Topochemical Polymerization in Phenylalanine Anchored Chiral Diacetylenes for for Chiroptical Properties and Tunable Thermo-, Halo- and Solvatochromism

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Table of Contents

1. Materials and Methods:

Solvents used in synthesis were all AR grade. CH_2Cl_2 was distilled from CaH_2. The reagents 5-hexynoic acid, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimidehydrochloride, 4-dimethylaminopyridine were purchased from TCI chemicals and Merck. Thionyl Chloride was purchased from Spectrochem. All chemicals except DMAP were used without additional purification. DMAP was recrystallized from ethyl acetate.

NMR spectra were acquired on a Bruker 400 MHz NMR spectrophotometer. Proton and carbon chemical shifts are reported in ppm downfield of tetramethylsilane using the resonance of the deuterated solvent as internal standard. Splitting patterns are designated as singlet (*s*), doublet (*d*), triplet (*t*) and multiplet (*m*).

Mass spectra were acquired on a Fiinigan Mat LCQ mass spectrometer with LCMS (TOF MS ES^+), using methanol as solvent.

Specific rotation of enantiomers was measured in a MCP 300 Modular Circular Polarimeter, Anton Paar using Sodium D-Line laser (589 nm) at 25 ^{O}C. Samples were dissolved in $CHCl_3$ at a concentration of 0.040 g/100 ml and specific rotation value was recorded using pure $CHCl_3$ as blank. Value shown was average of 5 scan values.

IR spectra were recorded in the range of 4000 to 400 cm^{-1} as an attenuated total reflectance (ATR) mode using Bruker Vertex 70 FTIR spectrophotometer and analyzed through Opus Software.

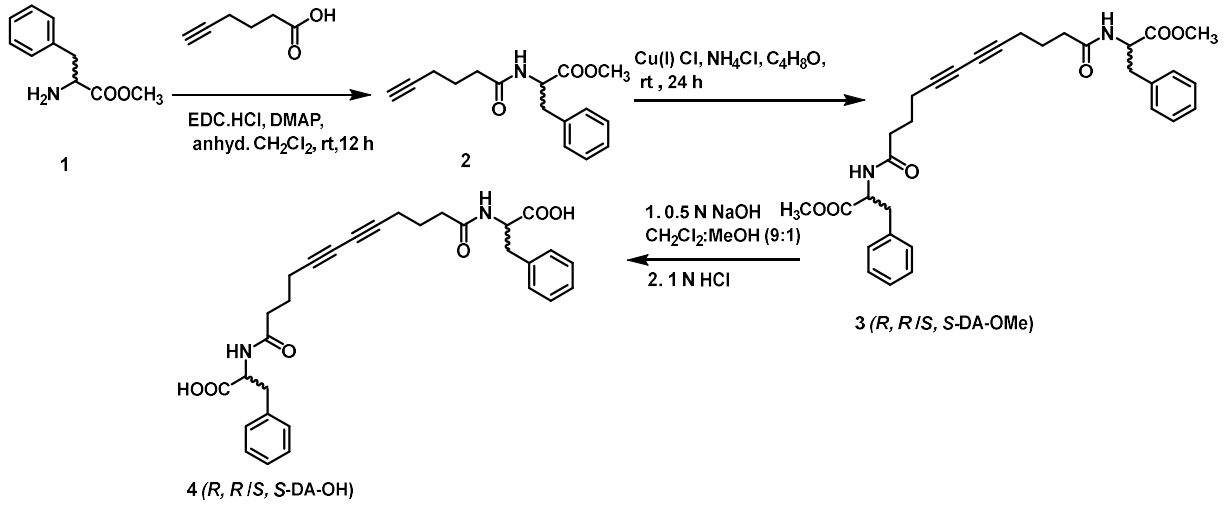
Raman studies were done on a DAC Raman spectrophotometer where the sample films were irradiated using a 632 nm laser.

The monomer diacetylene film was kept at a distance of 15 cm from UV lamp for irradiation. UV polymerization was performed using an UV chamber equipped 1*8W UV_C lamp (λ_{max} = 254 nm, intensity at 15 cm = 820 $\mu W/cm^2$). Luminous intensity of irradiation at time *t* was determined in J/cm^2 by the formula [($\mu W/cm^2$) /106]*t (s). UV spectra were recorded using Agilent Cary-60 spectrophotometer at a wavelength range of 700 to 350 nm.

Thermal studies were performed on Perkin Elmer Differential Scanning Calorimeter DSC 8000 model over a temperature range of (-20-200) ^{O}C at a heating rate of 5 ^{O}C /min.

