Supplementary Information
Direct organocatalytic enantioselective functionalization of SiO_x surfaces

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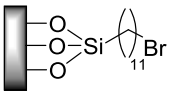
1. General Information

Reagents. Silicon wafers (P/Boron Si, Shin-Etsu Handotai Europe Ltd, Livingstone, UK) were cut into approximately 1.0×1.5 cm^2 sized pieces. 11-bromoundecyltrichlorosilane (Fluorochem, UK), was distilled before use. Sodium azide (Sigma Aldrich, UK), all arylacetic acids (Alfa Aesar, UK), $CuSO_4.5H_2O$ (Acros, UK) and (+)-sodium ascorbate (Sigma Aldrich, UK) were used as received. Dichloromethane (CH_2Cl_2) was obtained dry from a solvent purification system (MBraun, SPS-800). EtOH/DMF (Sigma Aldrich, UK) were used as received. L- and D-cysteine for modification of Au coated AFM probes were purchased from Merck, UK, and used as supplied. The synthesis of enone **2** has been reported previously.[1]

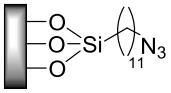
Cleaning procedure of silicon wafers. The silicon wafers were placed in a solution of concentrated H_2SO_4 (98%) and H_2O_2 (30% v/v) (2:1) at 70 °C for 15 min (*Caution 'piranha' solution reacts violently with many organic materials and should be handled with care*). The wafer was then placed in a solution of concentrated NH_4OH, DI water and H_2O_2 (30% v/v) (1:5:1) at 70 °C for 15 min. The wafer was then placed in a solution of concentrated HCl, DI water and H_2O_2 (30% v/v) (1:5:1) at 70 °C for 15 min and subsequently rinsed with copious amounts of DI water and dried under a stream of Ar gas. The wafers were then placed in an oven at 130 °C for 30 min.

Preparation of the Br terminated SAM



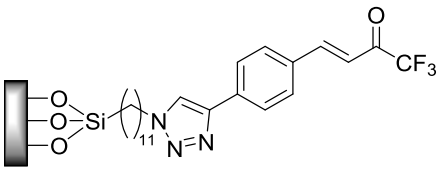
Freshly cleaned silicon wafers were placed in a 25 mL round bottom flask containing a freshly prepared solution of 11-bromoundecyltrichlorosilane (1.0 mM) and Et_3N (1.5 mM) in PhMe (5 mL per wafer) for 24 h. The wafer was removed and rinsed with PhMe, then sonicated in PhMe, EtOH and H_2O for 5 mins each, and dried under a stream of Ar.

Conversion of Br to N_3 terminated layer



The bromine terminated wafer was immersed in a saturated solution of sodium azide in DMF (2.5 mL) and the reaction was stirred for 24 h. The azide terminated wafer was removed and rinsed with DMF, then sonicated in EtOH and H_2O for 5 mins each, and dried under a stream of Ar.

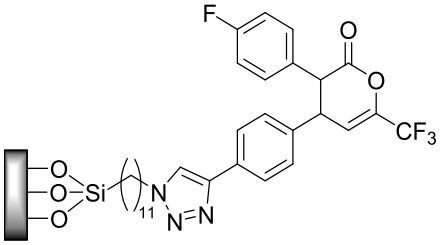
Click reaction to form a trifluoromethylenone terminated layer



Solutions of $CuSO_4.5H_2O$ (7.5 mg, 0.03 mmol) in H_2O (1 mL) and sodium ascorbate (8.9 mg, 0.045 mmol) in H_2O (1 mL) were added sequentially to enone **2** (6.5 mg, 0.03 mmol) in EtOH (8 mL). The azide terminated wafer was immersed in the reaction mixture for 24 h. The wafer was removed and rinsed with EtOH, then sonicated in EtOH and H_2O for 5 mins each, and dried under a stream of Ar.

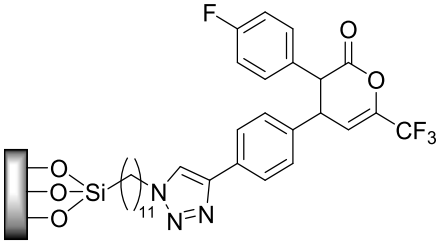
2. General Procedures and Synthesis

General Procedure 1: *click reaction to form a lactone terminated layer.*



Solutions of $CuSO_4.5H_2O$ (1 equiv.) in H_2O (1 mL) and sodium ascorbate (1.5 equiv.) in H_2O (1 mL) were added sequentially to the requisite lactone (1 equiv.) in EtOH (8 mL). The azide terminated wafer was immersed in the reaction mixture for 24 h. The wafer was removed and rinsed with EtOH, then sonicated in EtOH and H_2O for 5 mins each, and dried under a stream of Ar.

General Procedure 2: *surface Michael addition-lactonization with DHPB or HyperBTM.*



$^{i}Pr_2NEt$ (1.5 equiv.) and pivaloyl chloride (1.5 equiv.) were added to a solution of acid (1 equiv.) in CH_2Cl_2 (3 mL) at 0 °C, and the resultant mixture was stirred at 0 °C for 20 mins. The reaction mixture was cooled to −78 °C and the requisite catalyst (5 mol%), enone terminated wafer, and $^{i}Pr_2NEt$ (2.5 equiv.) were added, then resultant mixture was stirred at −78 °C for 24 h. The wafer was removed and rinsed with CH_2Cl_2, then sonicated in CH_2Cl_2 and $CHCl_3$ for 5 mins each, and dried under a stream of Ar.

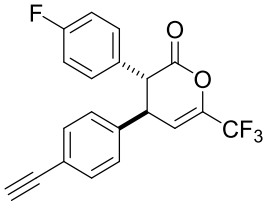
General Procedure 3: *Deposition of cysteine on Au coated SiO_2 and Au coated AFM tips*
The tip side of an AFM cantilever was coated with ~5 nm of Ti as an adhesion promotor followed by ~50 nm of Au using a thermal evaporator, which afforded Au coated AFM tips. Pieces of Si wafer were coated with Au alongside the cantilevers.
The Au coated AFM tip or wafer was rinsed with EtOH and immersed in a 2 mM solution of the appropriate cysteine in H_2O. After 24 h the AFM tip or wafer was removed from the solution and rinsed with H_2O, EtOH and dried under a stream of Ar to afford the appropriate cysteine terminated surface.[2] Characterization of the resulting organic films was performed on the planar Au coated pieces of Si wafer.

General procedure 4: *Michael addition lactonization using HyperBTM* ***3***
$^{i}Pr_2NEt$ (1.5 equiv) and pivaloyl chloride (1.5 equiv.) were added to a solution of acid (1 equiv.) in CH_2Cl_2 (3 mL) at 0 °C, and the resultant mixture was stirred at 0 °C for 20 min. The reaction mixture was cooled to −78 °C and the HyperBTM (5 mol %) was added. A pre-cooled (−78 °C) solution of enone **2** in CH_2Cl_2 (2 mL) added, followed by $^{i}Pr_2NEt$ (2.5 equiv). The reasultant mixture was stirred at −78 °C for 16 h, then aq. 1 M HCl (2 mL) was added. The aqueous phase was extracted with CH_2Cl_2 (2 × 7 mL) and the combined organic extracts were washed with brine (10 mL), dried ($MgSO_4$), and concentrated *in vacuo*. Purification via flash chromatography (pet. ether: Et_2O) gave the desired lactone.

Generation of D-, L- and (±)-cysteine terminated surfaces

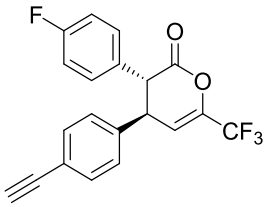
The Au coated AFM tip or wafer was rinsed with EtOH (10 mL) and immersed in a 2 mM solution (2.5 mg, 2 mmol) of the appropriate cysteine H_2O (10 mL). After 24 h the AFM tip or wafer was removed from the solution and rinsed with H_2O (10 mL), EtOH (10 mL) and dried under a stream of Ar to afford the appropriate cysteine terminated surface.

