Supporting Information

Fluorinated Zwitterionic Polymers as Dynamic Surface Coatings

Le Zhou,† Zhefei Yang,† James Nicolas Pagaduan, Todd Emrick*

Polymer Science & Engineering Department, Conte Center for Polymer Research, 120 Governors Drive, University of Massachusetts, Amherst, MA 01003

*Corresponding author: tsemrick@mail.pse.umass.edu

Materials. 11-Mercapto-1-undecanol (97%), bromine (99.99%), α-bromoisobutyryl bromide (98%), 2-methacryloyloxyethyl phosphorylcholine (MPC, 97%), CuBr (99.999%), 2,2′-bipyridyl (bpy, 99%), 4,4′-dinonyl-2,2′-dipyridyl (dNbpy, 97%), ethyl α-bromoisobutyrate (EBiB, 98%), α,α,α-trifluorotoluene (anhydrous, 99%), monopotassium phosphate, bovine serum albumin (BSA, 98%), lysozyme, and gold coated silicon wafers (99.999% (Au), layer thickness 1000 Å, 99.99% (Ti adhesion layer)) were purchased from Sigma Aldrich. Sodium chloride, potassium chloride, disodium phosphate, methanol and acetone were purchased from Fisher Scientific. 1H,1H,2H,2H-Tridecafluoro-n-octyl methacrylate (stabilized with HQ + MEHQ >98.0%) was purchased from TCI. 2,2,2-Trifluoroethanol (TFE) was purchased from Oakwood Chemical. The SIA kit Au from Cytiva was used to prepare chips for surface plasmon resonance study to characterize protein adsorption. MPC was washed with diethyl ether and dried *in vacuo*. Dichloromethane (DCM) and triethylamine (TEA) were dried by reflux and distillation over calcium hydride before use. Milli-Q water was obtained from Barnstead™ MicroPure™ Water Purification System and used for contact angle measurements and protein adsorption experiments. TDFOMA was purified by passing through a plug of basic alumina. Fluorinated zwitterionic monomers, HFIP-MCP and PFH-MCP (**Figure S1**), were synthesized according to reported procedures.[1]

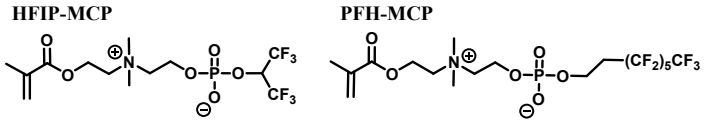
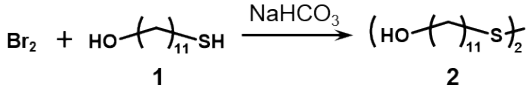


Figure S1. Chemical structures of FCP monomers

Surface Modification



*Synthesis of disulfide **2***[2]

11-Mercapto-1-undecanol (**1**) (3.6 g, 17.6 mmol) was dissolved in 132 mL of dry DCM in a round-bottom flask, followed by addition of 17.6 mL of 10% $NaHCO_{3(aq)}$ solution. Bromine (0.45 mL, 8.7 mmol) was added slowly to the stirring mixture using a dropping funnel. After ~40 minutes, the organic phase was collected using a separatory funnel, and the aqueous phase was washed with 2 x 50 mL DCM. The organic phase was combined and dried over anhydrous $MgSO_4$, followed by solvent removal by evaporation to isolate the pure product (**2**) in 72% yield. ^{1}H NMR (**Figure S2**) (500 MHz, $CDCl_3$, δ, ppm): 3.64 (t, J = 6.7 Hz, 4H), 2.68 (t, J = 6.5 Hz, 4H), 1.2-1.7 (m, 52H).

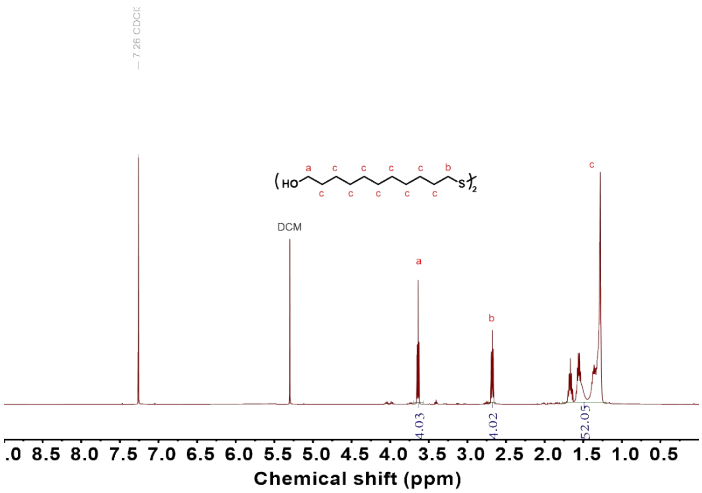
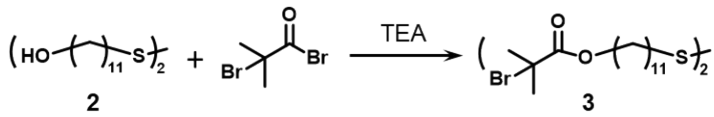