CD spectra were recorded using JASCO J-1500 Circular Dichroism Spectrometer, Easton, MD, USA. The diacetylene monomer and the resulting polydiacetylene film was placed in front of the illumination path with help of a spacer (0.1 mm path length, Hellma) and scanned for a wavelength range of 300 nm to 700 nm with scan speed of 50 nm min^{-1} at 20 ºC. The reported spectra are the average of 3 scans.

2. Synthesis of diacetylene monomers:



Scheme S1: General reaction scheme for the synthesis of chiral diacetylene molecules ***R, R*-DA-OMe**, ***S, S*-DA-OMe**, ***S, S*-DA-OH.**

Design and syntheses: Design of the monomer involved a basic diacetylene backbone, *R*- or *S*-phenylalanine as a chiral amino acid moiety with multiple noncovalent interactions *e.g.* amide hydrogen bonding and aromatic pi-pi stacking. The carboxyl groups of the *S*-Phe and *R*-Phe enantiomers were initially methylated at the C terminal end followed by amide bond formation between the amine at the *N*-terminus with 5-hexynoic acid using EDC. HCl as coupling reagent. Next, the resulting amide functionalized terminal acetylenes were oxidised in the presence of air using Cu(I)Cl as the transition metal catalyst, following the Glaser-Hay coupling to furnish enantiomers ***S,S*-DA-OMe** and ***R,R*-DA-OMe** with peripheral methyl ester functionality. Finally, the hydrolysis of the esters renders the corresponding enantiomers with acid termini, ***S,S*-DA-OH** and ***R,R*-DA-OH**. O_2 was purged at a high pressure for the initial 10 mins of the

reaction to initiate the oxidation of Cu to +2 state which is the active oxidation state for starting of the coupling reaction. Finally, the product was purified, dried *invacuo* vacuum and characterised by ^{1}H, ^{13}C NMR and mass spectra.

***R/S* -Phe-OMe (1):** Syntheses were performed as per literature protocol.[1] The amino acids *R/S*-Phe (1 g, 6.06 mmol) was taken in anhydrous methanol (5 mL) in a round bottom flask and was stirred for 10 mins under N_2 environment. Then the reaction mixture was cooled to 0 ^{O}C using icewater bath followed by dropwise addition $SOCl_2$ (0.7 mL, 9.6 mmol) and 1 drop of anhyd. DMF. The reaction mixture was stirred at room temperature for 2 h followed by refluxing at 70 ^{O}C for additional 2 h. Then the reaction mixture was allowed to cool to room temperature followed by evaporation of the methanol and $SOCl_2$ using vacuum pump. The product was obtained as white solid, with 100% yield. ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.63 (s, 3H, N*H*$_3$), 7.23, 7.19 (bs, 5H, C_6H_5), 4.32 (m, 1H, C_6H_5 -CH_2-C*H*-), 3.63 (s, 3H, OC*H*$_3$), 3.40-3.16 (m, 2H, C_6H_5 -C*H*$_2$-CH-).

Methyl hex-5-ynoyl-*R/S*-phenylalaninate (2): Syntheses were carried out following a literature protocol.[2] 5-Hexynoic acid (0.6 g, 5.35 mmol) was taken in a round bottom flask containing dry CH_2Cl_2 (3 mL) and EDC. HCl (1.2 g, 6.42 mmol) followed by stirring for 5 mins. *R /S*-Phe-OMe (0.966 g, 5.40 mmol) was taken in another round bottom flask in dry CH_2Cl_2 (3 mL) and DMAP (783 mg, 6.42 mmol). The mixture of DMAP and methyl ester of Phenylalanine (**1**) was added to the active ester of 5-hexynoic acid and was stirred in the dark for 12 h with constant monitoring of the TLC. Then the reaction mixture was diluted with deionized water and washed successively with 1N $NaHCO_3$ and 1N HCl. Finally, the organic layer was collected over anhydrous sodium sulphate and evaporated *in vacuo* to render **2** with 80% yield.

^{1}H-NMR (400 MHz, $CDCl_3$): δ = 7.23, 7.20 (bs, 5H,2 C_6H_5), 5.86 (s, 5H, N*H*), 4.83 (m, 1H, C_6H_5 -CH_2-C*H*-), 3.66 (s, 3H, OC*H*$_3$), 3.08-2.88 (m, 2H, C_6H_5 -C*H*$_2$-CH-), 2.2-2.3 (m, 4H, -CC-CH_2C*H*$_2$-C*H*$_2$-CO-NH-), 1.8-1.7 (m, 2H, -CC-C*H*$_2$$CH_2$-$CH_2$-CO-NH-).

TOF MS ES^+ [M+H^+] = 274.20 (calcd: 274.14).

