

Supporting Information

**Synthesis and characterization of innovative well-defined difluorophosphonylated-(co)polymers by RAFT polymerization**

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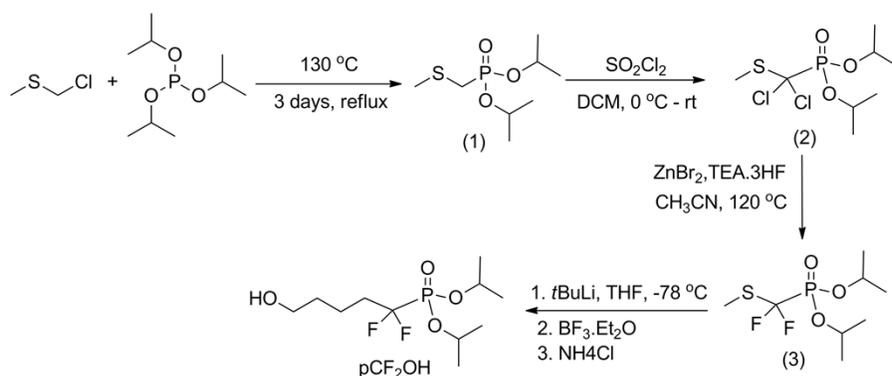
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**1. Synthesis of diisopropyl (1,1-difluoro-5-hydroxypentyl)phosphonate (pCF<sub>2</sub>OH)<sup>1</sup>**



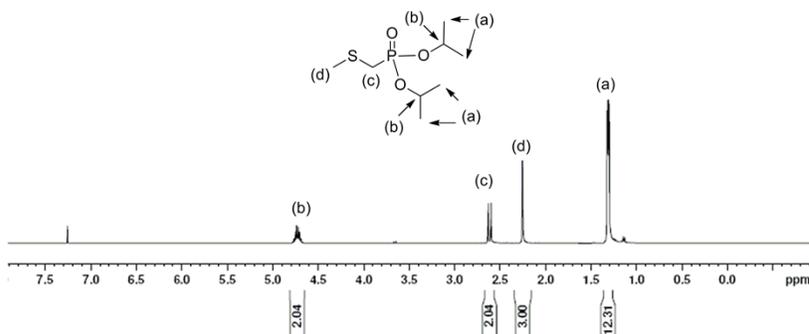
**Scheme S1:** Synthesis of diisopropyl (1,1-difluoro-5-hydroxypentyl)phosphonate (pCF<sub>2</sub>OH).

**1.1. Synthesis of diisopropyl [(methylthio)methyl] phosphonate (1)**

Chloromethyl methyl sulfide (25.0 g, 0.26 mol) and triisopropyl phosphite (95.80 mL, 0.39 mol) were added to a three-neck round bottom flask. The solution was then

<sup>1</sup> A. Henry-dit-Quesnel, L. Toupet, J.-C. Pommelet and T. Lequeux, *Org. Biomol. Chem.*, 2003, **1**, 2486-2491.

refluxed and stirred for 3 days at 130 °C. After distillation under vacuum, the final product was obtained as a colorless oil (bp  $_{9\text{mm Hg}} = 70\text{ °C}$ ) (m = 42.01 g). Yield: 72%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 1.31 [dd,  $J = 6.2, J = 3.0$ ,  $-\text{CH}(\text{CH}_3)_2$ ], 2.25 (s,  $\text{CH}_3\text{S}-$ ), 2.62 (d,  $J = 12.7$  Hz,  $\text{CH}_3-\text{S}-\text{CH}_2-$ ), 4.69-4.77 [m,  $-\text{CH}(\text{CH}_3)_2$ ],  $^{31}\text{P NMR}$  (162 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 22.61.