Figure S2. ^{1}H NMR spectrum of disulfide **2**.

*Synthesis of the disulfide initiator **3***[2]



Disulfide **2** (2.6 g, 6.4 mmol) was dissolved in 159 mL dry DCM in a flame-dried round-bottom flask, followed by addition of dry TEA (4.44 mL, 31.8 mmol). α-Bromoisobutyryl bromide (1.89 mL, 15.3 mmol) was added slowly using a dropping funnel while the mixture was stirred at 0 °C under $N_{2(g)}$ atmosphere. After 1 hour of stirring at 0 °C, the mixture was stirred for an additional 2 hours at room temperature. The mixture was then washed with 1 M $Na_2CO_{3(aq)}$ saturated with NH_4Cl, then dried over anhydrous $MgSO_4$. The mixture was then filtered and the solvent evaporated and the residue was subjected to column chromatography on silica gel, eluting with hexane/ethyl acetate (13/1) to afford disulfide **3** as a pale yellow, viscous liquid in 58% yield. ^{1}H NMR (**Figure S3**) (500 MHz, $CDCl_3$, δ, ppm): 4.16 (t, J = 6.6 Hz, 4H), 2.67 (t, J = 7.4 Hz, 4H), 1.92 (s, 12H), 1.66 (m, 8H), 1.21-1.43 (m, 30H). ^{13}C NMR (**Figure S4**) (500 MHz, $CDCl_3$, δ, ppm): 171.85, 66.26, 56.13, 39.28, 30.92, 29.58, 29.33, 29.28, 28.64, 28.46, 25.90. ESI-MS: m/z calc.: 704.7; found: 727.2 ($M + Na^+$).

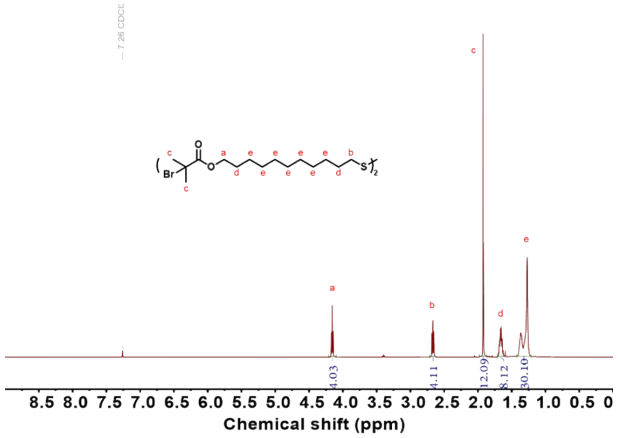


Figure S3. ^{1}H NMR spectrum of disulfide **3**.

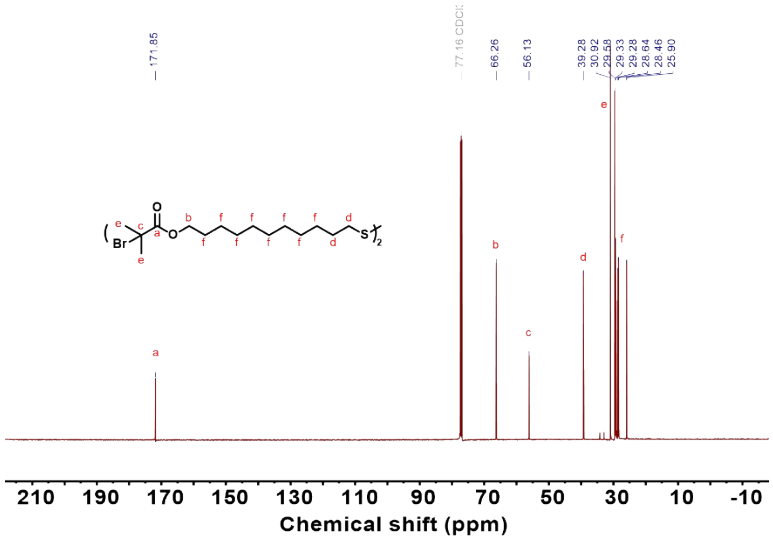


Figure S4. ^{13}C NMR spectrum of disulfide **3**.