***R,R/ S,S* -DA-OMe (3):** Syntheses were performed following available literature.[2] Methyl hex-5-ynoyl- *R/S*-phenylalaninate (1 g, 3.66 mmol), Cu(I)Cl (0.905 g, 9.15 mmol), NH_4Cl (1.4 g,

27.45 mmol) were taken in THF. The reaction mixtures were stirred at room temperature for 24 h with continuous purging of O_2. TLC was monitored for consumption of starting material. Then 1N HCl was poured into the mixture and stirred until Cu(I)Cl and NH_4Cl were dissolved in the aqueous layer, leaving behind a precipitate. The precipitate was dissolved in CH_2Cl_2 and purified by silica gel column chromatography with methanol-CH_2Cl_2 mixtures as eluents. Pure product was obtained with 60% yield that was stored at -20 ^{O}C freezer for future use.

^{1}H-NMR (400 MHz, $CDCl_3$): δ = 7.23, 7.20 (bs, 10H, 2 C_6H_5), 5.86 (s, 2H, 2N*H*), 4.83 (m, 2H, C_6H_5 -CH_2-C*H*-), 3.66 (s, 6H, 2OCH_3), 3.08-2.88 (m, 4H,2 C_6H_5 -CH_2-CH-), 2.2-2.3 (m, 8H,2 -CC-CH_2CH_2-CH_2-CO-NH-), 1.8-1.7 (m, 4H, 2-CC-C$H_2$$CH_2$-$CH_2$-CO-NH-).

^{13}C-NMR (100 MHz, $CDCl_3$): δ = 171.09, 170.75, 134.81, 128.23, 127.59, 126.14, 82.39, 68.22, 51.97, 51.33, 36.91, 33.76, 22.94, 16.70.

TOF MS ES^{+} [M+H^{+}] = 545.28 (calcd: 545.26).

***S,S- DA* -OH (4): *S,S* -DA-OMe** (200 mg, 0.36 mmol) was taken in 2 ml CH_2Cl_2 and cooled to 0 ^{o}C using ice-water bath followed by dropwise addition of 0.5 N NaOH in MeOH: DCM (1:9). Then the reaction mixture was stirred for 30 mins and TLC was monitored for consumption of starting material. Then the solvent was removed *in vacuo*. Neutralization with 1 N HCl in cold condition resulted in a white precipitate that was extracted in CH_2Cl_2. The organic layer was dried over anhydrous sodium sulphate to obtain the desired product in 100% yield.[3]

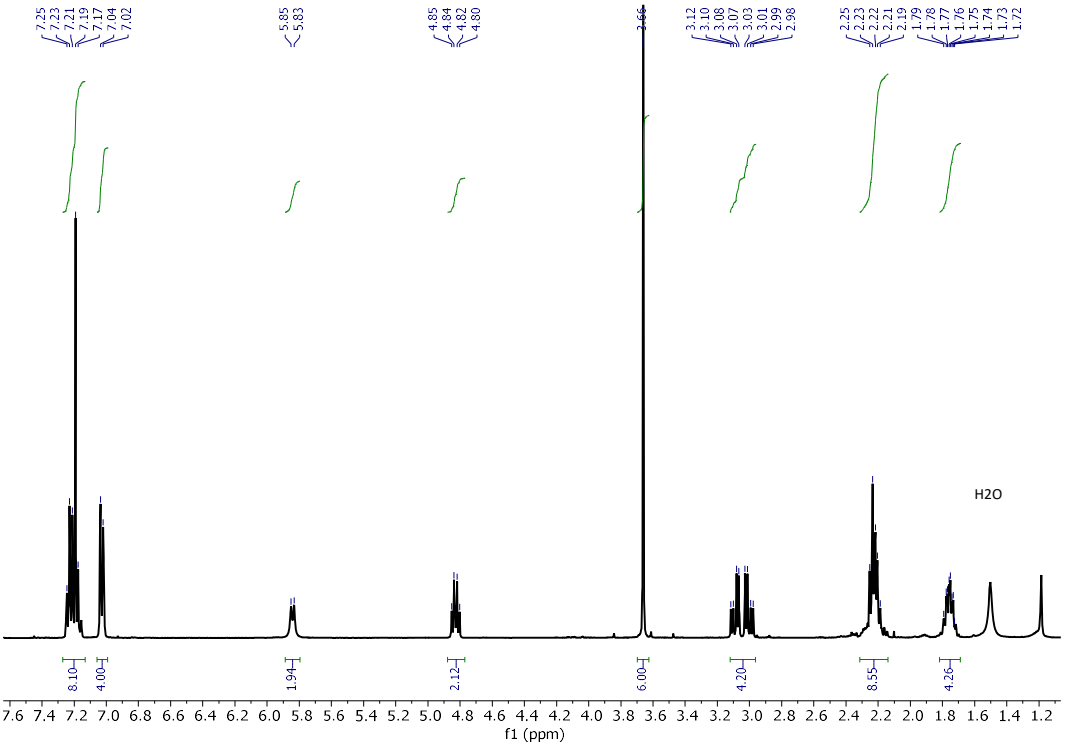
^{1}H-NMR (400 MHz, $CDCl_3$): δ = 7.23, 7.20 (bs, 10H,2 C_6H_5), 5.86 (s, 2H, 2N*H*), 4.83 (m, 2H, C_6H_5 -CH_2-C*H*-), 3.08-2.88 (m, 4H,2 C_6H_5 -CH_2-CH-), 2.2-2.3 (m, 8H,2 -CC-CH_2CH_2-CH_2-CO-NH-), 1.8-1.7 (m, 4H, 2-CC-C$H_2$$CH_2$-$CH_2$-CO-NH-).