(±)-4-(4-ethynylphenyl)-3-(4-fluorophenyl)-6-(trifluoromethyl)-3,4-dihydro-2H-pyran-2-one 4



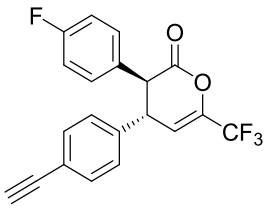
Following *General Procedure 4*, 4-fluorophenylacetic acid (138 mg, 0.892 mmol, 1 equiv.), pivaloyl chloride (165 µL, 1.34 mmol, 1.5 equiv.) and $^{i}Pr_2NEt$ (232 µL, 1.34 mmol, 1.5 equiv.) were stirred at 0 °C, followed by addition of (±)-HyperBTM-**3** (14 mg, 0.045 mmol, 5 mol%), enone **2** (200 mg. 0.982 mmol. 1 equiv.) and $^{i}Pr_2NEt$ (386 µL, 2.23 mmol, 2.5 equiv.) at −78 °C gave crude (±)-**4** (85:15 dr). The crude mixture was purified by Biotage® Isolera™ 4 [SNAP Ultra 10 g, 75 mL min^{-1}, pet. ether :Et_2O (100 : 0 3CV, 100 : 0 to 90 : 0 10 CV] afforded (±)-**4** as a colourless oil (155 mg, 48% yield, >95:5 dr); **Chiral HPLC analysis:** Chiralcel AD-H (10% *i*PrOH:hexane, flow rate 1 mL min^{-1}, 254 nm, 30 °C) t_R (3*R*,4*R*): 10.4 min, (3*S*,4*S*): 25.1 min, 50:50 er; ν_{max} (thin film, cm^{-1}) 3311 (C-H), 1786 (C=O), 1726 (C=C); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 3.09 (1H, s, C≡*H*), 3.87 (1H, d, *J* 10.7, C(3)*H*), 3.99 (1H, dd, *J* 10.7, 2.8, C(4)*H*), 6.11 (1H, d, *J* 2.8, C(5)*H*), 6.94 (2H, d, *J* 8.2, ArC(3,5)*H*), 6.98 (4H, m, ArC(2,6)*H* and ArC(2',6')*H*), 7.39 (2H, d, *J* 8.2, ArC(3,5)*H*); **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) δ_C: 44.9 (*C*(4)H), 52.1 (*C*(5)H), 78.3 (C≡*C*H), 82.8 (*C*≡CH), 110.7 (d, $^{3}J_{C\text{-}F}$ 3.1, *C*(5)H), 116.1 (d, $^{2}J_{C\text{-}F}$ 21.8, C(3)Ar*C*(3,5)H), 119.5 (q, $^{2}J_{C\text{-}F}$ 273.0, *C*F_3), 122.2 (C(4)Ar*C*(4)), 127.6 (C(3)Ar*C*(3,5)H), 130.3 (C(4)Ar*C*(2,6)H), 133.0 (C(3)Ar*C*(2,6)H), 139.3 (C(4)Ar*C*(1)), 141.3 (q, $^{2}J_{C\text{-}F}$ 38.3, *C*(6)), 162.5 (d, $^{1}J_{C\text{-}F}$ 247.8, C(3)Ar*C*(4)), 165.6 (*C*=O); **^{19}F {^{1}H} NMR** (470 MHz, $CDCl_3$) δ_F: −72.2 (C*F*$_3$), −113.3 (ArC*F*); **HRMS** (ESI^-) $C_{20}H_{11}O_2F_4$ $[M\text{-}H]^-$, found 359.0703, requires 359.0701 (+0.6 ppm).

(3*R*,4*R*)-4-(4-Ethynylphenyl)-3-(4-fluorophenyl)-6-(trifluoromethyl)-3,4-dihydro-2*H*-pyran-2-one 4



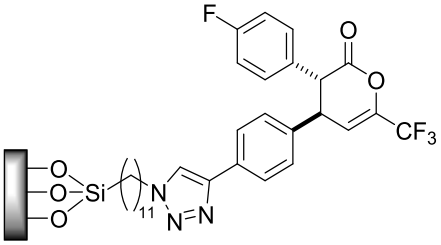
Following *General Procedure 4*, 4-fluorophenylacetic acid (138 mg, 0.892 mmol, 1 equiv.), pivaloyl chloride (165 µL, 1.34 mmol, 1.5 equiv.) and $^{i}Pr_2NEt$ (232 µL, 1.34 mmol, 1.5 equiv.) were stirred at 0 °C, followed by addition of (2*S*,3*R*)-HyperBTM **3** (14 mg, 0.045 mmol, 5 mol%), enone **2** (200 mg. 0.982 mmol. 1 equiv.) and $^{i}Pr_2NEt$ (386 µL, 2.23 mmol, 2.5 equiv.) at −78 °C affording crude (3*R*,4*R*)-**4** (85:15 dr). The crude mixture was purified by Biotage® Isolera™ 4 [SNAP Ultra 10 g, 75 mL min^{-1}, pet. ether :Et_2O (100 : 0 3CV, 100 : 0 to 90 : 0 10 CV] afforded **4** as a colourless oil (155 mg, 48% yield, >95:5 dr); $[\alpha]_D^{20}$ = −105.3 (*c* 1.0 $CHCl_3$); **Chiral HPLC analysis:** Chiralcel AD-H (10% *i*PrOH:hexane, flow rate 1 mL min^{-1}, 254 nm, 30 °C) t_R (3*R*,4*R*): 10.4 min, (3*S*,4*S*): 25.2 min, 92.5:7.5 er. All spectroscopic data were identical to those of (±)-**4**.

(3*S*,4*S*)-4-(4-Ethynylphenyl)-3-(4-fluorophenyl)-6-(trifluoromethyl)-3,4-dihydro-2*H*-pyran-2-one 4



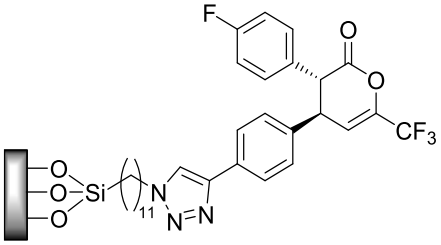
Following *General Procedure 4*, 4-fluorophenylacetic acid (138 mg, 0.892 mmol, 1 equiv.), pivaloyl chloride (165 µL, 1.34 mmol, 1.5 equiv.) and $^{i}Pr_2NEt$ (232 µL, 1.34 mmol, 1.5 equiv.) were stirred at 0 °C, followed by addition of HyperBTM (2*R*,3*S*)-**3** (14 mg, 0.045 mmol, 5 mol%), enone **2** (200 mg. 0.982 mmol. 1 equiv.) and $^{i}Pr_2NEt$ (386 µL, 2.23 mmol, 2.5 equiv.) at −78 °C affording crude (3*S*,4*S*)-**4** (90:10 dr). The crude mixture was purified by Biotage® Isolera™ 4 [SNAP Ultra 10 g, 75 mL min^{-1}, Pet. ether:Et_2O (100 : 0 3CV, 100 : 0 to 90 : 0 10 CV] afforded **4** as a colourless oil (133 mg, 42% yield, >95:5 dr); $[\alpha]_D^{20}$ = +71.6 (*c* 1.0 $CHCl_3$); **Chiral HPLC analysis:** Chiralcel AD-H (10% *i*PrOH:hexane, flow rate 1 mL min^{-1}, 254 nm, 30 °C) t_R (3*R*,4*R*): 10.4 min, (3*S*,4*S*): 25.2 min, 92.5:7.5 er. All spectroscopic data were identical to those of (±)-**4**.

Generation of (±)-4-(4-ethynylphenyl)-3-(4-fluorophenyl)-6-(trifluoromethyl)-3,4-dihydro-2H-pyran-2-one terminated surface 6 via click-reaction



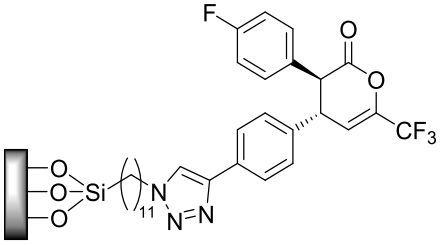
Following *General Procedure 1*, an azide terminated wafer **5** was reacted with (±)-**4** (10 mg, 0.027 mmol) in EtOH (8 mL) in the presence of $CuSO_4.5H_2O$ (7.5 mg, 0.03 mmol, in 1 mL H_2O) and sodium ascorbate (8.9 mg, 0.045 mmol, in 1 mL H_2O) at rt for 24 h to give (±)-surface **6**.