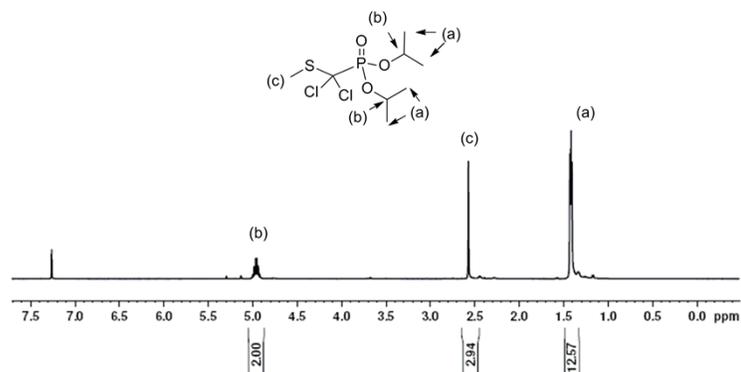


**Figure S1:**  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ ) spectrum of (1).

### 1.2. Synthesis of diisopropyl [dichloro(methylthio)methyl]phosphonate (2)

Under argon atmosphere, diisopropyl [methylthio)methyl]phosphonate (1) (40.00 g, 0.177 mol) and anhydrous dichloromethane (DCM, 150.0 mL) were added in a round bottom flask. The resulting solution was then stirred and cooled at  $-10\text{ °C}$  for 10 min. Sulfuryl chloride ( $\text{SO}_2\text{Cl}_2$ , 29.0 mL, 0.354 mol) was subsequently added dropwise under stirring and the temperature was maintained at  $0\text{ °C}$ . After completed addition of sulfuryl chloride, the reaction mixture was allowed to react at  $0\text{ °C}$  for 30 min and then at room temperature during 90 min. The solvent was then eliminated under vacuum. The product was obtained as a pale yellow oil with without further purification.

$^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 1.40 [(dd,  $-\text{OCH}(\text{CH}_3)_2$ ], 2.57 (s,  $\text{CH}_3\text{S}-$ ), 4.92 [sept,  $-\text{OCH}(\text{CH}_3)_2$ ].  $^{31}\text{P NMR}$  (162 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 6.68.

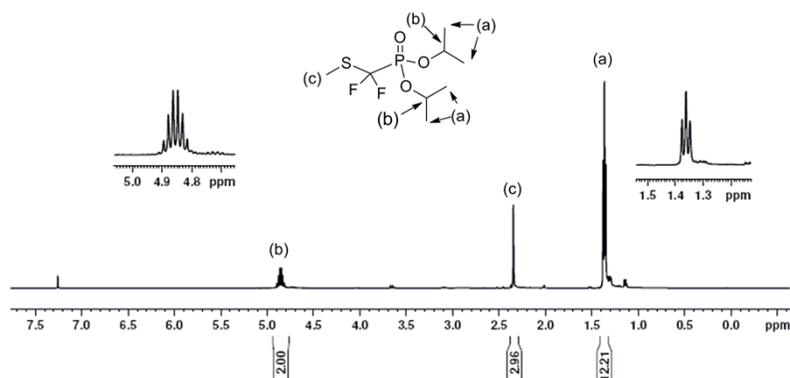


**Figure S2:**  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) spectrum of (2).

### 1.3. Synthesis of diisopropyl [difluoro(methylthio)methyl]phosphonate (3)

Zinc (5.80 g,  $88.6 \times 10^{-3}$  mol) and anhydrous acetonitrile ( $\text{CH}_3\text{CN}$ , 200.0 mL) were added in a three-necked round bottom flask, equipped a reflux condenser. The solution was then stirred and refluxed at 120 °C under argon. 1,2-dibromoethane (15.25 mL, 0.177 mol) was subsequently added dropwise. The mixture became cloudy with a vigorous gas evolution. The solution was refluxed until all of the zinc was consumed and gas evolution ceased, about 120 min. The flask was then cooled to room temperature. Diisopropyl [dichloro(methylthio)methyl]phosphonate (52.24 g, 0.177 mol) was added to the reaction mixture. After 10 min, triethylamine trihydrofluoride ( $\text{TEA} \cdot 3\text{HF}$ , 101 mL, 0.620 mol) was added dropwise. The flask was placed in a thermostated oil bath and heated up to 120 °C for 2 h then cooled to room temperature. A saturated solution of  $\text{NH}_4\text{Cl}$  (10 mL) was added. The mixture was extracted with diethyl ether/dichloromethane: 50/50 and the combined organic layers were washed with a saturated solution of  $\text{NaHCO}_3$ , then with a saturated solution of  $\text{NaCl}$ , dried over  $\text{MgSO}_4$ , filtered and evaporated under reduced pressure. The purification by distillation under vacuum (bp 7.5 mmHg = 58-68 °C) provides the pure product as a colorless oil (25.01 g). Yield: 54%.