^{13}C-NMR (100 MHz, $CDCl_3$): δ = 171.09, 170.75, 134.81, 128.23, 127.59, 126.14, 68.22, 51.97, 51.33, 36.91, 33.76, 22.94, 16.70.

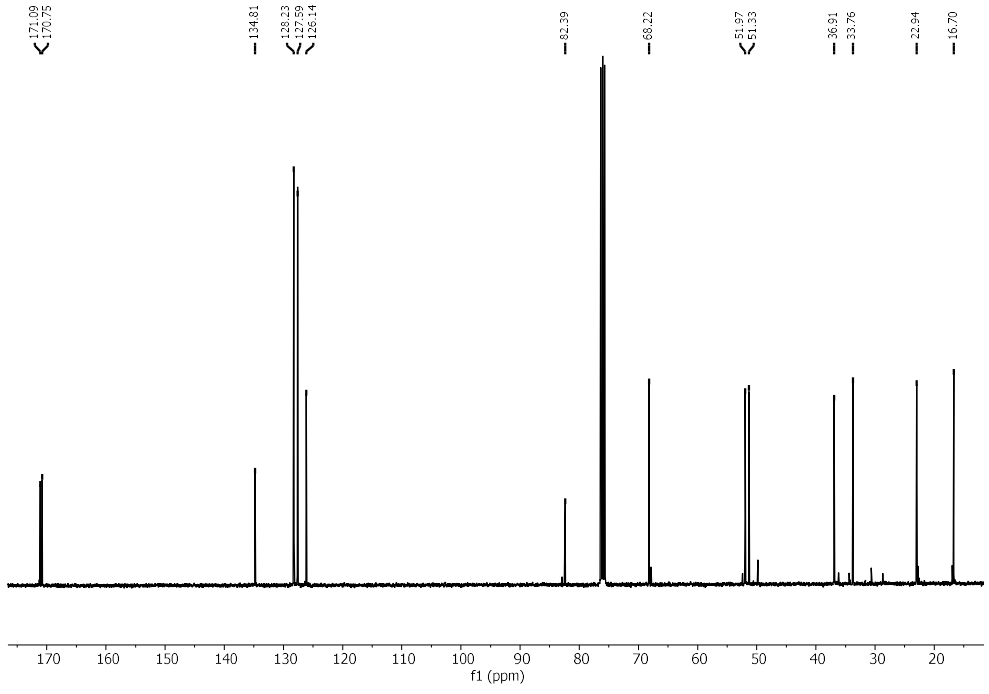
TOF MS ES^{+} [M+H^{+}] = 517.23 (calcd: 517.23)

3. ^{1}H AND ^{13}C Spectra for the diacetylene molecules:

