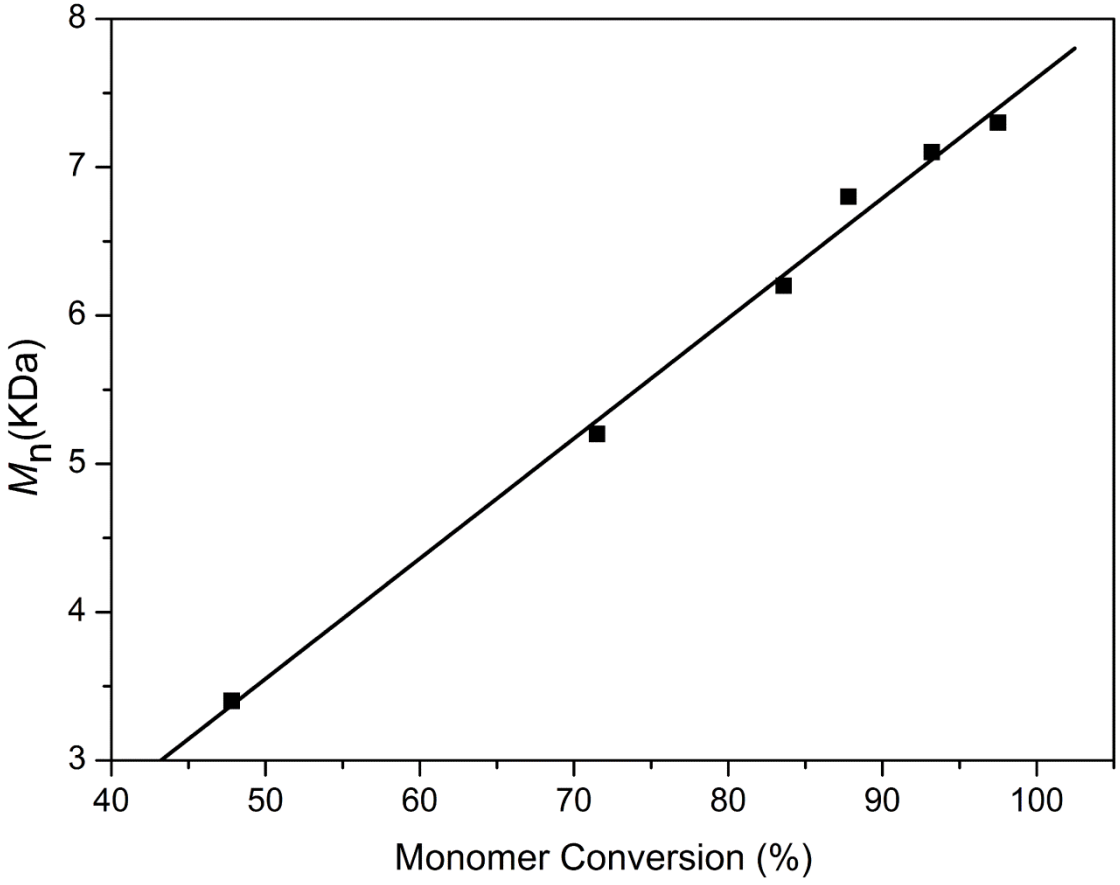
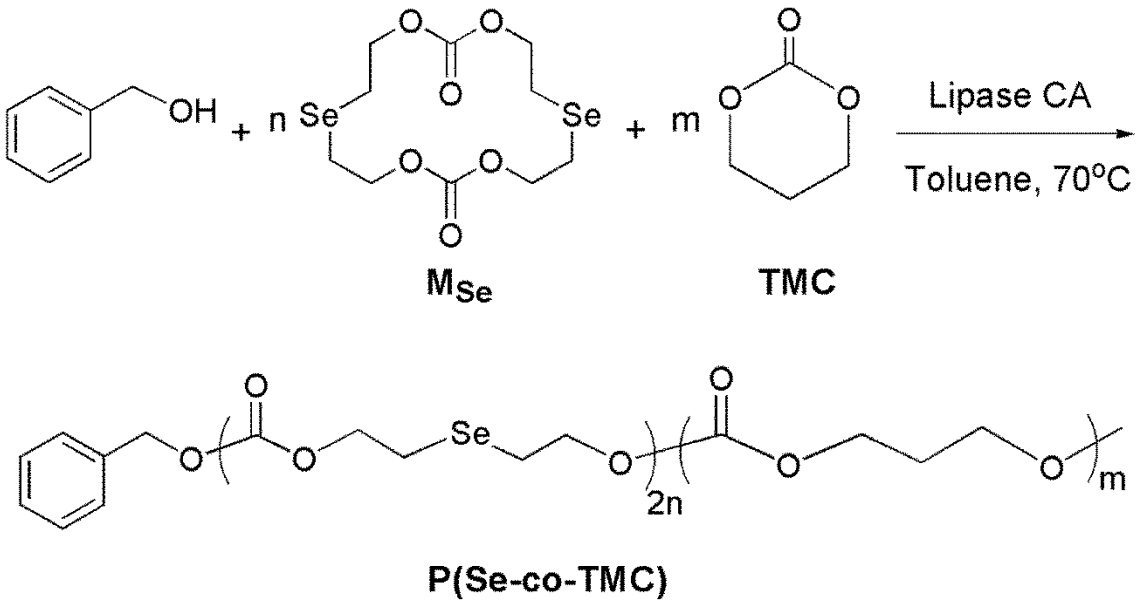