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 1.36 [dd,  $J = 6.0$  Hz,  $-\text{OCH}(\text{CH}_3)_2$ ], 2.34 (s,  $-\text{SCH}_3$ ), 4.82-4.89 [m,  $-\text{OCH}(\text{CH}_3)_2$ ].  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 1.76 ( $J = 103.2$  Hz).  $^{19}\text{F}$  NMR (376 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): -89.44 ( $J = 103.2$  Hz).

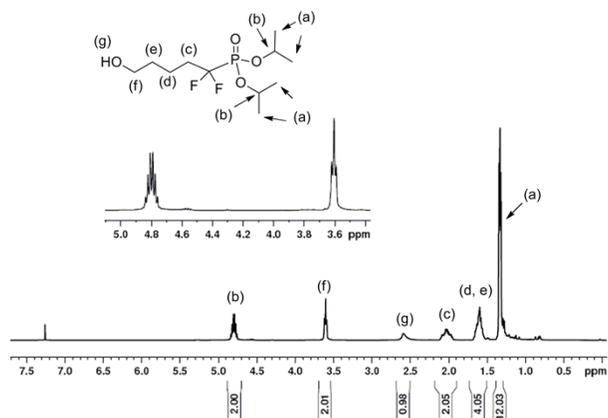


**Figure S3:**  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) spectrum of (3).

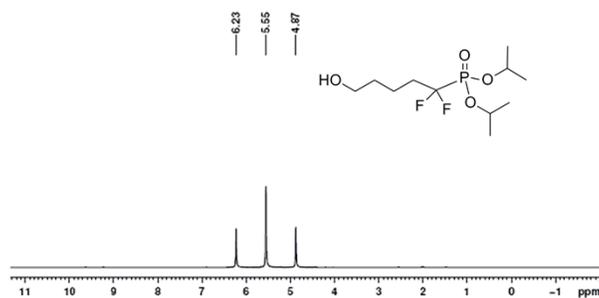
#### 1.4. Synthesis of diisopropyl (1,1-difluoro-5-hydroxypentyl)phosphonate ( $\text{pCF}_2\text{OH}$ )

Under an inert argon atmosphere, anhydrous THF (10.0 mL) was introduced to a round bottom flask and cooled to  $-78\text{ }^\circ\text{C}$ . A solution of *t*-butyllithium 1.1 M in pentane (*t*BuLi, 4.2 mL,  $4.62 \times 10^{-3}$  mol) was added dropwise. The mixture was stirred for 20 min at  $-78\text{ }^\circ\text{C}$ . diisopropyl difluoro(methylthio)methylphosphonate ((3), 1.00 g,  $3.82 \times 10^{-3}$  mol) was added dropwise. After 20 min, trifluoroborate etherate ( $\text{BF}_3 \cdot 2\text{xEt}_2\text{O}$ , 1.00 mL,  $4.95 \times 10^{-3}$  mol) was added and the mixture was stirred at  $-78\text{ }^\circ\text{C}$  for 40 min. The reaction mixture was quenched with an aqueous saturated solution of  $\text{NH}_4\text{Cl}$  (5.0 mL) then warmed up to room temperature. The mixture was then extracted twice with  $\text{Et}_2\text{O}/\text{CH}_2\text{Cl}_2$  (50/50: v/v) and the combined organic layers were washed twice with saturated solution of NaCl, dried over  $\text{MgSO}_4$ . After elimination of the solvent under reduced pressure, the crude product was purified by column chromatography with a mixture of ethyl acetate/pentane (80/20: v/v) to give the final product (OH- $\text{pCF}_2$ , 0.56 g) as colorless oil. Yield = 51%.

