Supporting Information

Photo-induced ring-closure via a looped flow reactor

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Content

Materials

Methyl acrylate (MA) (Acros, 99%) was deinhibited over a column of activated basic alumina, prior to use. 1,1'-azobis(isobutyronitrile) (AIBN) (Sigma-Aldrich, 98%) was recrystallized twice from methanol prior to use. Methyl 4-((2-formyl-3-methylphenoxy)methyl)benzoic acid was prepared according to a literature procedure.[1] 4-Cyano-4-(phenylcarbonothioylthio)pentanoic acid (> 97%, Sigma-Aldrich), triethylene glycol (99 %, Sigma-Aldrich), *N*-(3-dimethylaminopropyl)-*N*'-ethylcarbodiimide hydrochloride (99+%, Roth), 4-(dimethylamino)pyridine (99%, abcr) and chloroform-d_1 ($CDCl_3$, 99.8%, EURISO-TOP) were used as received. *N*,*N*-dimethylformamide , dichloromethane, ethyl acetate and cyclohexane were purchased as analytical grade (Sigma-Aldrich) and used as received. Acetonitrile (ACN) was purchased from VWR and was used as received. Toluene (Sigma-Aldrich) was dried via the use of a MB-SPS 800 system.

Characterization

Monomer conversions and the disappearance of polymer end groups were determined via Nuclear Magnetic Resonance (NMR) spectroscopy, which were recorded in $CDCl_3$ at ambient temperature on a Varian Inova spectrometer at 400 MHz for ^1H NMR using a 5 mm OneNMR PFG probe (Agilent Technologies Inc, Santa Clara, CA, USA). Free induction decays were collected with a 90° pulse of 6.9 μs, a spectral width of 6400 Hz, an acquisition time of 3 s, a preparation delay of 12 s and 64 accumulations. A line-broadening factor of 0.2 Hz was applied before Fourier transformation to the frequency domain.

Size-exclusion chromatography (SEC) was performed on a Tosoh EcoSEC HLC-8320GPC, operated by PSS WinGPC software, equipped with a PLgel 5.0 μm guard column (50 x 7.5 mm), followed by three PLgel 5 μm mixed-C columns (300 x 8 mm) and a differential refractive index detector using THF as eluent at 40°C with a flow rate of 1 mL min^{-1}. The SEC system was calibrated using linear narrow PS standards ranging from 474 to 7.5 x 10^6 g mol^{-1} (K = 14.1 x 10^{-5} dL g^{-1} and α = 0.70), and toluene as a flow marker. Molar masses and dispersity values were calculated against the Mark-Houwink parameters of PnBuA (K = 12.2 x 10^{-5} dL g^{-1} and α = 0.70).

UV-Vis measurements were recorded on a Varian Cary 500 UV-Vis-NIR spectrometer (scan rate 600 nm · min^{-1}, continuous run from 200 to 800 nm).

Reactor set-up

A looped flow reactor was developed (Figure 2) based on a tubular reactor loop, made of gastight perfluoroalkoxy polymer (PFA) tubing (Advanced Polymer Tubing GmbH, 1/16" OD, 0.75 mm ID) wrapped around a 312 nm UV lamp. A 1 mL tubular reactor was employed here. As main feature of the looped flow reactor, a Knauer Azura P 2.1S HPLC Pump was used as loop pump ('L') to provide a continuous recycle stream from the reservoir ('R', solvent + product) through the loop. As starting conditions, the reservoir was filled with pure acetonitrile. A syringe pump (Chemyx) was employed as injection pump ('P') to inject the α,ω-functionalized linear precursor gradually into the reactor system, via the use of a check valve ('C') (CV-3500, Idex Upchurch Scientific). The injected solution is immediately diluted by the recycle stream via the use of a static mixing tee ('M') (PEEK static mixing tee fitted with a UHMWPE frit, U-466, Idex Upchurch Scientific).

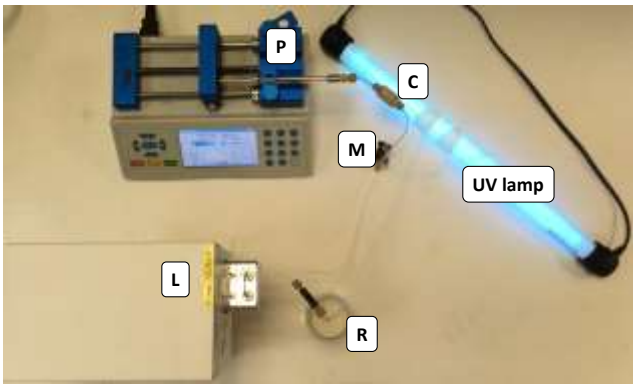

Figure S1. Developed looped flow reactor for the light-induced ring-closure of a linear precursor toward cyclic polymers. (Generally, the reactor set-up is completely shielded from light.)