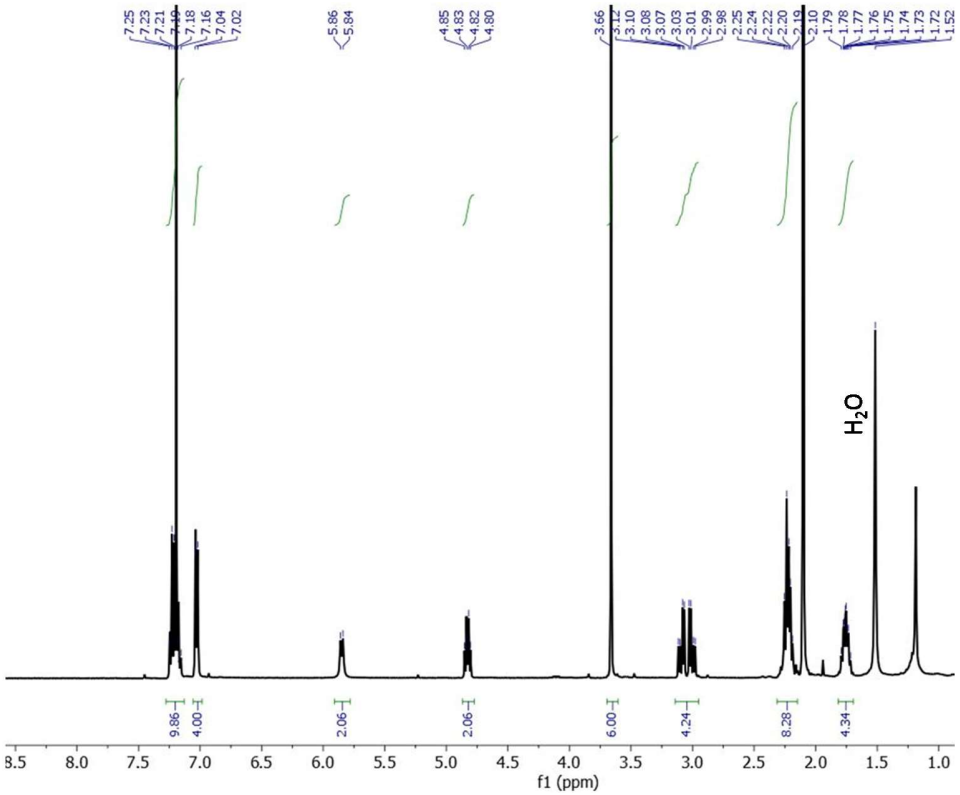
S, S -DA-OMe ($CDCl_3$-^{1}H):



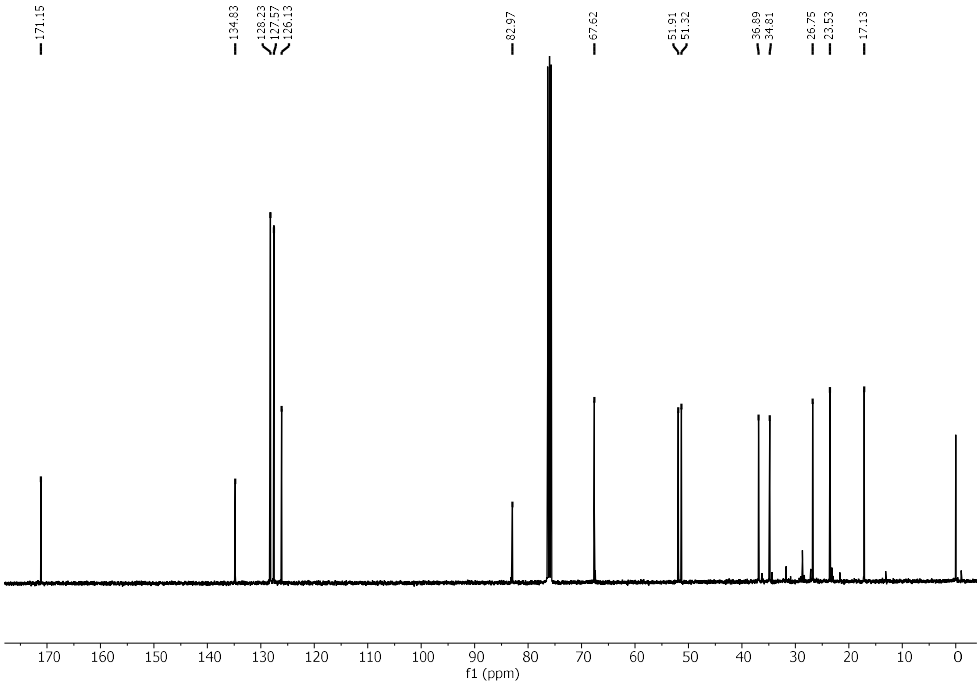
S, S-DA-OMe ($CDCl_3$-^{13}C):