Generation of (3*R*,4*R*)-terminated surface 6



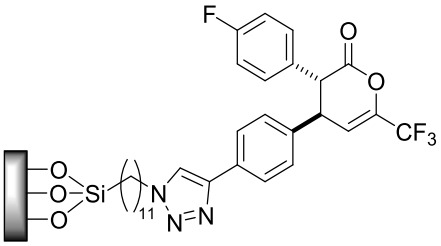
Following *General Procedure 1*, azide terminated wafer **5** was reacted with (3*R*,4*R*)-**4** (10 mg, 0.027 mmol) in EtOH (8 mL) in the presence of $CuSO_4.5H_2O$ (7.5 mg, 0.03 mmol, in 1 mL H_2O) and sodium ascorbate (8.9 mg, 0.045 mmol, in 1 mL H_2O) at rt for 24 h to give (3*R*,4*R*)-derived surface **6**.

Generation of (3*S*,4*S*)-terminated surface 6



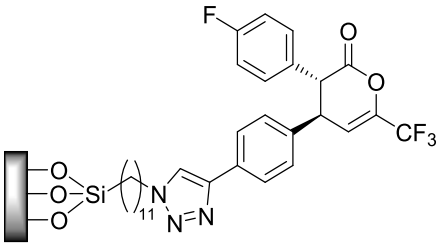
Following *General Procedure 1*, azide terminated wafer **5** was reacted with (3*S*,4*S*)-**4** (10 mg, 0.027 mmol) in EtOH (8 mL) in the presence of $CuSO_4.5H_2O$ (7.5 mg, 0.03 mmol, in 1 mL H_2O) and sodium ascorbate (8.9 mg, 0.045 mmol, in 1 mL H_2O) at rt for 24 h to give (3*S*,4*S*)-derived surface **6**.

Generation of (±)-4-(4-ethynylphenyl)-3-(4-fluorophenyl)-6-(trifluoromethyl)-3,4-dihydro-2H-pyran-2-one terminated surface through organocatalysis



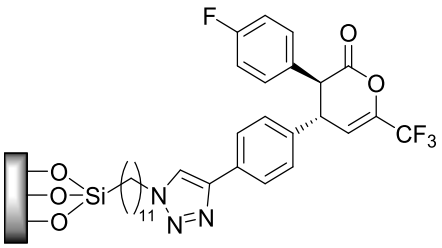
Following *General Procedure 2*, 4-fluorophenylacetic acid **1** (30 mg, 0.195 mmol), pivaloyl chloride (33 µL, 0.268 mmol) and $^{i}Pr_2NEt$ (51 µL, 0.293 mmol) were stirred at 0 °C, followed by addition of enone terminated wafer, (±)-HyperBTM-**3** (3 mg, 0.010 mmol) and $^{i}Pr_2NEt$ (85 µL, 0.488 mmol) at −78 °C, to give the corresponding (±)-surface.

Generation of (3*R*,4*R*)- terminated surface through organocatalysis



Following *General Procedure 2*, 4-fluorophenylacetic acid **1** (30 mg, 0.195 mmol), pivaloyl chloride (33 µL, 0.268 mmol) and $^{i}Pr_2NEt$ (51 µL, 0.293 mmol) were stirred at 0 °C, followed by addition of enone terminated wafer, (2*S*,3*R*)-HyperBTM-**3** (3 mg, 0.010 mmol) and $^{i}Pr_2NEt$ (85 µL, 0.488 mmol) at −78 °C, to give the corresponding enantioenriched surface.

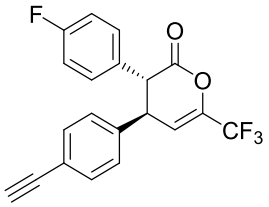
Generation of (3*S*,4*S*)- terminated surface through organocatalysis

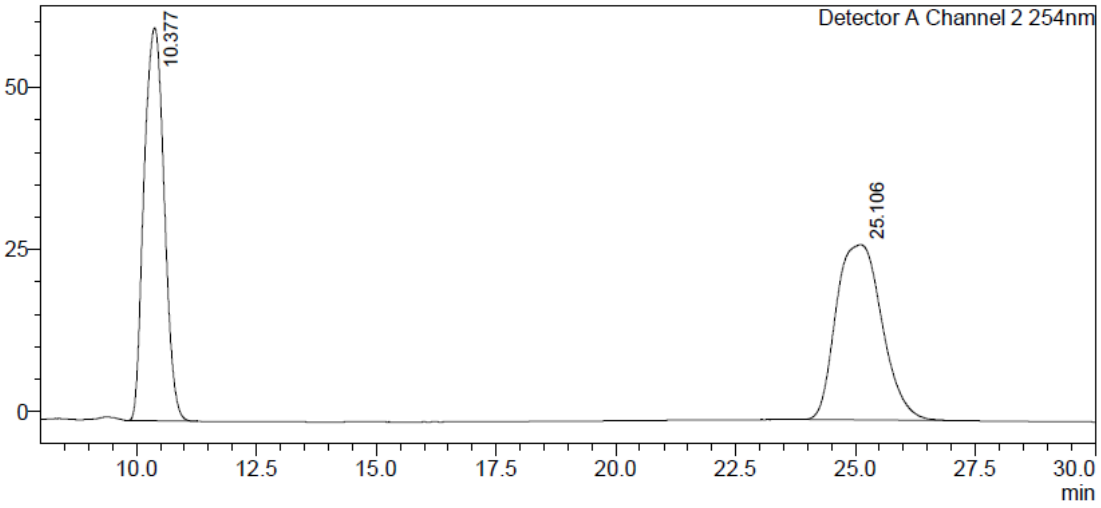


Following *General Procedure 2*, 4-fluorophenylacetic acid **1** (30 mg, 0.195 mmol), pivaloyl chloride (33 µL, 0.268 mmol) and $^{i}Pr_2NEt$ (51 µL, 0.293 mmol) were stirred at 0 °C, followed by addition of enone terminated wafer, (2*R*,3*S*)-HyperBTM-**3** (3 mg, 0.010 mmol) and $^{i}Pr_2NEt$ (85 µL, 0.488 mmol) at −78 °C, to give the corresponding enantioenriched surface.

3. HPLC Data

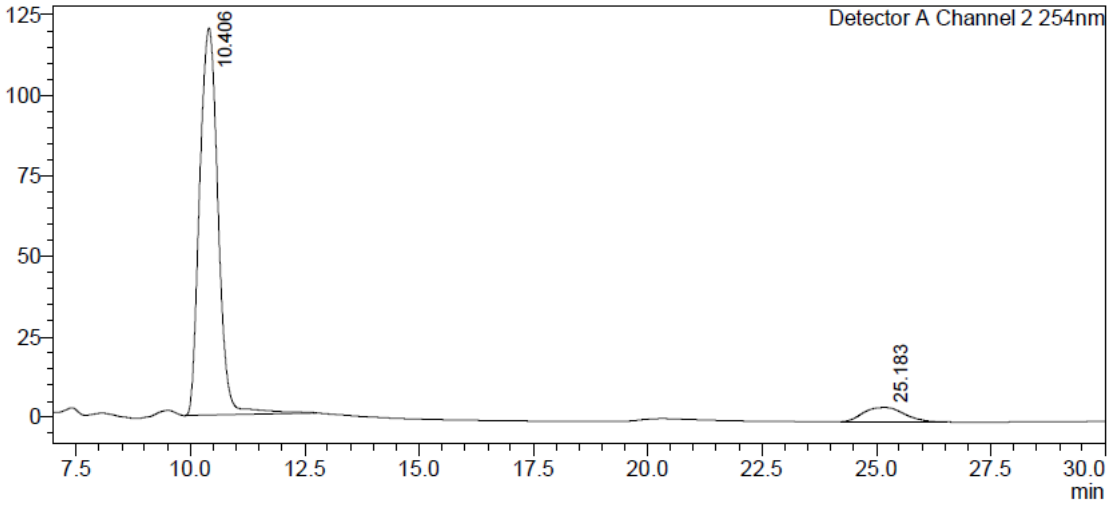
HPLC data for **4**: Chiralcel AD-H (10% *i*-PrOH:hexane, flow rate 1 mL min^{-1}, 254 nm, 30 °C), t_R (3*R*,4*R*): 10.4 min, (3*S*,4*S*): 25.2 min, 92.5:7.5 er.