Synthesis of the α-methyl benzaldehyde functional chain transfer agent (CTA)

Synthesis of 2-(2-(2-hydroxyethoxy)ethoxy)ethyl 4-cyano-4-((phenylcarbonothioyl)thio)pentanoate (CPADP-TEG):

4-Cyano-4-(phenylcarbonothioylthio)pentanoic acid (1.30 g, 4.65 mmol, 1.00 eq) and triethylene glycol (14.0 g, 93.1 mmol, 20.0 eq) were dissolved in 10 mL anhydrous dichloromethane. *N*-(3-dimethylaminopropyl)-*N*'-ethylcarbodiimide hydrochloride (1.34 g, 6.98 mmol, 1.50 eq) and 4-(dimethylamino)pyridine (56.9 mg, 93.1 mmol, 0.100 eq) were added at 0 °C and the reaction mixture was stirred at ambient temperature overnight. 100 mL saturated aqueous $NaHCO_3$ solution was added and extracted with dichloromethane. Subsequently, the organic phase was washed with 1 M HCl, water and brine, dried over Na_sSO_4 and purified using column chromatography (silica gel, ethyl acetate) to yield CPADP-TEG (1.40 g, 73 %).

^{1}H NMR (400 MHz, chloroform-*d*) δ/ppm = 7.93 – 7.88 (m, 2H), 7.61 – 7.52 (m, 1H), 7.43 – 7.36 (m, 2H), 4.28 (t, *J* = 4.7 Hz, 2H), 3.80 – 3.56 (m, 10H), 2.81 – 2.57 (m, 3H), 2.52 – 2.39 (m, 1H), 2.12 (s, 1H), 1.93 (s, 3H).

Synthesis of 3-cyano-3-methyl-6-oxo-1-phenyl-1-thioxo-7,10,13-trioxa-2-thiapentade can-15-yl 4-((2-formyl-3-methylphenoxy)methyl)benzoate (CTA):

CPADP-TEG (500 mg, 1.21 mmol, 1.00 eq) and methyl 4-((2-formyl-3-methylphenoxy)methyl)benzoic acid (328 mg, 1.21 mmol, 1.00 eq) were dissolved in 10 mL anhydrous dichloromethane and 1 mL anhydrous *N*,*N*-dimethylformamide. *N*-(3-dimethylaminopropyl)-*N*'-ethylcarbodiimide hydrochloride (349 mg, 1.82 mmol, 1.50 eq) and 4-(dimethylamino)pyridine (14.8 mg, 0.121 mmol, 0.100 eq) were added at 0 °C and the reaction mixture was stirred at ambient temperature overnight. 40 mL saturated aqueous $NaHCO_3$ solution was added and extracted with dichloromethane. Subsequently, the organic phase was washed with 1 M HCl, water and brine, dried over Na_sSO_4 and purified using column chromatography (silica gel, ethyl acetate/cyclohexane, 1/1, v/v) to yield CTA (672 mg, 84 %).

^{1}H NMR (400 MHz, chloroform-*d*) δ/ppm = 10.75 (s, 1H), 8.08 (d, *J* = 8.0 Hz, 2H), 7.89 (d, *J* = 7.4 Hz, 2H), 7.60 – 7.51 (m, 1H), 7.50 (d, *J* = 8.1 Hz, 2H), 7.42 – 7.32 (m, 3H), 6.88 – 6.82 (m, 2H), 5.22 (s, 2H), 4.52 – 4.46 (m, 2H), 4.29 – 4.23 (m, 2H), 3.87 – 3.81 (m, 2H), 3.75 – 3.62 (m, 6H), 2.75 – 2.60 (m, 3H), 2.59 (s, 3H), 2.47 – 2.34 (m, 1H), 1.92 (s, 3H).