Figure S9. Plot of M_n obtained by ^{1}H NMR versus the monomer conversion.



Scheme S1. The copolymerization of M_{Se} and trimethylene carbonate (TMC) to generate random copolymers.

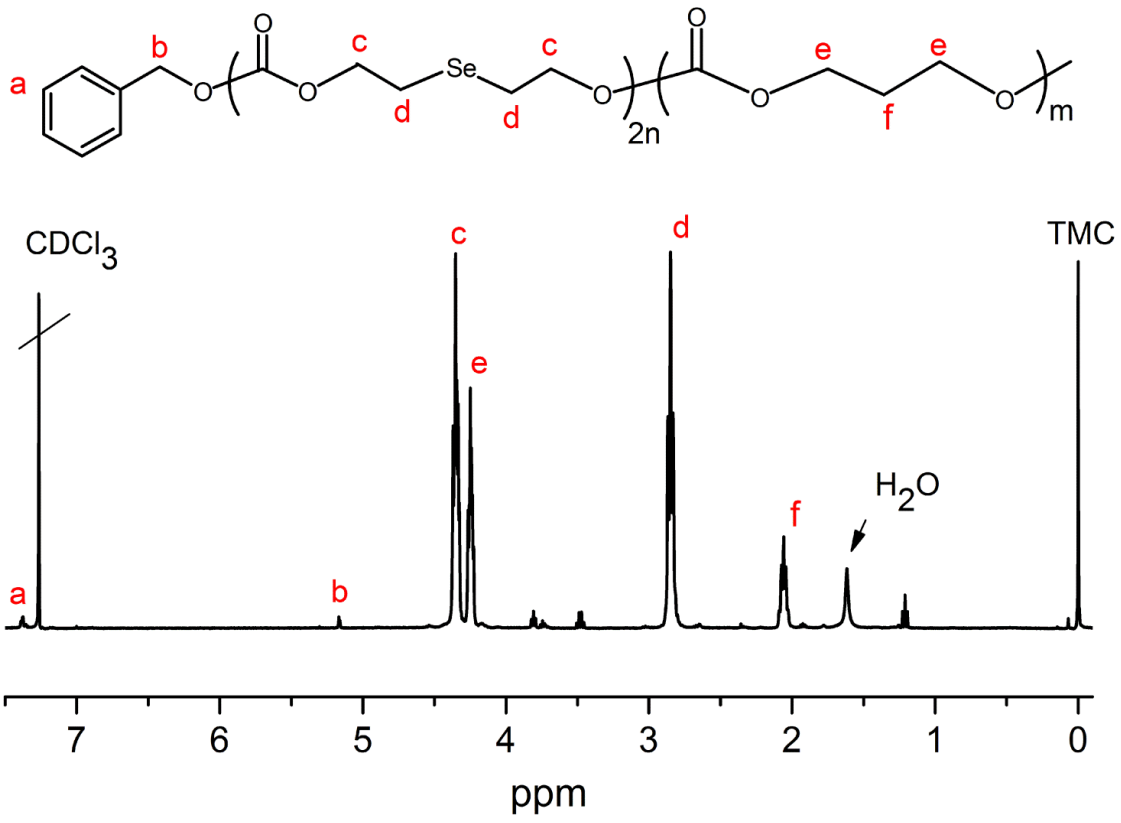


Figure S10. Representative ^{1}H NMR spectrum of random copolymer PSe_{19}-*ran*-$PTMC_{21}$.