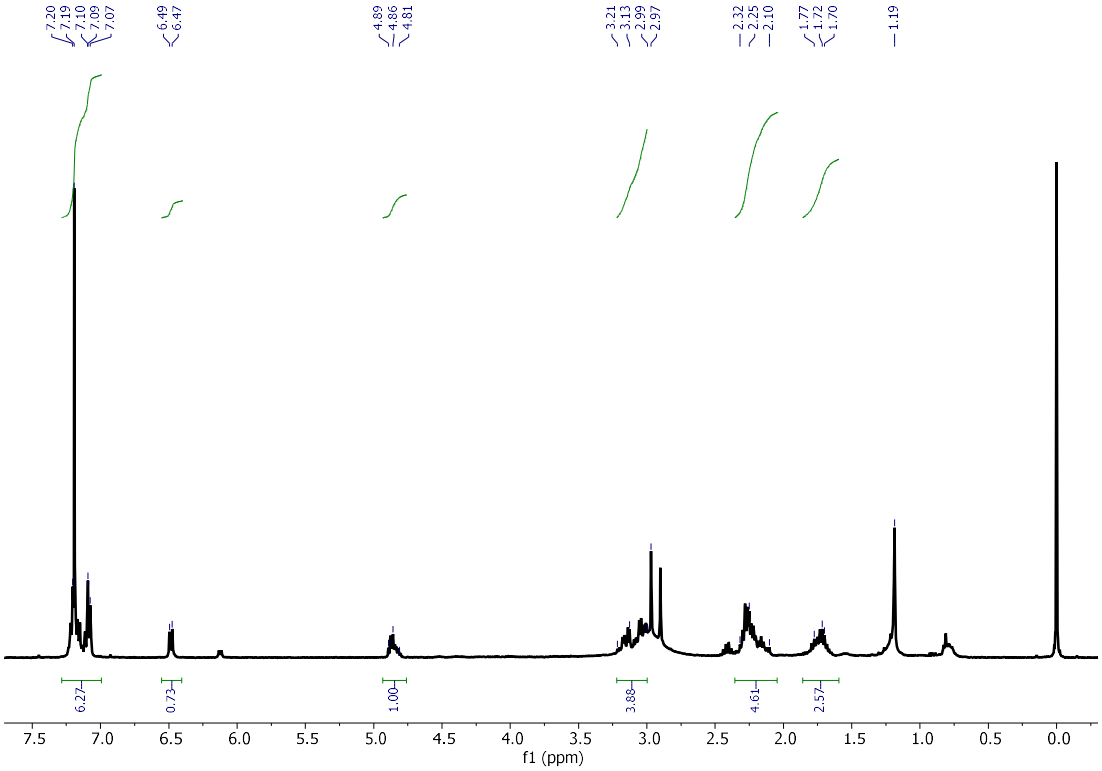
***R, R*-DA-OMe ($CDCl_3$-^1H):**



***R, R*-DA-OMe ($CDCl_3$-^{13}C):**



***S*, *S*-DA-OH ($CDCl_3$-^1H):**



4. Polymerisation of *S*, *S*-DA-OH:

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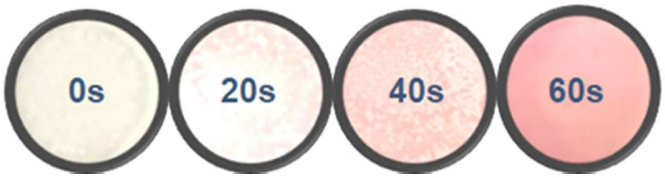

Fig. S1. Visual colour change upon UV_c irradiation of ***S*, *S*-DA-OH** for 60 s.

5. Optical purity:

Specific rotation values using Sodium D-Line laser (589 nm) of ***S, S* -PDA-OMe** and ***R, R*-PDA-OMe** at 25 ^{O}C.

Chiral Polymers	Specific rotation in $CHCl_3$
***S*, *S* -PDA-OMe**	+78.8
***R*, *R* -PDA-OMe**	-62.4

6. Raman data:

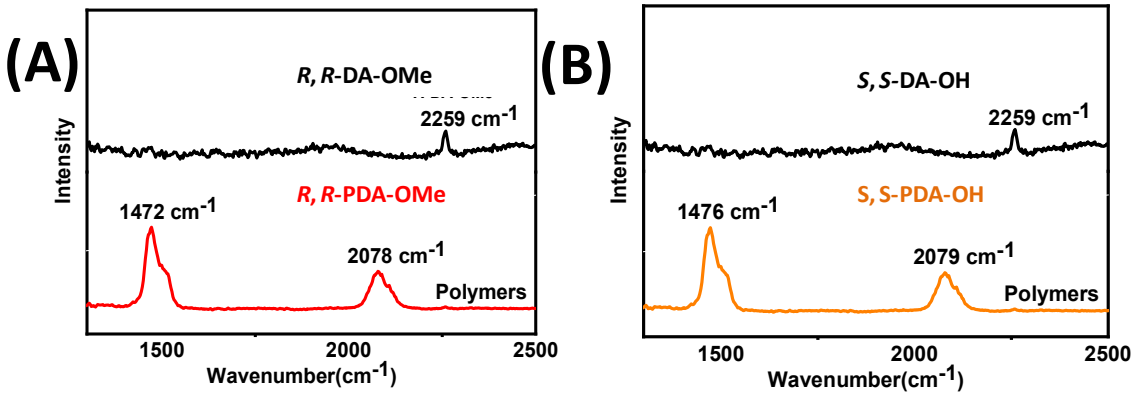

Fig S2: Comparative Raman spectra of (A) ***R, R*-DA-OMe *R*** & ***R*-PDA-OMe** and (B) ***S, S* -PDA-OH** & ***S, S* -PDA-OH.**