^{13}C{^{1}H} NMR (76 MHz, chloroform-*d*) δ/ppm = 222.39, 192.08, 171.59, 166.21, 161.99, 144.63, 142.38, 141.59, 134.52, 133.13, 130.21, 130.01, 128.68, 126.95, 126.78, 124.81, 123.78, 118.59, 110.44, 70.84, 70.73, 70.02, 69.38, 69.16, 64.28, 64.24, 45.85, 33.47, 29.85, 24.23, 21.59.

ESI-MS: $[M + Na]^+$, $[C_{35}H_{37}NO_8S_2Na]^+$, theoretical: 686.185; experimental:. 686.186

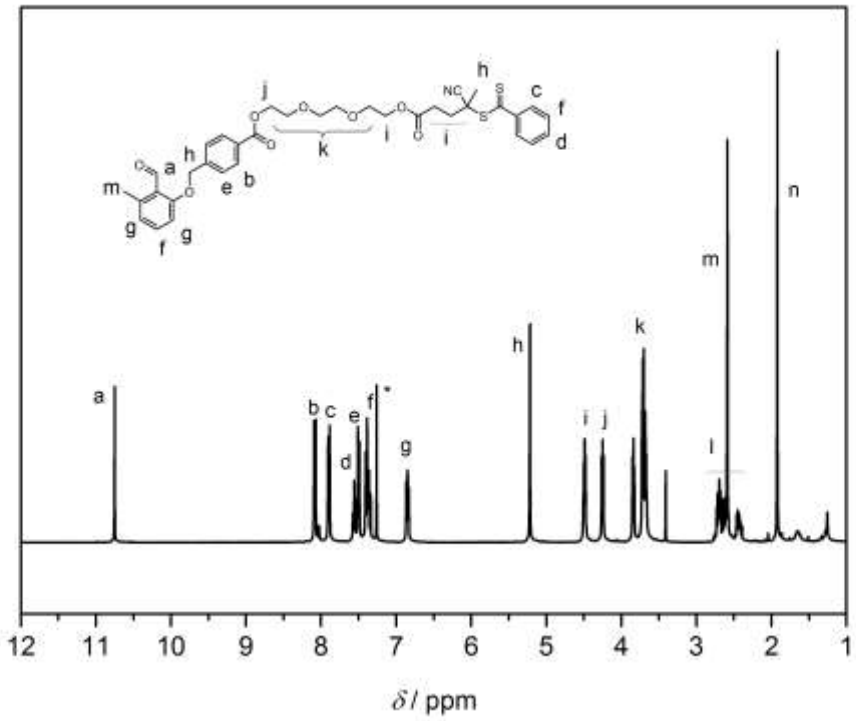

Figure S2. ^{1}H NMR spectrum (400 MHz, $CDCl_3$) of 3-cyano-3-methyl-6-oxo-1-phenyl-1-thioxo-7,10,13-trioxa-2-thiapentadecan-15-yl 4-((2-formyl-3-methylphenoxy)methyl)benzoate (CTA). Solvent residue ($CHCl_3$) is marked with an asterisk.

Synthesis of the α,ω functionalized linear precursor

A solution of 0.6 mg AIBN (0.05 eq), 50 mg RAFT agent (1 eq) and 0.648 g MA (100 eq) in 0.648 g toluene was prepared and purged with argon prior to use. The reaction solution was heated to 70°C. After 19 h reaction time, 68% monomer conversion was observed, and an α,ω-functionalized MA polymer was collected with a molecular weight of 6890 g · mol^{-1} and a dispersity of 1.27.

Intramolecular coupling toward cyclic polymers

A stock solution of 19 mg α,ω-functionalized MA polymer in 3.8 mL acetonitrile (5 mg mL^{-1}) was prepared and purged with argon. A gastight syringe was filled and placed on a syringe pump as 'injection pump'. Pure acetonitrile was injected via the loop pump into the system to dilute the precursor polymer before entering the reactor. Different times were tested by changing the flow rates of the injection and the loop pump respectively. The concentration of the precursor polymer could easily be adjusted via varying the ratio between the injection and the loop pump. The reaction mixture was collected at the outlet of the reactor tube (as a non-looped system) and was evaporated under nitrogen flow before analysis.

Cyclic polymer preparation in a looped flow reactor

The intramolecular coupling of the α,ω-functionalized precursor polymer was carried out as described above. At the start of the reaction, the reservoir was filled with 10 mL pure acetonitrile. The outlet van de reactor was then collected in the reservoir to allow dilution of the injected precursor polymer with a solvent/product mixture. A residence time of 30 min was applied to every cycle and a total run time of 16.7 h was foreseen.