Novel organotin(IV) Complexes derived from 4-fluorophenyl-selenoacetic acid: synthesis, characterization and *in vitro* cytostatic activity evaluation†

Ya-Ru Qiu,[a] Ru-Fen Zhang*[a], Shao-Liang Zhang,[a] Shuang Cheng,*[b] Qian-Li Li,[a] Chun-Lin Ma*[a]

[a]*School of Chemistry and Chemical Engineering, Liaocheng University, Liaocheng, 252059, China.*

Email: zhangrf856@163.com, macl856@163.com, chengshuang@lcu.edu.cn

[b]*School of Agriculture, Liaocheng University, Liaocheng, 252059, China.*

Supporting Information

Table of contents

1. Experimental section

Synthesis of complex 5-8

Synthesis of complex 5. The reaction was carried out under nitrogen atmosphere using standard Schlenk techniques. Complex **5** was synthesized by dissolving 4-fluorophenylthioacetic acid (0.186 g, 1.0 mmol), sodium ethoxide (0.068 g, 1.0 mmol) in dry benzene (30 ml) and stirring for 30 min, followed by the addition of trimethyltin chloride (0.199 g, 1.0 mmol) and stirred for 12 h at 45 ℃. The reaction mixture was filtered and the solvent was gradually evaporated by vacuum distillation until a white solid product was obtained. The resulting product was then recrystallized from petroleum ether, and transparent colourless crystals were formed. Yield: 90%. M.P.: 90-93 ℃. Anal. Calc. for $C_{11}H_{15}FO_2SSn$: C 37.86, H 4.33%; Found: C 38.08, H 4.50%. IR (KBr, cm^{-1}): ν_{as}(COO), 1578; ν_s(COO), 1409; [$\Delta\nu=\nu_{as}$(COO)-ν_s(COO), 169]; ν(O-Sn-O), 632; ν(Sn-C), 518; ν(Sn-O), 499. ^{1}H NMR ($CDCl_3$, ppm): δ 7.38-7.42, 6.96-7.00 (m, 4H, Ar-H), 3.61 (s, 2H, -SCH_2), 0.53 (t, $^2J_{Sn-H}$= 56Hz, 9H, -3CH_3). ^{13}C NMR ($CDCl_3$, ppm): δ 174.2 (*C*OO), 163.2, 160.8, 132.5, 115.9, (Ar-*C*), 38.2 (*C*H_2-COO), -2.4 (*C*H_3). ^{119}Sn NMR ($CDCl_3$, ppm): δ 149.7.

Synthesis of complex 6. Complex **6** was synthesized by following the method given for complex **5**, using 4-fluorophenylthioacetic acid (0.372 g, 2.0 mmol), methanol (30 ml), sodium ethoxide (0.136 g, 2.0 mmol), dimethyltin chloride (0.220g, 1.0 mmol) as the starting source. The white solid was recrystallized from petroleum ether and transparent colourless crystals were formed. Yield: 80%. M.P.: 158-161 ℃. Anal. Calc. for $C_{40}H_{48}F_4O_{10}S_4Sn_4$: C 35.12, H 3.54%; Found: C 35.31, H 3.29%. IR (KBr, cm^{-1}): ν_{as}(COO), 1633, 1580; ν_s(COO), 1496, 1329; [$\Delta\nu=\nu_{as}$(COO)-ν_s(COO), 137, 251]; ν(O-Sn-O), 628; ν(Sn-C), 568; ν(Sn-O), 486. ^{1}H NMR ($CDCl_3$, ppm): δ 7.31-7.35, 6.96-7.00 (m, 16H, 4Ar-H), 3.50 (s, 8H, -4SCH_2), 0.73 (t, 24H, -8CH_3). ^{13}C NMR ($CDCl_3$, ppm): δ 174.9 (*C*OO), 163.1, 160.6, 131.1, 116.1 (Ar-*C*), 38.9 (*C*H_2-COO), 6.5(*C*H_3). ^{119}Sn NMR ($CDCl_3$, ppm): δ -172.3, -187.7.