Detector A Channel 2 254nm

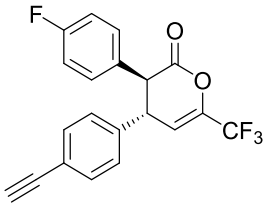
Peak#	Ret. Time	Area%
1	10.377	49.603
2	25.106	50.397
Total		100.000

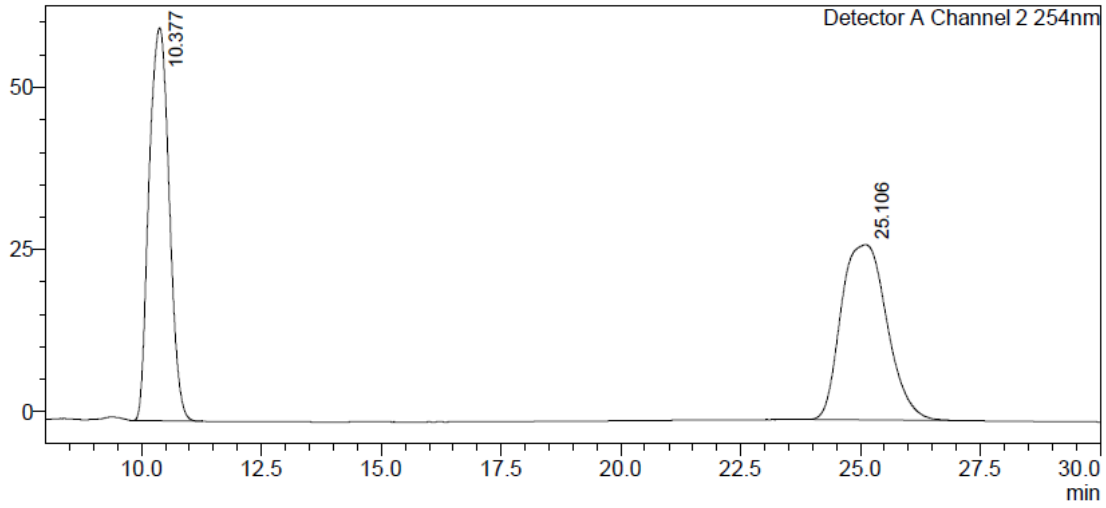


Detector A Channel 2 254nm

Peak#	Ret. Time	Area%
1	10.406	92.548
2	25.183	7.452
Total		100.000

HPLC data for **4**: Chiralcel AD-H (10% *i*-PrOH:hexane, flow rate 1 mL min^{-1}, 254 nm, 30 °C), t_R (3*R*,4*R*): 10.4 min, (3*S*,4*S*): 25.2 min, 92.5:7.5 er.





Detector A Channel 2 254nm

Peak#	Ret. Time	Area%
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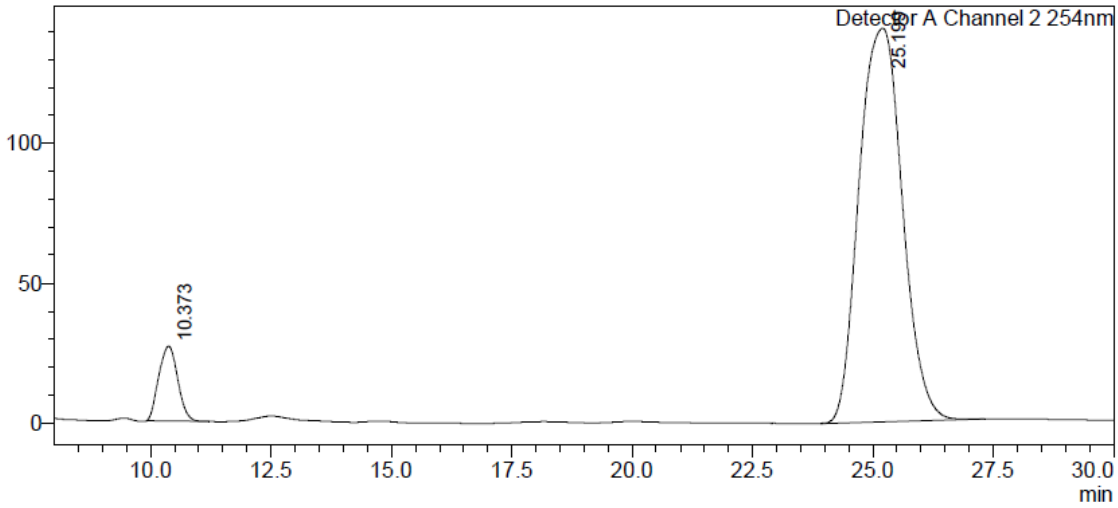
2	25.106	50.397
Total		100.000



Detector A Channel 2 254nm

Peak#	Ret. Time	Area%
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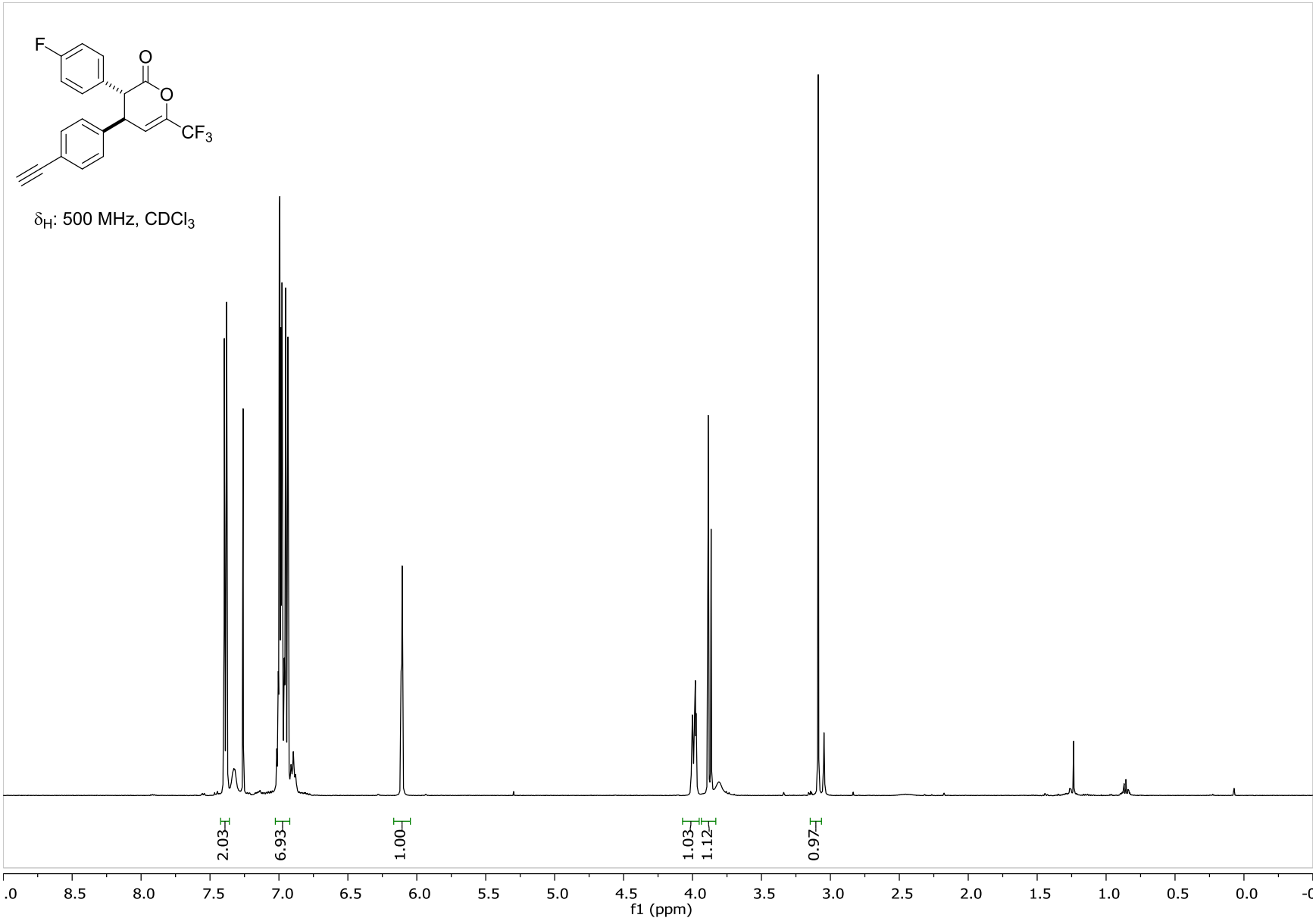
2	25.199	92.360
Total		100.000