7. Polymerization kinetics:

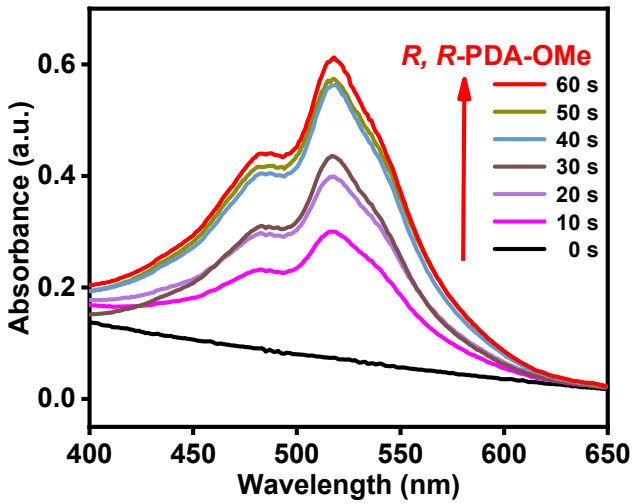

Fig. S3.UV-vis spectra of ***R, R*- DA-OMe** upon UV_c irradiation over a period of 60 s.

8. ATR-IR data:

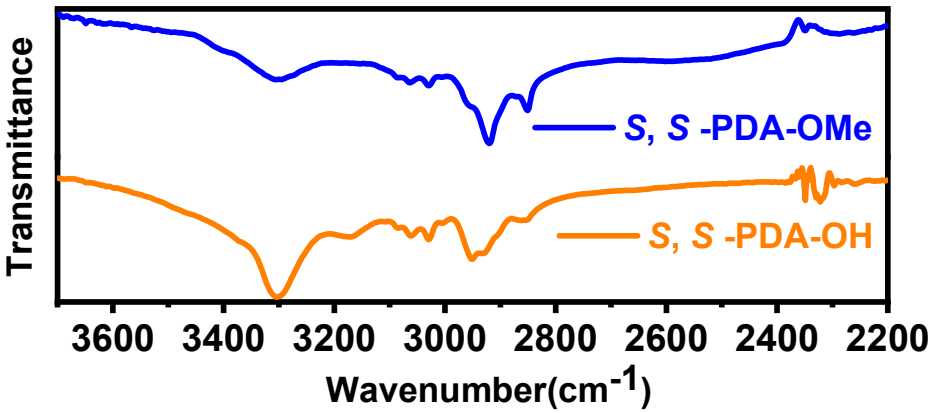

Fig. S4. ATR-IR spectra of ***S,S*-PDA-OMe** and ***S, S*-PDA-OH** showing the hydrogen bonding of the carboxylic acids.

9. Induced chirality in the polymers:

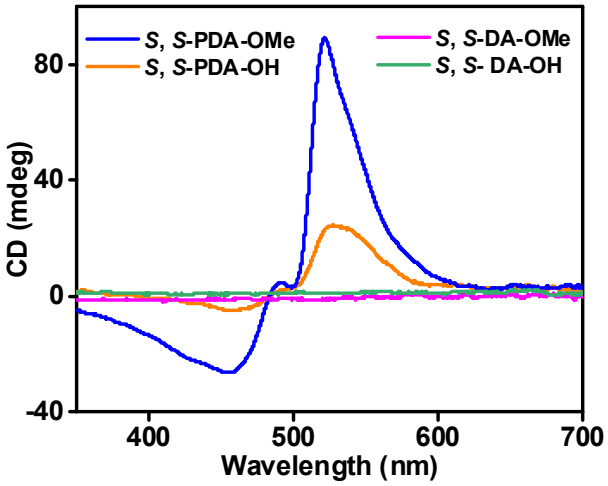

Fig. S5. Comparative CD spectra depicting induced chirality in ***S, S*- PDA-OMe** and ***S,S*-PDA-OH**.