Synthesis of complex 7. Unlike other complexes, complex **7** was prepared through a condensation reaction. A mixture of tri-*n*-butyltin oxide (0.596 g, 1.0 mmol) and 4-fluorophenylthioacetic acid (0.372 g, 2.0 mmol) in dry benzene (30 mL) was refluxing for 10 h at

80 ℃. The solvent was slowly removed in vacuo to afford oily solid. The solid was recrystallized from the mixed solvent ($V_{diethyl\ ether}/V_{petroleum\ ether}$ = 3:1) and transparent colourless needle-shaped crystals were formed. Yield: 78%. M.P.: 61-64 ℃. Anal. Calc. for $C_{40}H_{66}F_2O_4S_2Sn_2$: C 50.55, H 7.00%; Found: C 50.75, H 6.76%. IR (KBr, cm^{-1}): ν_{as}(COO), 1576; ν_s(COO), 1412; [$\Delta\nu=\nu_{as}$(COO)-ν_s(COO), 164]; ν(O-Sn-O), 632; ν(Sn-C), 570; ν(Sn-O), 510. ^{1}H NMR ($CDCl_3$, ppm): δ 7.37-7.40, 6.94-6.98 (m, 4H, Ar-H), 3.61 (s, 2H, -SCH_2), 1.22-1.56 (m, 18H, $3CH_2CH_2CH_2$), 0.90 (t, $^2J_{Sn-H}$ = 16Hz, 9H, -$3CH_3$). ^{13}C NMR ($CDCl_3$, ppm): δ 174.2 (*C*OO), 163.1, 160.6, 132.1, 115.9 (Ar-*C*), 29.7 (*C*H_2-COO), 27.7, 27.0, 16.6, 13.6 (*n*-Bu). ^{119}Sn NMR ($CDCl_3$, ppm): δ 126.2.

Synthesis of complex 8. Complex **8** was synthesized by following the method given for complex **1**, using 4-fluorophenylthioacetic acid (0.372 g, 2.0 mmol), dry benzene (30 ml), sodium ethoxide (0.136 g, 2.0 mmol), di-*n*-butyltin chloride (0.304 g, 1.0 mmol) as the starting source. The white solid was recrystallized from petroleum ether and transparent colourless crystals were formed. Yield: 85%. M.P.: 84-87 ℃. Anal. Calc. for $C_{24}H_{30}F_2O_4S_2Sn$: C 47.78, H 5.01%; Found: C 48.02, H 4.72%. IR (KBr, cm^{-1}): ν_{as}(COO), 1593; ν_s(COO), 1462; [$\Delta\nu=\nu_{as}$(COO)-ν_s(COO), 131]; ν(O-Sn-O), 684; ν(Sn-C), 632; ν(Sn-O), 512. ^{1}H NMR ($CDCl_3$, ppm): δ 7.39-7.43, 6.97-7.00 (m, 8H, 2Ar-H), 3.65 (4H, -$2SCH_2$), 1.24-1.54 (m, 12H, $2CH_2CH_2CH_2$), 0.84 (t, $^2J_{Sn-H}$ = 8Hz, 6H, $2CH_3$). ^{13}C NMR ($CDCl_3$, ppm): δ 179.4 (*C*OO), 163.4, 160.9, 131.3, 116.1 (Ar-*C*), 37.2 (*C*H_2-COO), 26.4, 26.3, 25.5, 13.5 (*n*-Bu). ^{119}Sn NMR ($CDCl_3$, ppm): δ -133.9.

2. X-ray crystallography

Table S1 Selected bond lengths [Å] and angles [°] for complex **1**.