4. Representative ^{1}H, ^{13}C, and ^{19}F NMR spectra for lactone 4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O
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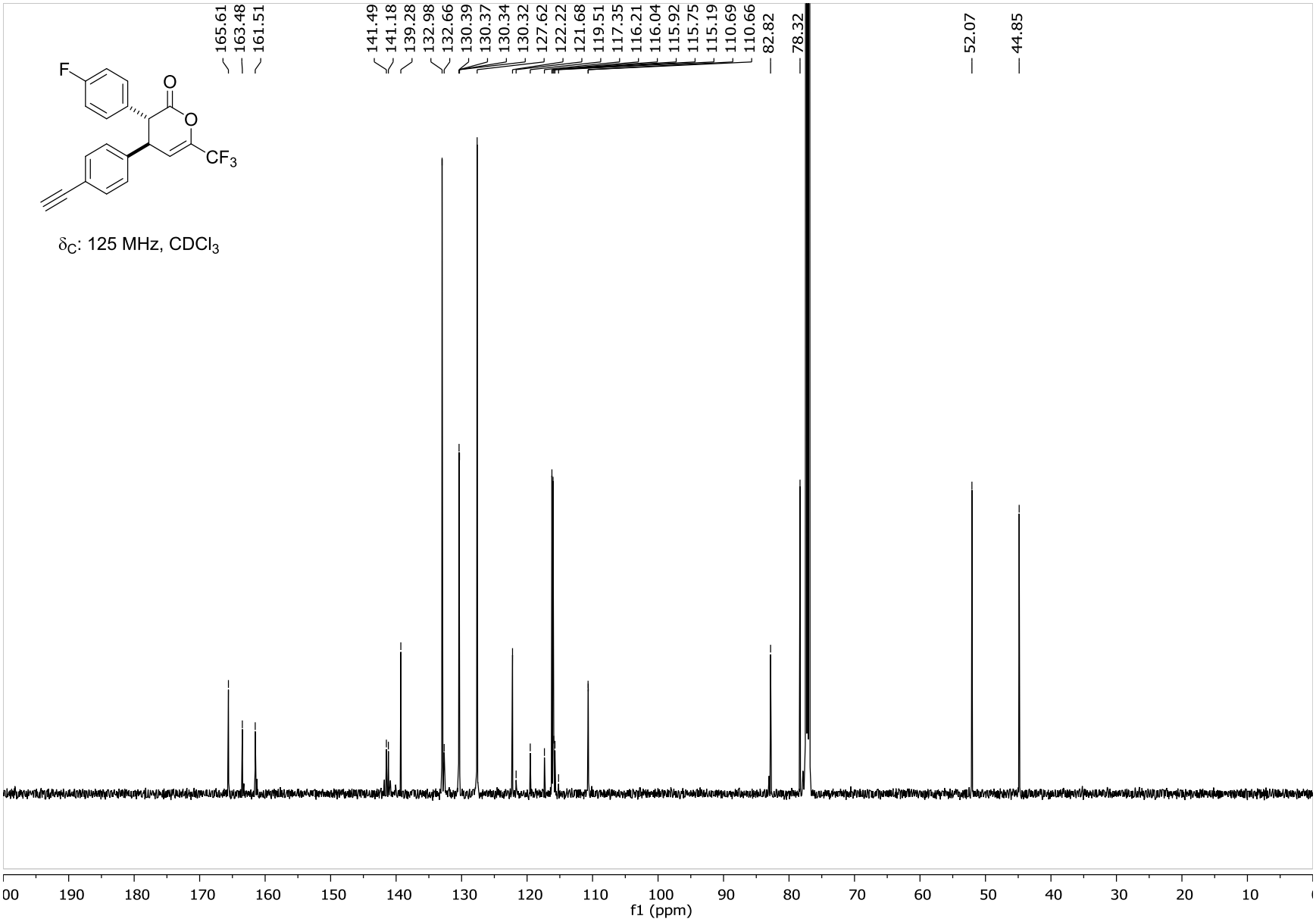
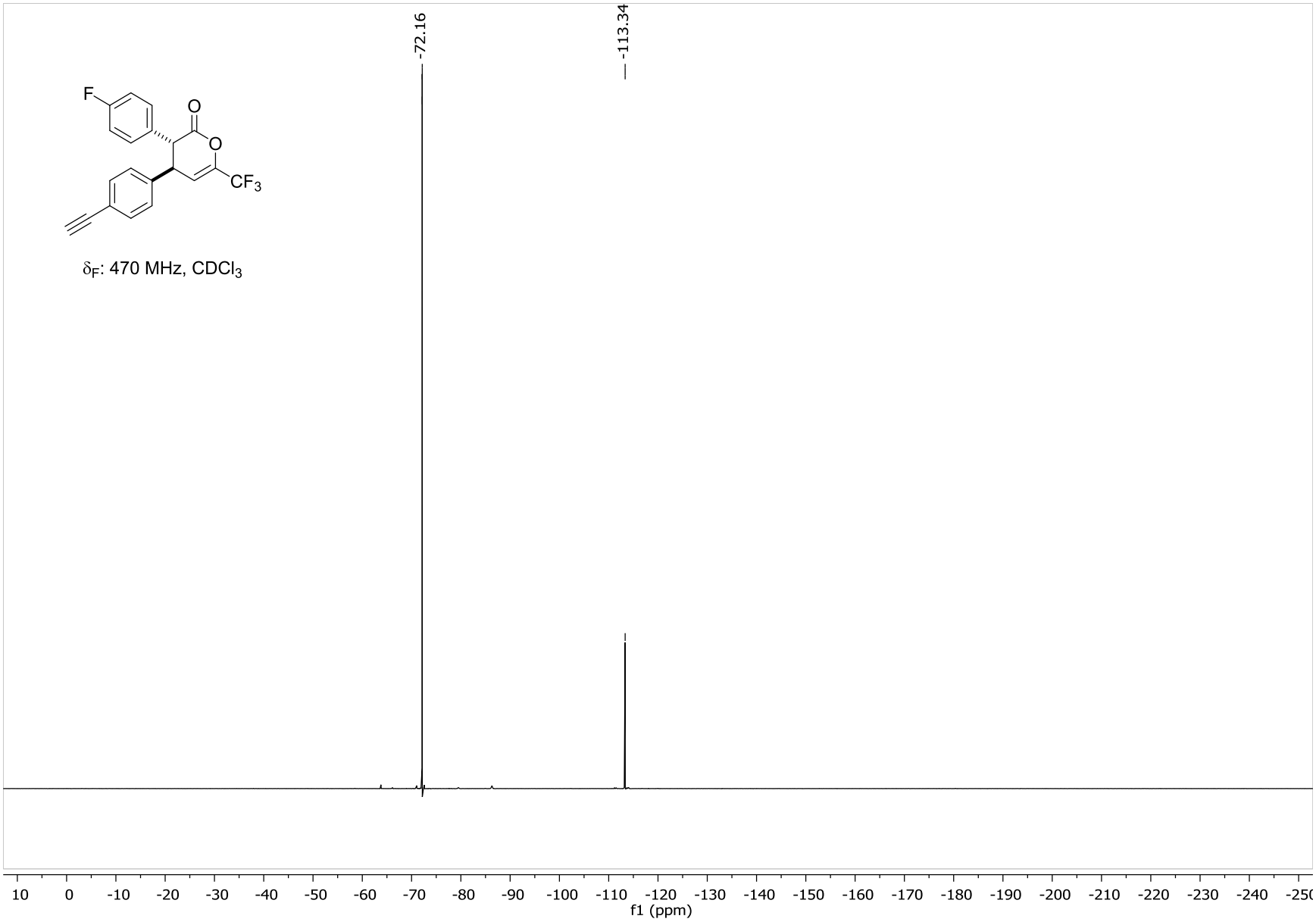
6.93
1.00
1.03
1.12
0.97
f1 (ppm)


165.61
163.48
161.51
141.49
141.18
139.28
132.98
132.66
130.39
130.37
130.34
130.32
127.62
122.22
121.68
119.51
117.35
116.21
116.04
115.92
115.75
115.19
110.69
110.66
82.82
78.32
52.07
44.85
F
O
O
CF3
δC: 125 MHz, CDCl3
f1 (ppm)


-72.16
-113.34
F
O
O
CF3
δF: 470 MHz, CDCl3
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210 -220 -230 -240
f1 (ppm)

5. Instrumentation and Characterization of the Films

5.1 Contact Angle Measurements. Static contact angle values were measured with Millipore filtered DI water using a G10 contact angle goniometer (Krüss GmbH, Hamburg, Germany) in ambient conditions. Droplets of ~3 μL were dispensed from a microburette. Contact angle values reported were taken from an average of at least two samples, each sample's contact angle being the average of the value measured on each side of three droplets.