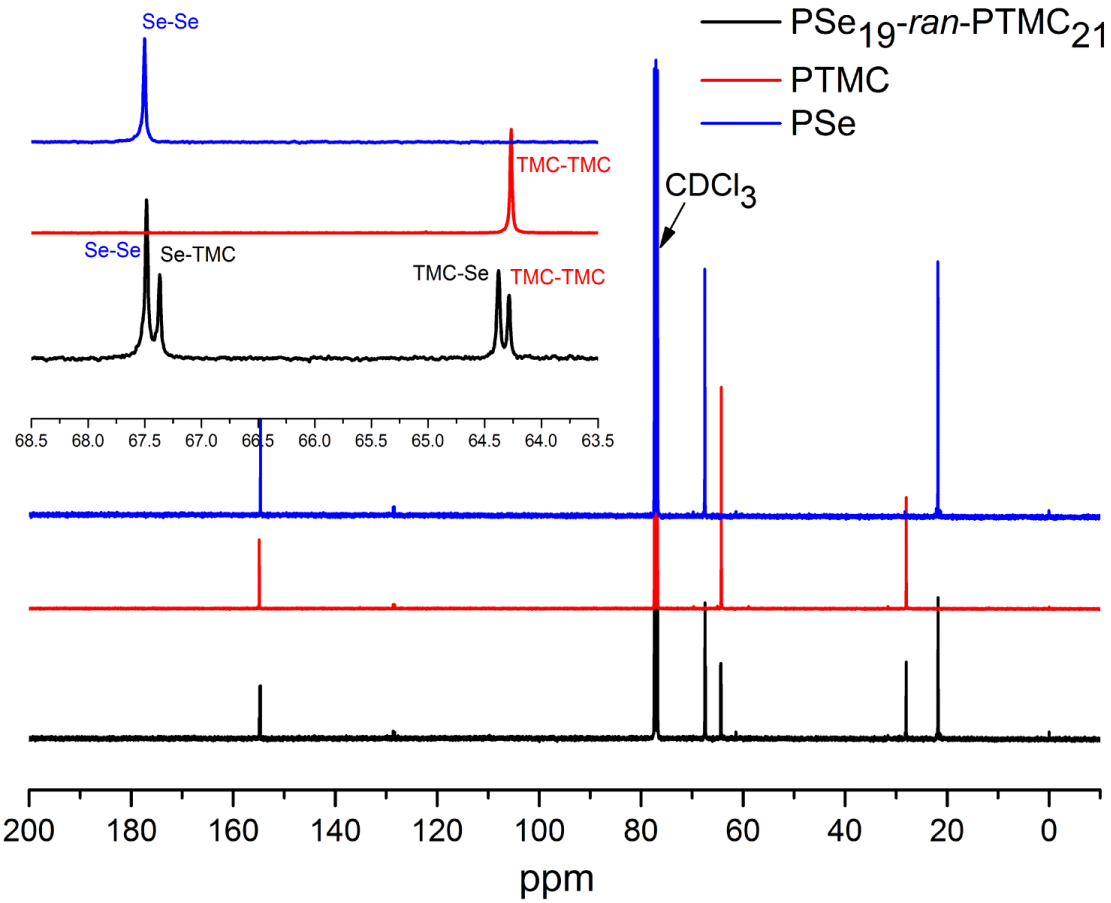


Figure S11. ^{13}C NMR spectra of PSe_{19}-ran-$PTMC_{21}$ (black), PTMC (red) and PSe (blue), indicated the random structure copolymers.