Complex **1**			
Sn(1)-C(9)	2.111(8)	C(8)-O(1)	1.276(10)
Sn(1)-C(10)	2.159(9)	C(8)-O(2)	1.224(9)
Sn(1)-C(11)	2.104(10)	C(19)-O(3)	1.329(11)
Sn(2)-C(20)	2.102(11)	C(19)-O(4)	1.213(9)
Sn(2)-C(21)	2.138(9)	C(9)-Sn(1)-C(10)	126.4(3)
Sn(2)-C(22)	2.127(10)	C(11)-Sn(1)-C(9)	116.4(4)
Sn(1)-O(2)	2.451(6)	C(11)-Sn(1)-C(10)	115.5(4)
Sn(1)-O(1)#1	2.185(6)	O(1)#1-Sn(1)-O(2)	175.5(2)
O(1)-Sn(1)#3	2.185(6)	C(20)-Sn(2)-C(21)	124.6(4)
Sn(2)-O(3)#2	2.176(6)	C(20)-Sn(2)-C(22)	111.5(5)
Sn(2)-O(4)	2.432(5)	C(21)-Sn(2)-C(22)	121.6(5)
O(3)-Sn(2)#4	2.176(6)		

Symmetry code for complex **1**: #1 x+1/2,-y+3/2,-z+2; #2 x-1/2,-y+3/2,-z+1; #3 x-1/2,-y+3/2,-z+2; #4 x+1/2,-y+3/2,-z+1.

Table S2 Selected bond lengths [Å] and angles [°] for complex **2**.

Complex **2**			
Sn(1)-C(9)	2.076(9)	C(9)-Sn(1)-C(10)	152.4(4)
Sn(1)-C(10)	2.101(9)	O(2)-Sn(1)-O(4)	171.6(2)
Sn(1)-O(1)	2.831	O(3)-Sn(1)-C(9)	103.9(3)
Sn(1)-O(2)	2.236(6)	O(3)-Sn(1)-C(10)	103.3(3)
Sn(1)-O(3)	2.049(5)	C(11)-Sn(2)-C(12)	141.0(5)
Sn(1)-O(4)	2.259(7)	O(3)-Sn(2)-O(5)	91.2(2)
Sn(2)-C(11)	2.094(10)	O(3)-Sn(2)-C(11)	107.5(4)

Sn(2)-C(12)	2.100(9)	O(3)-Sn(2)-C(12)	109.8(3)
Sn(2)-O(5)	2.323(7)	O(3)#1-Sn(2)-O(5)	168.0(2)
Sn(2)-O(3)	2.025(5)	O(3)-Sn(2)-O(3)#1	77.0(2)
Sn(2)-O(3)#1	2.142(5)	Sn(2)-O(3)-Sn(2)#1	103.0(2)
O(3)-Sn(2)#1	2.142(5)		

Symmetry code for complex **2**: #1 -x+1/2, -y+3/2, -z.

Table S3 Selected bond lengths [Å] and angles [°] for complex **3**.

Complex **3**			
Sn(1)-C(28)	2.147(5)	C(36)-Sn(1)-O(1)#1	89.8(2)
Sn(1)-C(32)	2.147(6)	C(28)-Sn(1)-O(3)	86.75(18)
Sn(1)-C(36)	2.153(6)	C(32)-Sn(1)-O(3)	87.35(19)
Sn(1)-O(1)#1	2.201(4)	C(36)-Sn(1)-O(3)	85.5(2)
Sn(2)-C(16)	2.138(7)	O(1)#1-Sn(1)-O(3)	175.33(13)
Sn(2)-C(20)	2.146(6)	C(20)-Sn(2)-C(16)	121.0(3)
Sn(2)-C(24)	2.139(5)	C(20)-Sn(2)-C(24)	122.3(3)
Sn(2)-O(4)	2.219(4)	C(16)-Sn(2)-C(24)	115.3(2)
Sn(2)-O(2)	2.466(4)	C(20)-Sn(2)-O(4)	98.0(2)
C(28)-Sn(1)-C(36)	119.3(2)	C(16)-Sn(2)-O(4)	88.6(2)
C(32)-Sn(1)-C(28)	124.3(3)	C(24)-Sn(2)-O(4)	94.84(18)
C(32)-Sn(1)-C(36)	115.3(2)	C(20)-Sn(2)-O(2)	84.5(2)
C(28)-Sn(1)-O(1)#1	95.92(19)	C(16)-Sn(2)-O(2)	84.3(2)
C(32)-Sn(1)-O(1)#1	94.26(19)	C(24)-Sn(2)-O(2)	89.52(18)