Attaching disulfide initiator to Au substrates. Au substrates were cut into 1 × 1.2 cm pieces and cleaned by sonication in acetone and isopropanol for 10 min each, followed by drying under $N_{2(g)}$. After further cleaning by a 30-min UV/Ozone treatment (Jelight 342 UVO cleaner), the substrates were immersed in 2 mM of an ethanolic solution of disulfide **3** for 24 h. Then, the substrates were rinsed extensively with ethanol and dried under $N_{2(g)}$.

Preparation of polymer-grafted Au substrates via surface-initiated atom transfer polymerization (SI-ATRP). A) *Grafting PMPC*. In a 7 mL vial, 0.25 g MPC was dissolved in 1.5 mL TFE, and the initiator-immobilized Au substrate was placed in the vial. The monomer solution was purged with $N_{2(g)}$ for 10 minutes, then 165 µL solution of CuBr (2 mg/mL)/bpy (12 mg/mL) in MeOH was added to the monomer solution, which was purged with $N_{2(g)}$ for 10 minutes. The mixture was allowed to stand at room temperature under $N_{2(g)}$ for ~3 hours, after which the substrates were removed, rinsed with MeOH, water, and acetone, and dried in air.

B) *Grafting FCP-1*. In a 7 mL vial, 0.25 g HFIP-MCP was dissolved in 1.4 mL TFE, and the initiator immobilized Au substrate was placed in the vial. The monomer solution was purged with $N_{2(g)}$ solution for 10 minutes, then 115 µL solution of CuBr (2 mg/mL)/bpy (12 mg/mL) in MeOH was added to the monomer solution, which was purged with $N_{2(g)}$ for 10 minutes. The mixture was allowed to stand at room temperature under $N_{2(g)}$ for ~1.5 hours, after which the substrates were removed from the solution, rinsed with MeOH, TFE, water, and acetone, and dried in air.

C) *Grafting FCP-2*. In a 7 mL vial, 0.5 g PFH-MCP was dissolved in 1 mL TFE, and the initiator immobilized Au substrate was placed in the vial. The monomer solution was purged with $N_{2(g)}$ solution for 10 minutes, then 150 µL solution of CuBr (2 mg/mL)/bpy (12 mg/mL) in MeOH was added to the monomer solution, which was purged with $N_{2(g)}$ for 10 minutes. The mixture was allowed to stand under $N_{2(g)}$ for ~3 hours, after which the substrates were removed from the solution, rinsed with MeOH, TFE, water, and acetone, and dried in air.

D) *Grafting PTDFOMA*. In a 7 mL vial, 0.4 mL TDFOMA was mixed with 1.3 mL trifluorotoluene, the initiator immobilized Au substrate was added to the vial, and 3 mg CuBr and 45 mg dNbpy was added to the solution. The solution was purged with $N_{2(g)}$ for ~25 minutes, after which the system was heated to 60

°C. After ~10 hours, the substrates were removed from the solution, rinsed with trifluorotoluene, TFE, water, and acetone, and dried in air.

X-ray Photoelectron Spectroscopy (XPS). XPS was conducted using a Thermo Scientific™ Nexsa Surface Analysis System with a monochromatic aluminum Kα X-ray source (1486.6 eV). The flood gun was turned on during all measurements to prevent charging. All data were collected using a 72-W focused X-ray beam with a spot size of 400 mm at a base pressure of 5×10^{-7} millibar or lower. Survey scans were obtained with a pass energy of 200 eV and a step size of 1 eV. Narrow scans were obtained with a pass energy of 50 eV and a step size of 0.1 eV. The elemental compositions were calculated using the Thermo Avantage software package (v5.9925). Shirley-type smart background subtraction method was applied to the raw narrow scans. The peaks were deconvoluted using a Lorentzian-Gaussian product function (L/G mix = 30%) and integrated at their full widths at half maximum for quantification.