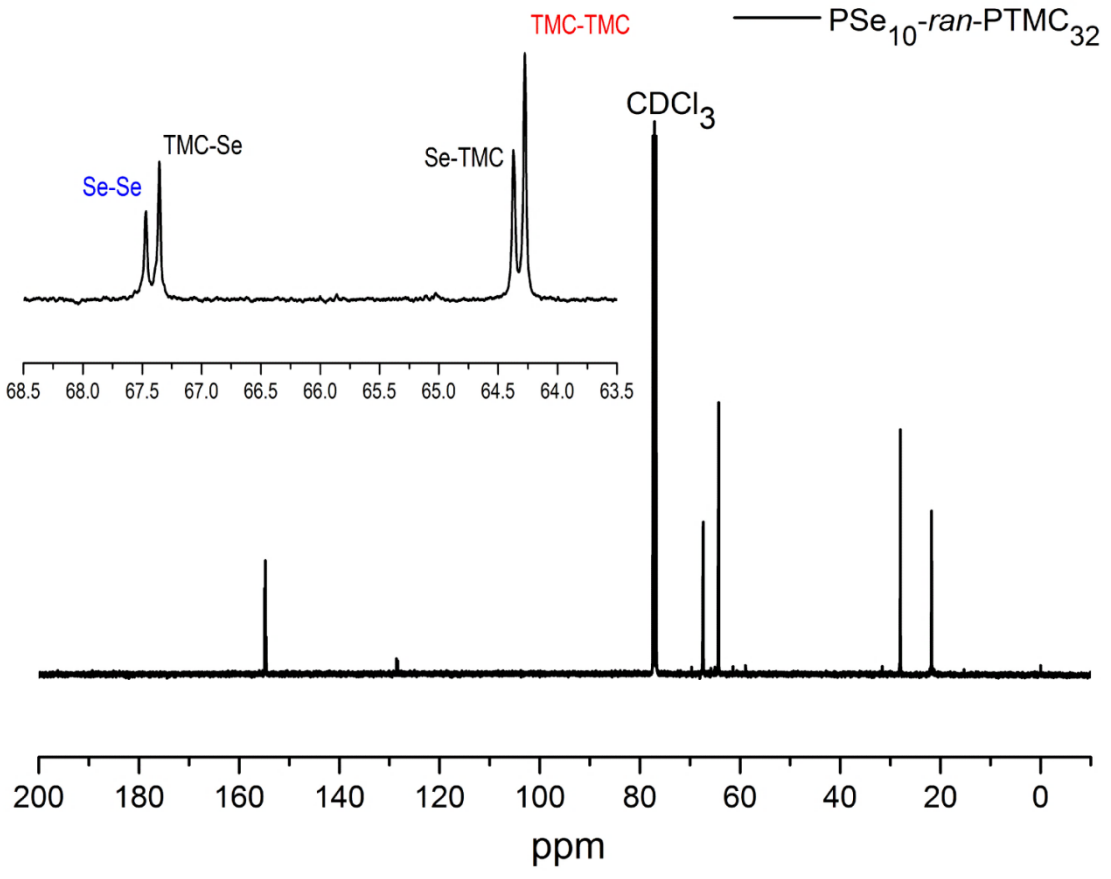


Figure S12. ^{13}C NMR spectra of PSe_{10}-*ran*-$PTMC_{32}$ indicated the random structure copolymers.