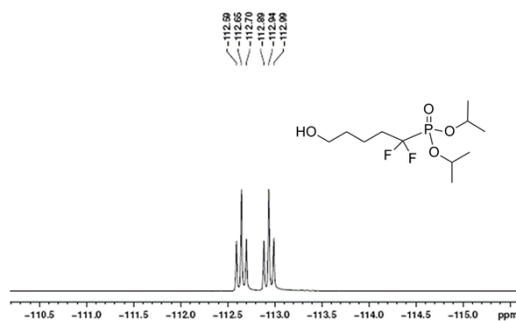
$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 1.33 [dd,  $J = 6.2\text{ Hz}$ ,  $J = 4.0\text{ Hz}$ ,  $-\text{OCH}(\text{CH}_3)_2$ ], 1.55-1.65 [m,  $-\text{CF}_2\text{CH}_2(\text{CH}_2)_2-$ ], 1.95-2.10 (m,  $-\text{CF}_2-\text{CH}_2-$ ), 3.60 (t,  $J = 6.1\text{ Hz}$ ,  $-\text{CH}_2\text{OH}$ ), 4.76-4.84 [m,  $-\text{OCH}(\text{CH}_3)_2$ ].  $^{13}\text{C}$  NMR (100.62 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 17.10-17.20 ( $-\text{CH}_2\text{CH}_2\text{CF}_2-$ ), 23.60-24.00 [ $-\text{OCH}(\text{CH}_3)_2$ ], 32.20 ( $-\text{CH}_2\text{CH}_2\text{OH}$ ), 33.30-33.80 ( $-\text{CH}_2-\text{CF}_2-$ ), 61.90 ( $-\text{CH}_2\text{OH}$ ), 73.50-73.60 [ $-\text{OCH}(\text{CH}_3)_2$ ], 116.80-124.10 ( $-\text{CF}_2-$ ).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): 5.55 ( $J = 109.4\text{ Hz}$ ).  $^{19}\text{F}$  NMR (376 MHz,  $\text{CDCl}_3$ ,  $\delta$  ppm): -112.79 ( $J = 109.4\text{ Hz}$ ,  $J = 19.8\text{ Hz}$ ).