5.2 Ellipsometry. The thickness of the SAMs was measured with an M-2000DI™ spectroscopic ellipsometer (J.A. Woollam Co., Inc., USA). Film thicknesses were extracted from fits to data collected at angles of incidence of 45°-70° in steps of 5° over wavelengths of 200 to 1000 nm. The sample was modelled as a 1 mm thick Si substrate with an oxide layer and a Cauchy layer atop to represent the SAM. The thickness of the silicon oxide after the oxidative cleaning treatment was 16 ± 1 Å (average of three samples). The thickness of the Cauchy layer was calculated using a value of 1.45 for the refractive index of the SAM at ~1000 nm.[3] The quoted thickness values were calculated from an average of at least two samples with data collected from two areas of each sample. The error based on the observed variation of the thickness of the organic films prepared under identical conditions was ~2 Å.

5.3 X-ray Photoelectron Spectroscopy.

XPS spectra were obtained using a Scienta 300 XPS instrument and Al Kα radiation. The base pressure in the test chamber was around 1×10^{-8} mbar. The detector had a take-off angle of 90° relative to the surface. Survey spectra and single region scans were recorded with the analyzer pass energy set to 150 eV. Some XPS spectra (samples prepared by click chemistry) were obtained using a K-Alpha instrument (Thermo Scientific) and Al Kα radiation (NEXUS, Newcastle, UK). During the analysis, the pressure in the instrument chamber was kept around 3×10^{-8} mbar. The detector had a take-off angle of 90° relative to the surface. For this instrument survey spectra were recorded with the analyzer pass energy set to 200 eV. Single region scans were recorded with the pass energy of the analyzer set to 20 eV.
All XPS spectra were corrected for charging by shifting the aliphatic C 1s peak to 284.6 eV. Elemental compositions of the various surfaces were determined from the area under individual elemental peaks using CasaXPS (Casa Software Ltd., UK) with sensitivity factors provided with the software as well as taking the transmission function of the analyzer into account. A Shirley background was subtracted and the spectra were fitted using Gaussian-Lorentzian (30% Gaussian, 70% Lorentzian) peak shapes.

5.4 Atomic Force Microscopy (AFM). Images for roughness determination were obtained using a Bruker Dimension Icon AFM system (Bruker, Santa Barbara, USA). AFM images were collected in the PeakForce Tapping™ mode using V-shaped cantilevers with a nominal spring constant of 0.58 N/m (Veeco SNL-A), a peak force set point of around 1-4 nN, and a scan rate of 1 Hz. The RMS roughness of the surfaces was obtained from 1×1 μm^2 images with 512×512 pixels after appropriate image levelling. Quoted roughness values were calculated from an average of at least two samples and three images of each sample.

Force curve collection. The same AFM system was used to collect force curves measured with the cysteine SAM coated AFM tips (Au coated Bruker cantilevers SNL-B or SNL-D with nominal spring constants of 0.12 and 0.06 N/m, respectively) on lactone terminated surfaces in Millipore filtered deionized water. Force curves were collected at a ramp rate of ~1 Hz with 0.2-0.5 s of surface dwell time, a ramp size of 200-500 nm, and with the maximum deflection in contact minimized on a cantilever by cantilever basis to be as small as possible (typically ~0.5-8.0 nm). Spring constant calibration was performed via the thermal noise method.
For each tip – sample system force curves were collected in grids. Typically 25 force curves were collected in 5×5 grids in each of four different 500 × 500 nm^2 areas resulting in at least 100 force curves per surface. The same tip was used to interrogate multiple samples sequentially without alteration of optical readout positioning when possible. Repeat measurements of samples were performed to check for tip changes. The modified tips were not used for imaging to preserve the thiol coating.
All force curves were analyzed with home-written MATLAB® routines to remove baseline slope (fitted in the non-contact region), to convert piezo movement to tip-sample separation, and to convert cantilever deflection into force. Force curves displaying behavior due to contamination were removed from the data set. A force curve was not considered if the maximum pull-off force was not well defined and forces were experienced by the tip over a distance greater than ~5 nm. Below, in figure S1, we show examples of force curves recorded with a D-tip on a (*3R,4R*)-modified surface prepared by Michael lactonization. Adhesion forces were extracted from the retract curves (approach curves are only shown for clarity). When it was clear from the force curve that (for example) the tip might have picked something up (as is the case for the force curves in the lower row of figure S1 because they display some interaction over more than 5nm from the surface based on the region indicated by the circle) then we did not use that force curve.

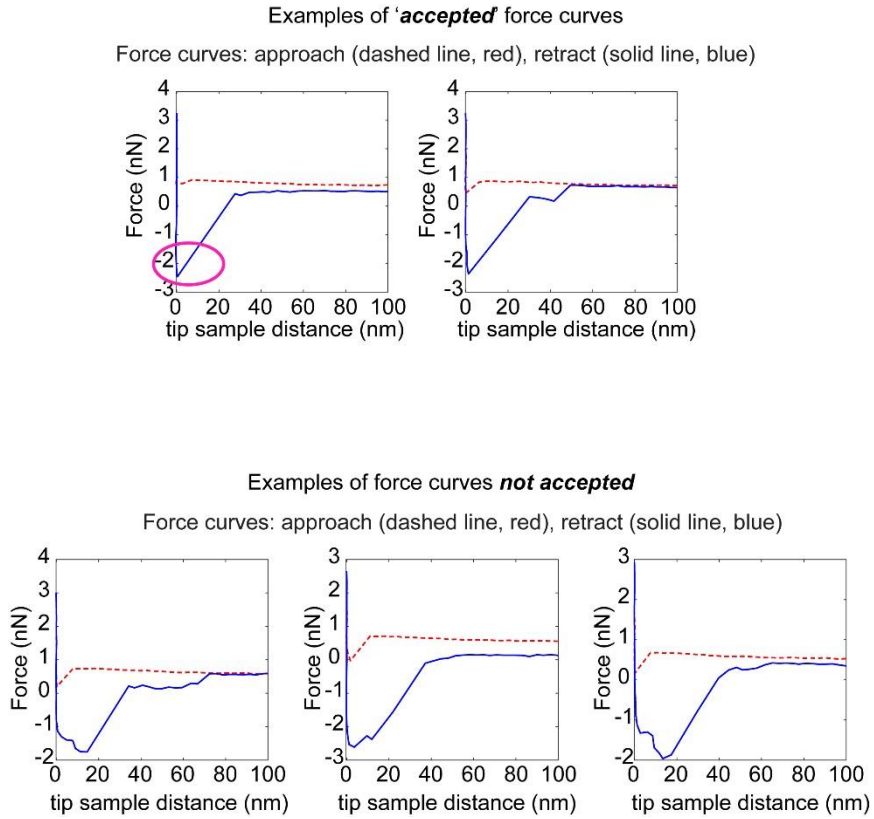


Figure S1: *Examples of force curves recorded with a D-tip on a (3R,4R)-covered surface.*

The maximum adhesion force was extracted from the retract part of each force curve, and the distribution of the adhesion forces plotted. The table below shows the number of force curves collected and the number of force curves used in the adhesion force distributions (number in brackets) in figures 2c and 3c.

	Cu-click		**Michael lactonization**		
	R click	***S click***	***(3R,4R)***	***(3S,4S)***	***racemic***
D tip	200 (172)	200 (177)	100 (77)	100 (78)	100 (98)
L tip	200 (193)	200 (173)	100 (95)	100 (96)	250 (149)

Table S1: *Number of force curves collected and the number of force curves used (in brackets) in figures 2c and 3c.*

The force distributions shown in figures 2c and 3c for a chirally modified surface were collected on one sample (they are not a combination of force curves from several surfaces collected with the same tip). For each column in figures 2c and 3c samples were measured with the same tip because of the experimental parameters that can have an impact on the

data, but data in different columns were measured with different tips. This is reflected in the width of the distributions, which is fairly constant within each column.

6. Results

Results on roughness, film thickness, and wettability (contact angles) were obtained on at least two independent samples for both clicked on and organocatalytically prepared lactone surfaces.

*6.1 Clicked on lactones **6**.*

RMS roughness values on these films were 0.370nm and 0.246nm over an area of 1x1 μm^2 for (3*S*,4*S*) and (*3R,4R*) terminated surfaces. The film thickness was 2.2(±0.2) nm and 2.4 (±0.2) nm, and the measured contact angle values 74.9° (±1.5) and 75.3° (±2.0) for (3*S*,4*S*) and (*3R,4*R), respectively. Each value is an average calculated from at least two samples of each lactone species.

XPS results.