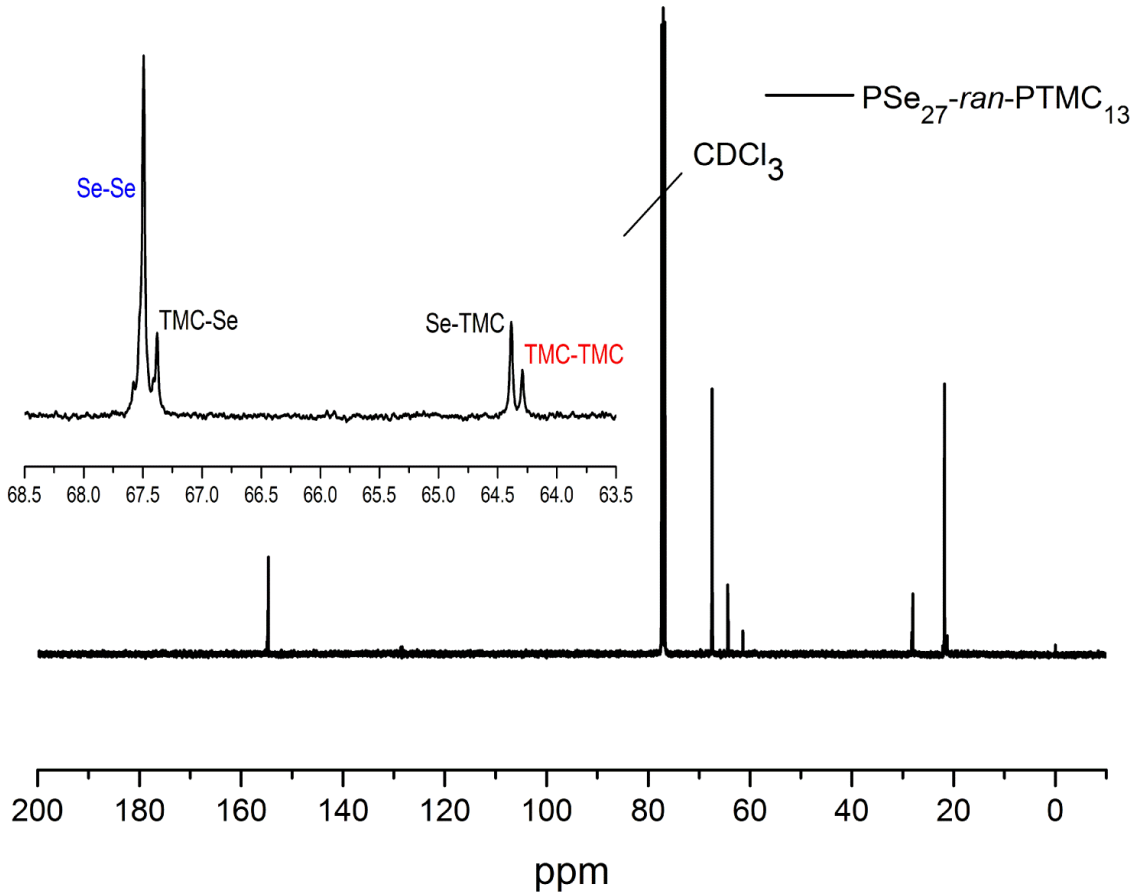


Figure S13. ^{13}C NMR spectra of PSe_{27}-*ran*-$PTMC_{13}$ indicated the random structure copolymers.