**Figure S4:**  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) spectrum of  $\text{pCF}_2\text{OH}$ .

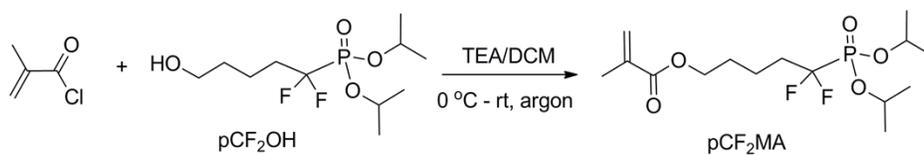


**Figure S5:**  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ ) spectrum of  $\text{pCF}_2\text{OH}$ .

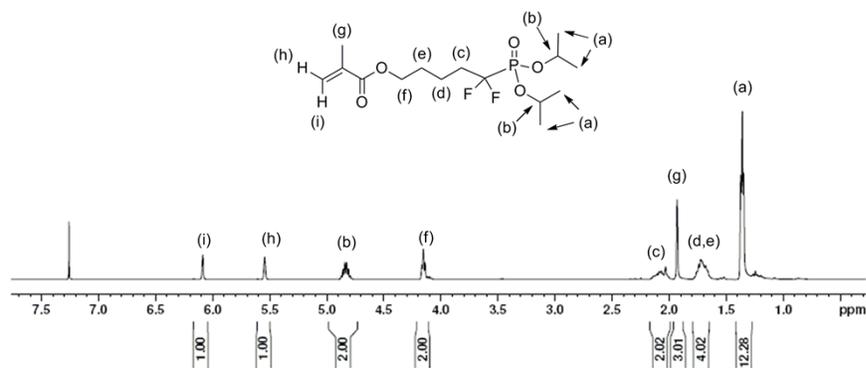


**Figure S6:**  $^{19}\text{F}$  NMR (376 MHz,  $\text{CDCl}_3$ ) spectrum of  $\text{pCF}_2\text{OH}$ .

## 2. Diisopropyl (1,1-difluoro-5-methacryloyloxypropyl)phosphonate ( $\text{pCF}_2\text{MA}$ )

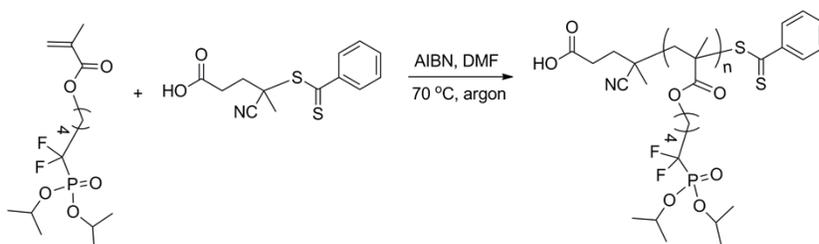


**Scheme S2:** Synthesis of diisopropyl (1,1-difluoro-5-methacryloyloxypropyl)phosphonate ( $\text{pCF}_2\text{MA}$  monomer).



**Figure S7:**  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) spectrum of  $\text{pCF}_2\text{MA}$  monomer.

### 3. Kinetic polymerization of $\text{pCF}_2\text{MA}$ using CTP agent ( $\text{DP}_{n,\text{th}} = 40$ )

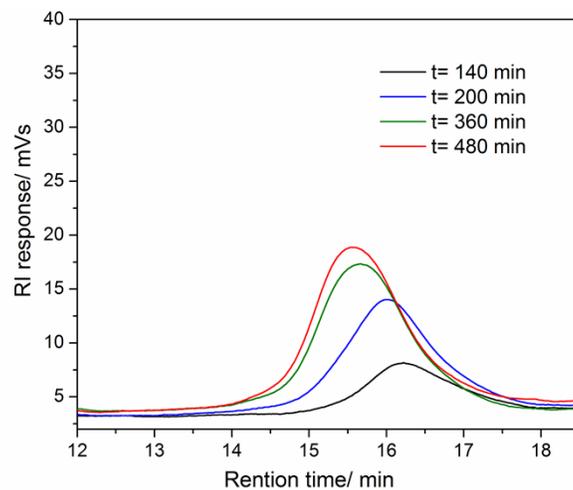


**Scheme S3:** RAFT polymerization of difluorophosphonate monomer using CTP with  $[\text{pCF}_2\text{MA}]_0 : [\text{CTP}]_0 : [\text{AIBN}]_0 = 40 : 1 : 0.18$  in DMF at  $70\text{ }^\circ\text{C}$ .

**Table S1:** RAFT polymerization of  $\text{pCF}_2\text{MA}$  use CTP agent as chain transfer agent in DMF at  $70\text{ }^\circ\text{C}$  with  $[\text{pCF}_2\text{MA}]_0 : [\text{CTP}]_0 : [\text{AIBN}]_0 = 40 : 1 : 0.18$

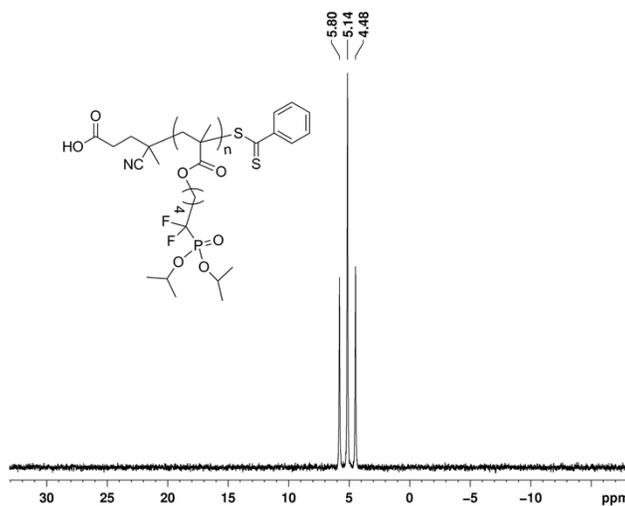
Time (min)	Conv. <sup>a</sup> (%)	$M_{n,\text{th}}^b$ ( $\text{g}\cdot\text{mol}^{-1}$ )	$M_{n,\text{SEC}}^c$ ( $\text{g}\cdot\text{mol}^{-1}$ )	$D_M^c$
0	0	279	-	-
60	11	1845	-	-
100	15	2415	3600	1.08
140	19	2985	3890	1.10
200	27	4124	4430	1.13
280	35	5263	5030	1.18
480	47	6972	6140	1.14