In addition to a survey spectrum single region scans were recorded for C 1s, N 1s, O 1s, F 1s and Si 2p. The O 1s and F 1s region both showed a single symmetric peak, which did not allow extraction of more detailed information, in contrast to the C 1s and N 1s regions. Spectra obtained for a clicked on (3*R*,4*R*) lactone sample are shown in figure 2 in the manuscript. The reported conversion from the azide to the clicked on (3*R*,4*R*) lactone of 82% is only slightly lower than the conversion of ~90% for clicked on enones reported earlier,[1] and might be due to the slightly bigger size of the lactones. Azide decomposition as well as a loss of nitrogen can occur during longer exposure to X-rays with the release of molecular nitrogen during the decomposition reaction.[4] This does not appear to play a major role in our experiments, but a minor influence on the N 1s signal cannot be excluded.

In the C 1s region (manuscript figures 2b and 3b) six peaks/structures were fitted as listed below in table S2.

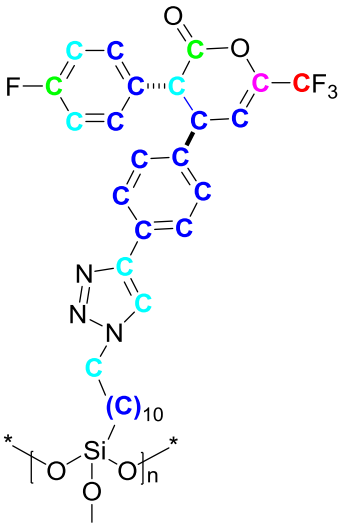
	C1s	Energy (eV)	description	
P1	C-C C=C	284.6	Aliphatic C-C and C=C (blue)	
P2	C-N **C**-CO_2 **C**-CF	~286.1	C-N, **C**-CF, **C**-CO_2 (cyan)	
P3	O-**C**-CF_3	~287.2	From both enone and lactone, equal to CF_3 peak (magenta)	
P4	O=C-O C-F	~288.6	lactone only, indicative of lactone (twice CF_3 intensity for clicked on samples) (green)	
P5	Shake-up structure	~290.1	due to the π–π* transition in the C1s spectra of the aromatic compounds[5] (yellow)	
P6	CF_3	292.5	from both lactone and enone if present (red)	

Table S2: *Assignment of XPS peaks in the C 1s region.*

The experimentally determined ratios Pn/P6 (n=1,..,5) of the individual peaks relative to the CF_3 peak for the (3*R*,4*R*) lactone (Fig. 2b) are: 29.8, 5.5, 1.0, 2.0, and 0.7. The widths and the positions of P4 and P5 relative to P6 were fixed by fitting constraints. The theoretical ratios based on the molecule shown in table S2 (right) are 21, 6, 1, 2, and 'small'. The ratios are thus close to the expected ones. The higher aliphatic signal is most likely due to contamination (these samples were sent to Newcastle, UK, for XPS analysis). The P2 signal (carbon bonded to nitrogen) will be silightly attenuated by the part of the molecule which covers these carbon atoms, which can explain the slightly lower P2/P6 ratio.

The corresponding N 1s and C 1s spectra for the (3*S*,4*S*) lactone prepared by click-chemistry are shown below in figure S2.

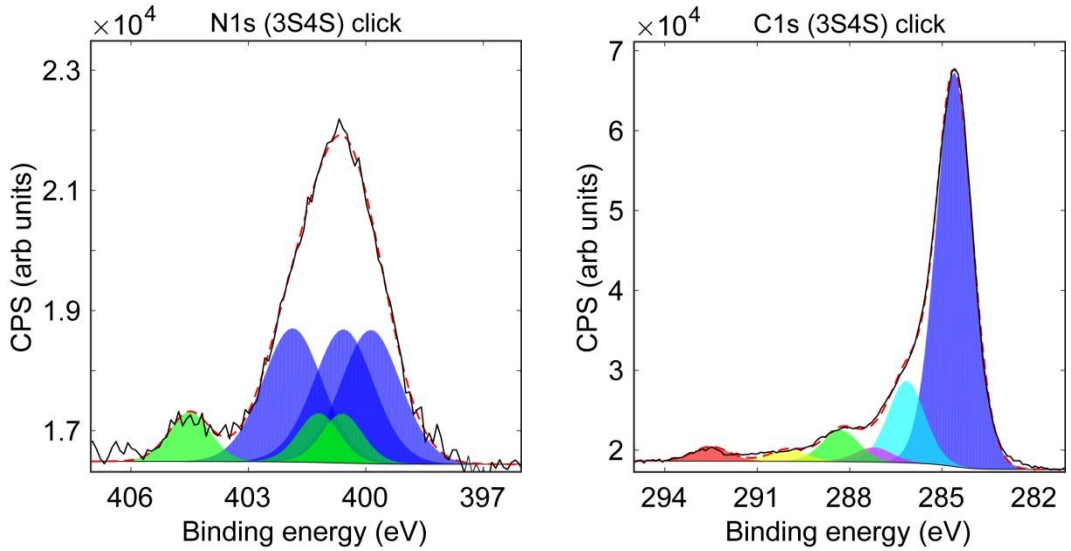


Figure S2: *N 1s and C 1s region of (3S,4S) clicked on lactones. Black solid lines are the experimental data, the red dashed lines show the overall fit.*

The conversion rate from the azide to the lactone based on the N 1s signal is ~80%. The C1s spectrum is very similar to the one observed for the (3*R*,*4R*) sample as expected and the same holds for the ratios Pn/P6 (n=1,..,5), which are 25.8, 5.4, 1.0, 2.0, and 0.8.

6.2 Michael lactonization

AFM showed smooth surfaces with an RMS roughness of ~0.170 (±0.038) nm over an area of 1x1 μm^2 for surfaces prepared with (2*S*,3*R*)-HyperBTM, and 0.155 (±0.040) nm for surfaces prepared with (2*R*,3*S*)-HyperBTM, which is similar to previous results obtained on racemic mixtures (0.178 ±0.054 nm).[1]

The thickness values obtained with ellipsometry of 1.84 (±0.15) nm on the (3*R*,4*R*) lactones and 1.86 (±0.07) nm on (3*S*, 4*S*) are only slightly lower than the length of the molecule (~2.1nm). Water contact angle values were 73.6° (±1.9) for films prepared with (2*S*,3*R*)-HyperBTM and 75.1 (±1.6) for samples prepared with (2*R*,3*S*)-HyperBTM, and hence similar to the value found for racemic surfaces (71°).[1]

Each value for roughness, film thickness, and contact angle is an average calculated from at least three examples of each lactone species.

XPS results.

The measured ratios (Pn/P6, n=1,..,5) of the individual peaks in the C 1s region of the (3*R*, 4*R*) lactones (see manuscript, figure 3b) are 20.6, 3.9, 1.0, 0.73, and 0.32. In case of Michael lactonization the ideal ratio P1/P6 is less than 21 because not all enones are

converted to lactones. The enones contribute 17 ‘aliphatic carbons’ per molecule. With 37% conversion from enone to lactone the ideal ratio is 18.9. The ratio of 20.6 most likely indicates a small amount of contamination to be present. Similarly, P2/P6 is significantly lower than 6 because some of the carbons coloured in cyan in table S2 do not contribute to P2 in case of enones. Furthermore, the lower P5/P6 ratio compared to the clicked on lactones is consistent with the smaller number (~50%) of aromatic structures present compared to the clicked on lactones.

XPS spectra for lactones prepared by Michael lactonization with chiral catalyst HyperBTM (2*R*,3*S*) are shown in figure S3 below.