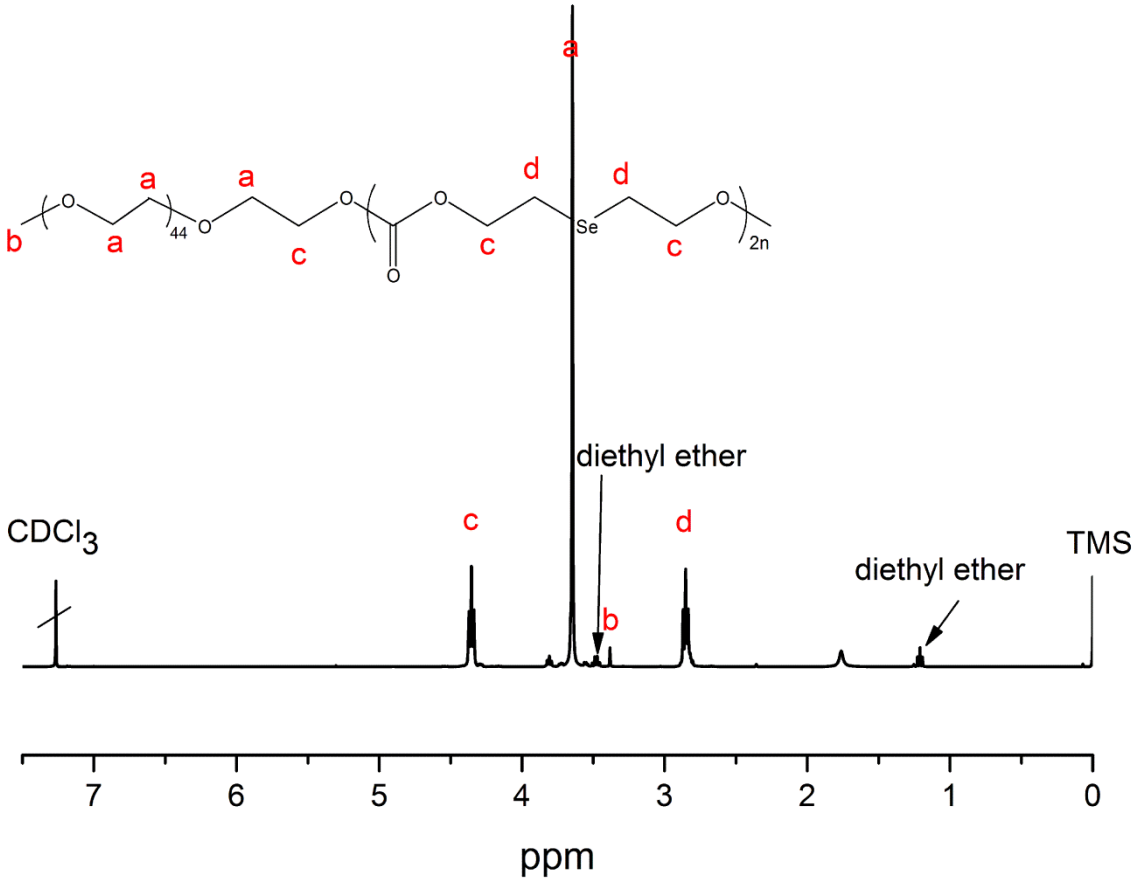


Figure S14. ^{1}H NMR spectrum of mPEG-PSe_9 diblock copolymers in $CDCl_3$.

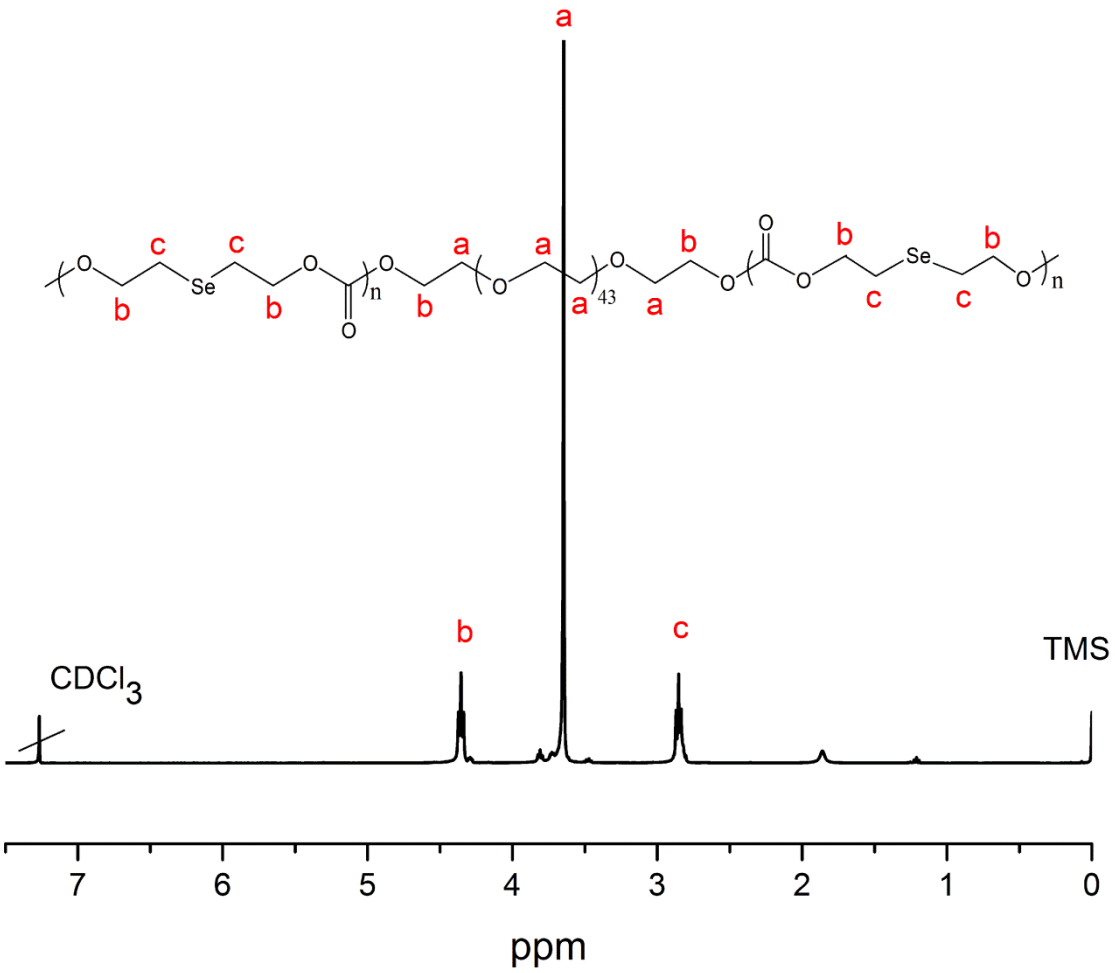


Figure S15. ^{1}H NMR spectrum of PEG-PSe$_9$ triblock copolymers in $CDCl_3$.