<sup>a</sup>  $\text{pCF}_2\text{MA}$  conversion rate determined by  $^1\text{H}$  NMR spectroscopy by comparing the integration area value of the signal at 5.49 ppm and 6.03 ppm.  $[\text{CH}_2=\text{C}(\text{CH}_3)-]$  and of the signal at 4.86 ppm  $[-\text{OCH}(\text{CH}_3)_2]$ . <sup>b</sup>  $M_{n,\text{th}} = [([\text{pCF}_2\text{MA}]_0/[\text{CTP}]_0) \times \text{conv.}/100] \times 356 + 279$ . <sup>c</sup> Determined by SEC in DMF using poly(methyl methacrylate) standards.

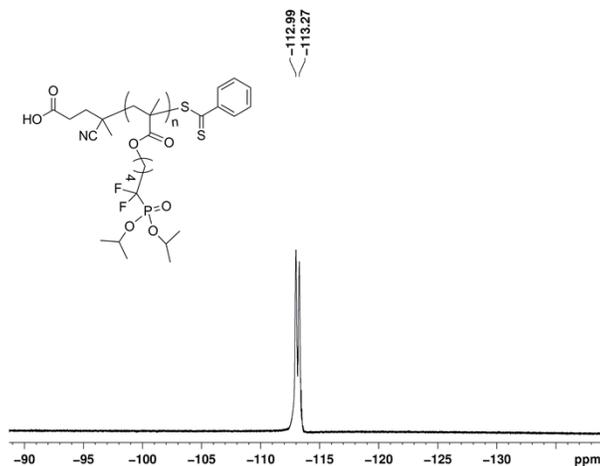


**Figure S8:** Evolutions SEC traces of poly(pCF<sub>2</sub>MA) with time for RAFT polymerization of pCF<sub>2</sub>MA with [pCF<sub>2</sub>MA]<sub>0</sub>:[CTP]<sub>0</sub>:[AIBN]<sub>0</sub>= 40: 1: 0.18 in DMF at 70 °C.

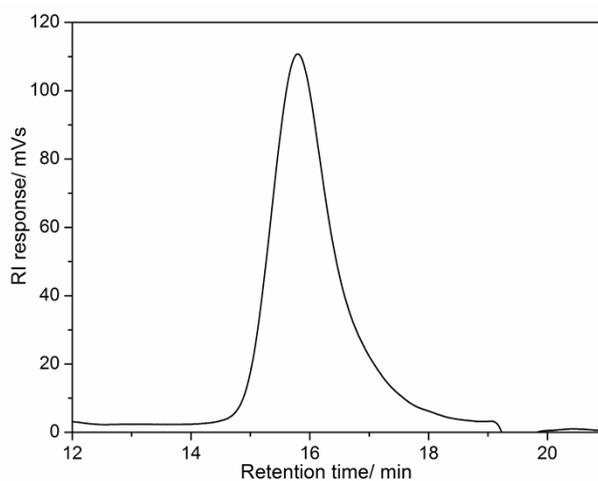
#### 4. Polymerization of pCF<sub>2</sub>MA using CTP agent (DP<sub>n,th</sub> = 31)