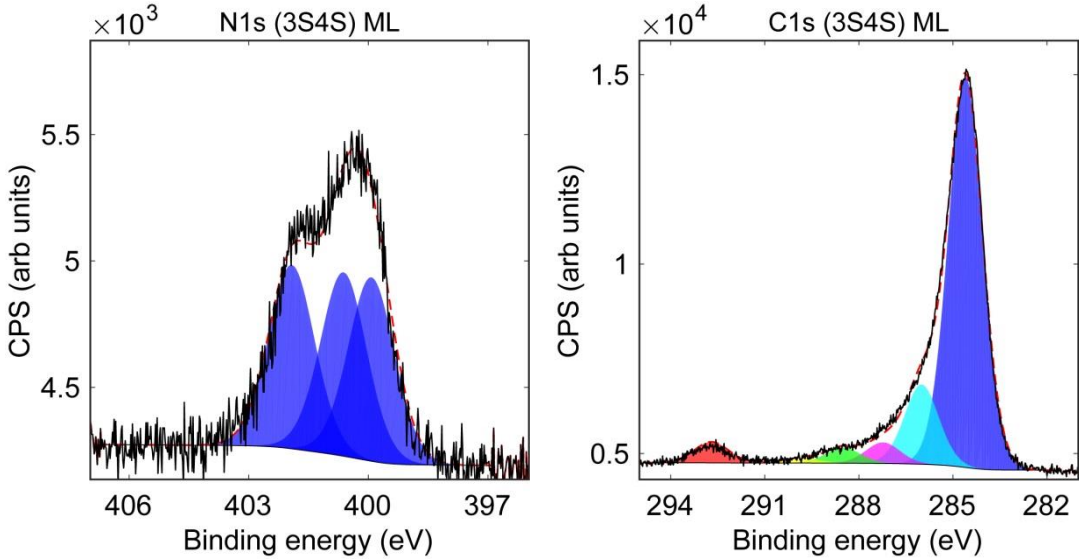


Figure S3: *N 1s and C 1s region of the (3S,4S) lactone-terminated surface prepared by Michael lactonization. Black solid lines show the experimental data, the red dashed lines show the overall fit.*

Similar to the sample prepared with HyperBTM (2*S*,*3R*) the N 1s region shows no signal for the azide. The conversion from the enone to the lactone based on the ratio of the O=C-O/ C-F signal (P4, green) and the CF_3 signal (P6, red) with a value of P4/P6=0.74 is ~37%, and hence identical to the one found for HyperBTM (2*R*,3*S*).
The ratios Pn/P6 (n=1,...,5) are 18.5, 3.78, 1.0, 0.74, and 0.24. The P1/P6 ratio is close to the ideal one of 18.9. We expect small amounts of contamination to be present, which should give a ratio >18.9. However, the signal from the aliphatic carbon chain will be slightly attenuated by the covering enone and lactone groups. In addition, a small error in the fitted CF_3 signal P6 (slightly too high) might also contribute to the slightly smaller ratio.

6.3 Chirally modified AFM tips and test system.

In order to assess the quality of the chiral AFM tips prepared, a model system consisting of surfaces and probe tips both functionalized with L-and D-cysteine was devised and studied with chiral force microscopy first. Cysteine was chosen because of its commercial availability. D-cysteine and L-cysteine were deposited onto separate Au coated Si surfaces (figure S4 (a)) and Au coated AFM probe tips (figure S4 (b)).

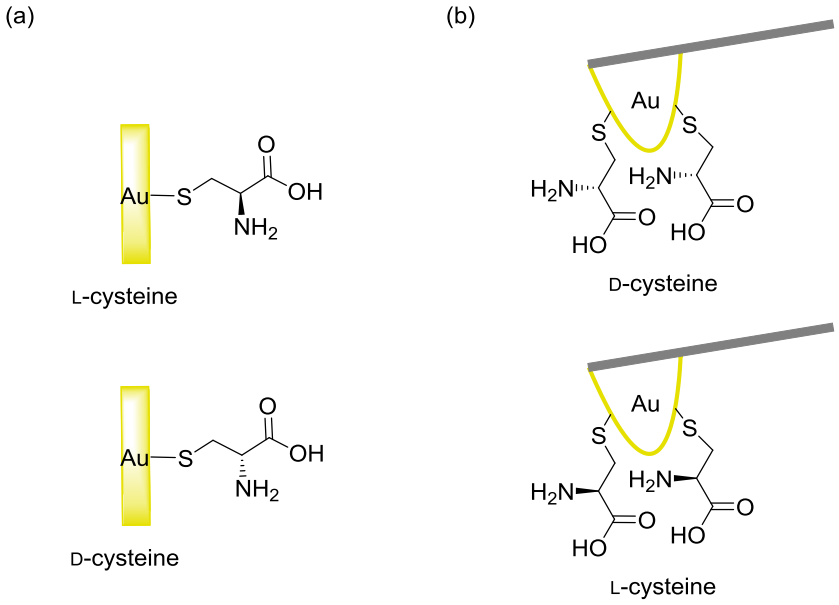


Figure S4*: (a) Both enantiomers of cysteine deposited on Au surfaces, (b) both enantiomers of cysteine deposited on Au coated AFM tips.*

The cysteine SAMs deposited onto Au surfaces displayed static water contact angle values of 33±2° for L-cysteine and 31±2° for D-cysteine, which is within the range of values for SAMs of cysteine reported in the literature.[2, 6]

Measurements of the adhesion force distributions are shown in figure S5.

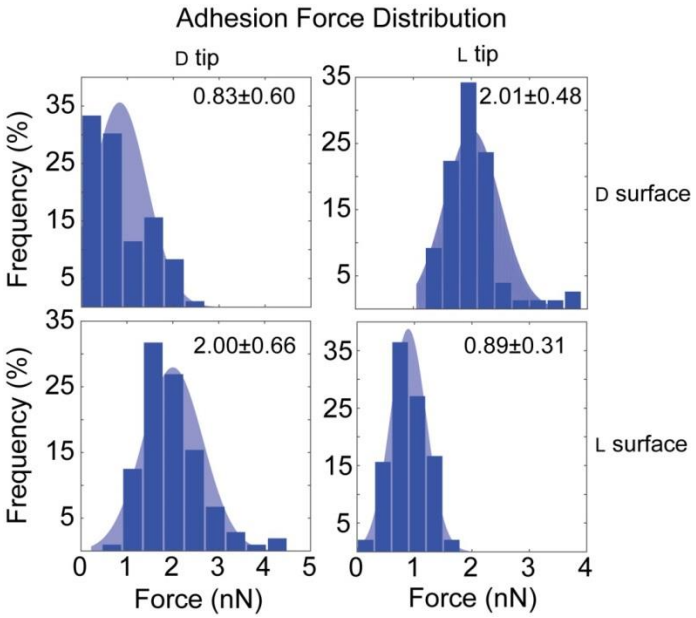


Figure S5: *Adhesion force distributions for D-cysteine modified AFM tips (left) and L-cysteine modified AFM tips (right). Both tips were tested with D- (top) and L-cysteine modified surfaces (bottom). Average adhesion force values (in nN) and the standard deviations based on the distribution of the forces are also reported.*

The histograms in figure S5 (left) display the distribution of adhesion forces obtained with a D-cysteine coated AFM tip tested against both D-cysteine and L-cysteine films deposited on Au-coated surfaces. The tip shows a different adhesion force for the two enantiomers. Importantly, when an L-cysteine modified AFM tip was tested against the two surfaces (figure S5, right) the adhesion force distributions interchanged.

The reported force values have some error due to the uncertainty in the calibration of the spring constant. However, the relative forces obtained on different surfaces with the same tip are not affected by this. The observed force pattern corresponds to that expected for a chiral interaction if the enantiomers on both probe and surface are exchanged. The results therefore confirm that the quality of the chiral tips prepared is sufficiently high to allow for discrimination between enantiomers of simple chiral molecules.

The widths of the distributions are determined by the properties of both the tip and the surface. The Au surfaces on different tips/substrates might have different roughness values, which has an influence on the observed width.[7] It appears that the tip is mainly responsible for the observed width of the distribution.

References

[1] R. Chisholm, J. D. Parkin, A. D. Smith, G. Hähner, *Langmuir* **2016**, *32*, 3130-3138.
[2] A. D. Filimon, P. Jacob, R. Hergenroder, A. Jurgensen, *Langmuir* **2012**, *28*, 8692-8699.
[3] a) N. Tillman, A. Ulman, J. S. Schildkraut, T. L. Penner, *J. Am. Chem. Soc.* **1988**, *110*, 6136-6144; b) D. L. Angst, G. W. Simmons, *Langmuir* **1991**, *7*, 2236-2242.
[4] T. Heinrich, C. H. H. Traulsen, E. Darlatt, S. Richter, J. Poppenberg, N. L. Traulsen, I. Linder, A. Lippitz, P. M. Dietrich, B. Dib, W. E. S. Unger, C. A. Schalley, *RSC Adv.* **2014**, *4*, 17694-17702.
[5] M. Jung, U. Baston, G. Schnitzler, M. Kaiser, J. Papst, T. Porwol, H. J. Freund, E. Umbach, *J. Mol. Struct.* **1993**, *293*, 239-244.
[6] X. Yao, Y. W. Hu, B. Cao, R. Peng, J. D. Ding, *Biomaterials* **2013**, *34*, 9001-9009.
[7] R. McKendry, M. E. Theoclitou, C. Abell, T. Rayment, *Langmuir* **1998**, *14*, 2846-2849.