10. Thermochromism of the PDA films:

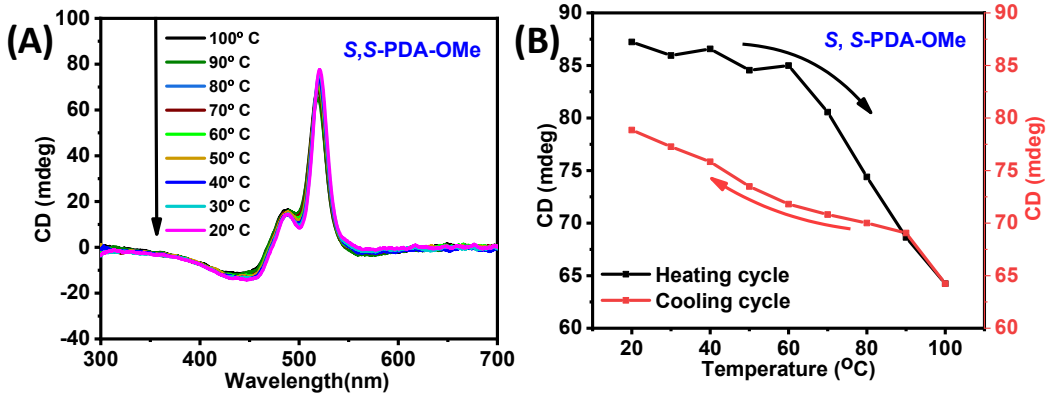

Fig. S6. (A) CD spectra of ***S, S*-PDA-OMe** upon decreasing temperature from 100 to 20 °C and (B) Temperature dependence of induced chiral signature in ***S, S*-PDA-OMe** upon heating and cooling cycles.

11. Solvatochromism of the PDA film:

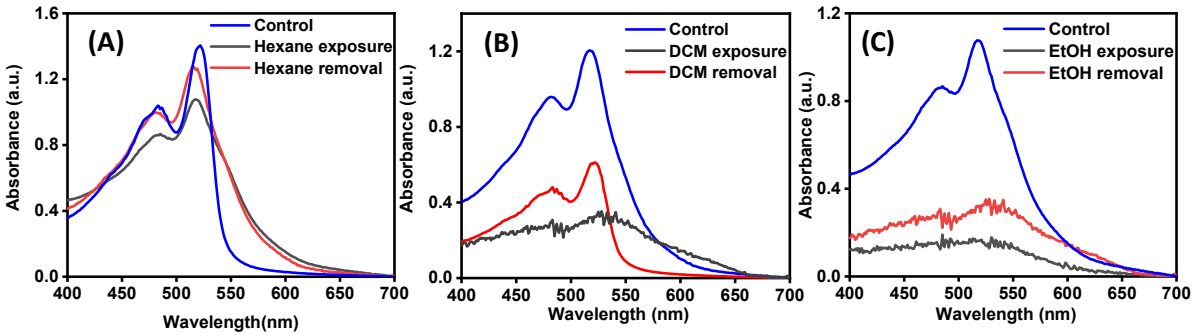

Fig. S7. Solvatochromism behaviour of ***S, S*-PDA-OMe** film as studied by UV-vis spectra showing change after exposure and removal of (A) hexane, (B) dicholoromethane and (C) ethanol vapours.

12. Halochromism of the PDA film:

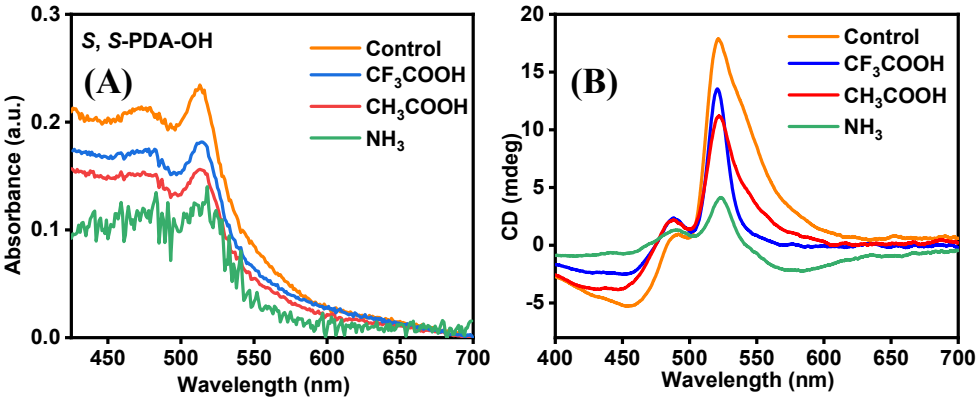

Fig. S8. (A) Comparative UV-vis spectra showing the change in absorbance and (B) comparative CD spectra showing the change in chiroptical properties of ***S*, *S*-PDA-OH** upon exposure to volatile acids and bases.

13. References:

1. M. R. Wilson , J. Solà, A. Carlone, S. M. Goldup, N. Lebrasseur and D. A. Leigh, *Nature,* 2016, **534**, 235.
2. J. M. Kim, S. Angupillai, K. Min, M. Ramalingam and Y. A. Son, *ACS Appl. Mater. Interfaces,* 2018, **10**, 24767.
3. V. Theodorou, K. Skobridis, A. G.Tzakos, V. Ragoussis, *Tetrahedron Lett.,* 2007, **48**, 8230.