**Figure S9:** <sup>31</sup>P NMR (162 MHz, acetone D<sub>6</sub>) spectrum of poly(pCF<sub>2</sub>MA)<sub>16</sub>.

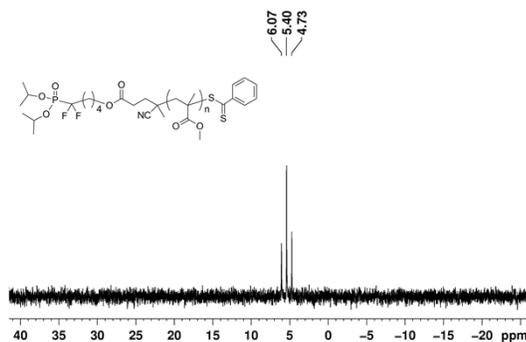


**Figure S10:**  $^{19}\text{F}$  NMR (376 MHz, acetone  $\text{D}_6$ ) spectrum of poly( $\text{pCF}_2\text{MA}$ ) $_{16}$ .

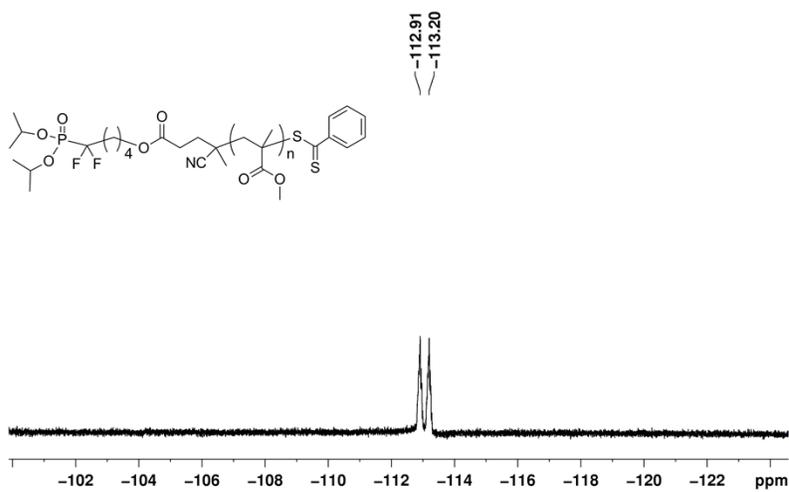


**Figure S11:** SEC trace of poly( $\text{pCF}_2\text{MA}$ ) $_{16}$  for RAFT polymerization of  $\text{pCF}_2\text{MA}$  with  $[\text{pCF}_2\text{MA}]_0:[\text{CTP}]_0:[\text{AIBN}]_0 = 31:1:0.18$ .

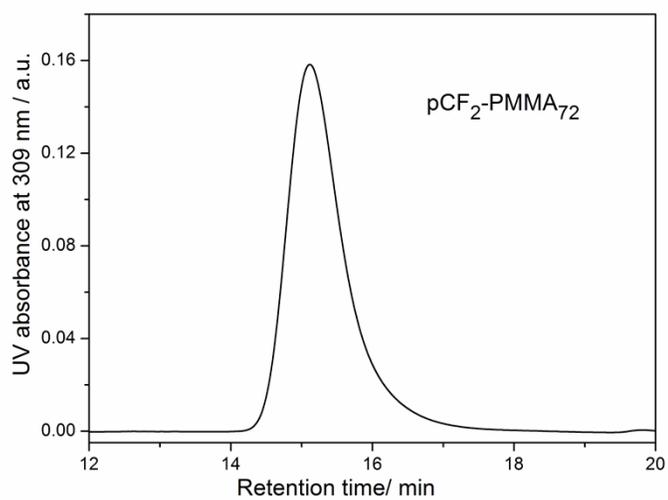
## 5. RAFT polymerization of methyl methacrylate using $\text{pCF}_2\text{-CTA}$



**Figure S12:**  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ ) spectrum of  $\text{pCF}_2\text{-PMMA}_{72}$ .



**Figure S13:** <sup>19</sup>F NMR (376 MHz, CDCl<sub>3</sub>) spectrum of pCF<sub>2</sub>-PMMA<sub>72</sub>.



**Figure S14:** UV trace of pCF<sub>2</sub>-PMMA<sub>72</sub> extracted at 309 nm.