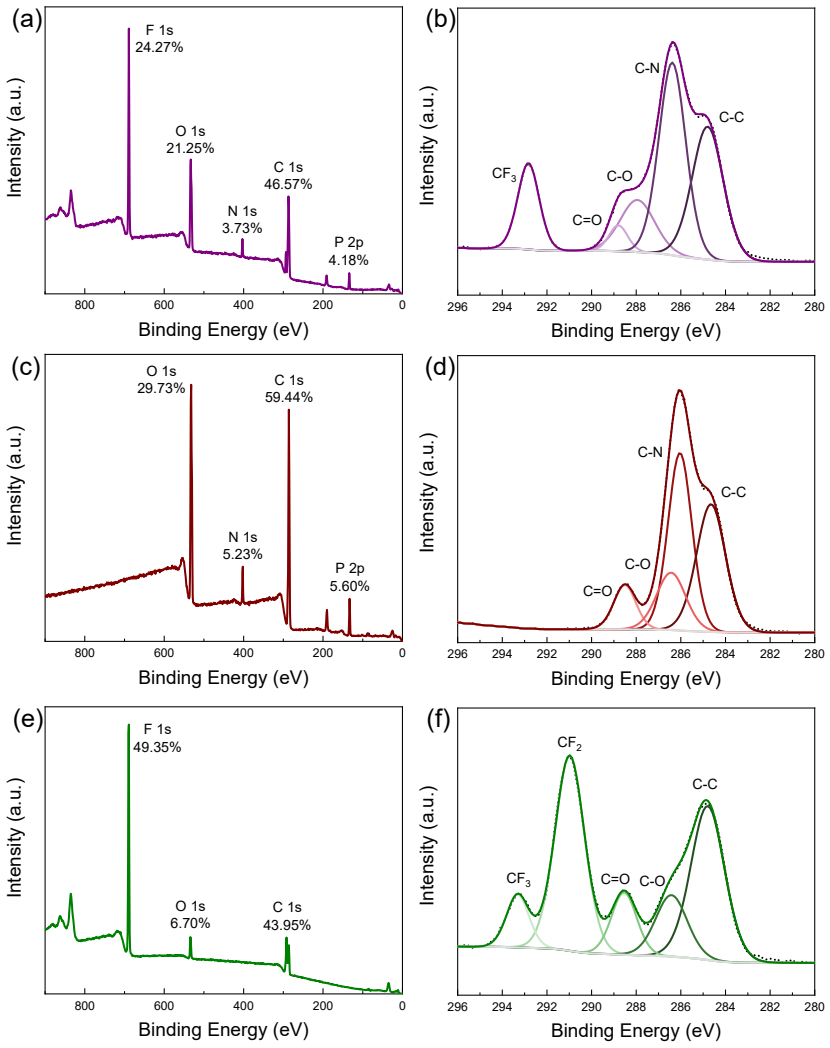


Figure S5. XPS spectra of FCP-1-, PMPC- and PTDFOMA-grafted Au: (a), (c) and (e) survey spectra and (b), (d) and (e) C1s scan.

Ellipsometry. Thickness values for the grafted polymers were measured by ellipsometry using a J.A. Woollam RC2 spectroscopic ellipsometer. The measurements was conducted at varying angles of incidence (45°, 50°, 55°, 60°, 65°) and values were calculated by fitting experimental data with the Cauchy equation (**Equation S1**),

$$n = A + \frac{B}{\lambda^2}$$

Equation S1

where n is the refractive index, λ is the light wavelength in μm, and A and B are constants with value of 1.5 and 0.01, respectively.

Calculation of grafting density. The grafting density of chains was calculated according to reported procedures,[3] using **Equation S2**, where d is the density of the polymers (1.30 g/cm^3)[4], L_d is the thickness of the polymers on the surface measured by ellipsometry, and N_A is Avogadro's number. EBiB was added to the reaction and M_n of the free polymers in solution (measured by gel permeation chromatography with TFE (contains 20 mM sodium trifluoroacetate) as eluent, calibrated against PMMA standards) was assumed to be the same as that for polymers grafted on the surface.

$$\sigma = \frac{dL_d N_A \times 10^{-21}}{M_n}$$

Equation S2

Contact angle measurements. Contact angle measurements were conducted using a Biolin Scientific theta attension optical tensiometer. For the static contact angle, 2.5-μL of liquid was released onto the surface, followed by 1-min measurements at 2.3 frames per second to obtain the average results. Measurements on three different spots were collected for each sample to obtain the average value and standard deviation. The dynamic contact angle was measured by changing volume of an existing droplet on the surface. A 2.5-μL probe liquid droplet was released onto the surface, with the needle in direct contact with the droplet. Vertical position of the needle was adjusted to keep the contact angle identical with the static contact angle. Then the probe liquid was injected at a rate of 0.2 μL/s using an auto-dispenser. The advancing contact angle was determined by averaging contact angles during the process in which the length of baseline increased and the droplet volume increased. Similarly, the receding contact angle was determined during the process in which the probe liquid was withdrawn from the droplet at a rate of 0.2 μL/s. When the length of baseline decreased, the droplet volume decreased, and the contact angles were collected and averaged to obtain the receding contact angle. The recorded contact angles, and the results of surface energy calculations, are shown in **Table S1**.

Table S1. Contact angle and surface energy values of PMPC, FCP-1, FCP-2, and PTDFOMA-grafted substrates.

	PMPC	FCP-1	FCP-2	PTDFOMA
water, static (°)	14.8 ± 6.8	68.5 ± 1.9	85.3 ± 0.6	119.6 ± 0.1
water, advancing (°)	14.5 ± 0.5	79.3 ± 2.3	114.7 ± 3.8	125.0 ± 0.7
water, receding (°)	< 10	16.7 ± 1.5	24.7 ± 1.1	77.2 ± 1.5
diiodomethane, static (°)	21.2 ± 4.0	67.7 ± 1.0	72.3 ± 3.2	99.7 ± 1.0
glycerol, static (°)	37.7 ± 2.1	72.2 ± 1.3	90.2 ± 7.3	108.4 ± 0.6
TFT in water, static (°)	160.5 ± 2.1	154.7 ± 1.4	142.3 ± 1.7	30.9 ± 0.9
dispersive component γ_s^d (mJ/m^2)	40.9 ± 3.4	20.5 ± 1.1	17.6 ± 2.9	8.9 ± 0.4
polar component γ_s^p (mJ/m^2)	29.5 ± 1.3	13.7 ± 1.4	5.8 ± 0.2	0.4 ± 0.1
surface free energy γ_{SV} (mJ/m^2)	70.4 ± 4.8	34.2 ± 0.3	23.4 ± 2.7	9.3 ± 0.4
Water/surface interfacial free energy γ_{SL} (mJ/m^2)	0.3	7.5 ± 2.0	17.4 ± 1.9	45.3 ± 0.5

Table S2. Water contact angles of PMPC, FCP-1, FCP-2, and PTDFOMA-grafted substrates with various thickness.

Polymers	Thickness/nm	water, static (°)
PMPC	67.2	15
	34.3	10
	8.5	10
FCP-1	88.6	72
	30.4	67
	10.0	55
FCP-2	67.0	88
	28.8	100
	8.0	109
PTDFOMA	59.6	120
	42.2	119
	10.9	119

Protein adsorption experiments. Protein adsorption was measured *via* SPR with a BIACORE T200 system at 25 °C. The unmounted gold surfaces in the purchased SIA kit Au were modified with PMPC, FCP-1, FCP-2, and PTDFOMA using procedures described in the surface modification section, in a 15 mL glass tube as the reaction container, and the modified sensor surfaces were assembled with the chip supports following manufacturer's instruction. The chips were tested with BSA and lysozyme in PBS buffer (137 mM NaCl, 2.7 mM KCl, 2 mM KH_2PO_4, and 10 mM Na_2HPO_4, pH 7.4). In each measurement, three start-up cycles were performed for system equilibration before the protein adsorption assay. For protein adsorption measurements, PBS buffer first flowed through the sensor for 50 seconds, a protein solution (1 mg/mL BSA or lysozyme in PBS buffer) then flowed through surface for 300 seconds, followed by rinsing with PBS buffer for 300 seconds to remove loosely bound protein.

Figure S6. Lysozyme adsorption on grafted substrates measured by SPR.

References

1 L. Zhou, A. Triozzi, M. Figueiredo and T. Emrick, *ACS Macro Lett.*, 2021, **10**, 1204–1209.

2 R. R. Shah, D. Merreceyes, M. Husemann, I. Rees, N. L. Abbott, C. J. Hawker and J. L. Hedrick, *Macromolecules*, 2000, **33**, 597–605.

3 M. Kobayashi, Y. Terayama, H. Yamaguchi, M. Terada, D. Murakami, K. Ishihara and A. Takahara, *Langmuir*, 2012, **28**, 7212–7222.

4 W. Yan, M. Fantin, S. Ramakrishna, N. D. Spencer, K. Matyjaszewski and E. M. Benetti, *ACS Appl. Mater. Interfaces*, 2019, **11**, 27470–27477.