Symmetry code for complex **3**: #1 x+1, y, z; #2 x-1, y, z.

Table S4 Selected bond lengths [Å] and angles [°] for complex **4**.

Complex **4**			
Sn(1)-C(9)	2.102(19)	C(9)#1-Sn(1)-C(9)	122.0(10)
Sn(1)-C(9)#1	2.102(19)	O(1)-Sn(1)-O(2)	53.6(2)

Sn(1)-O(1)	2.112(6)	O(1)#1-Sn(1)-O(2)	133.2(2)
Sn(1)-O(1)#1	2.112(6)	O(1)-Sn(1)-O(1)#1	79.6(4)
Sn(1)-O(2)	2.610(7)	O(2)-Sn(1)-O(2)#1	173.11
O(1)-C(1)	1.274(10)	O(2)#1-Sn(1)-O(2)#1	51.43
O(2)-C(1)	1.233(10)		

Symmetry code for complex **4**: #1 -x+1, y, -z+3/2.

Table S5 Crystallographic data and structure refinement parameters for complexes **5-8**.

Complex	**5**	**6**	**7**	**8**
Empirical formula	$C_{11}H_{15}FO_2SSn$	$C_{40}H_{48}F_4O_{10}S_4Sn_4$	$C_{40}H_{66}F_2O_4S_2Sn_2$	$C_{24}H_{30}F_2O_4S_2Sn$
Formula weight	348.98	1367.78	950.43	603.29
Wavelength [Å]	0.71073	0.71073	0.71073	0.71073
Crystal system	Monoclinic	Monoclinic	Triclinic	Monoclinic
Space group	P2(1)/c	P2(1)/n	P-1	C2
a [Å]	11.0008(11)	11.6817(9)	10.5943(9)	18.6301(16)
b [Å]	10.2461(9)	11.9698(10)	14.4760(13)	5.1010(5)
c [Å]	13.0833(12)	17.8333(15)	16.9105(14)	16.2579(14)
α [ ]	90	90	87.2930(10)	90
β [ ]	107.192(2)	94.4010(10)	90.023(2)	119.173(3)
γ [ ]	90	90	68.535(11)	90
V [Å^3]	1408.8(2)	2486.2(4)	2410.4(4)	1349.0(2)
Z	4	2	2	2
Dcalc (Mg/m^3)	1.645	1.827	1.309	1.485
μ(mm^{-1})	1.958	2.219	1.163	1.142
F(000)	688	1336	976	612
Crystal size(mm)	0.46x0.38x0.22	0.31x0.18x0.10	0.37x0.11x0.10	0.42x0.16x0.15
Reflections collected	6851	12195	11635	3404
Unique reflections	2475	4368	8277	2198
Goodness-of-fit on F^2	1.076	0.962	1.154	1.101

Final R indices [I>2σ(I)]	R_1 = 0.0381,	R_1 = 0.0437,	R_1 = 0.1231,	R_1 = 0.0677,
	wR_2 = 0.0791	wR_2 = 0.0779	wR_2 = 0.3111	wR_2 = 0.1772
R indices (all data)	R_1 = 0.0675,	R_1 = 0.0874,	R_1 = 0.2379,	R_1 = 0.0702,
	wR_2 = 0.0942	wR_2 = 0.0930	wR_2 = 0.3430	wR_2 = 0.1810

[a]$R_1 = \sum||Fo| - |Fc||/\sum|Fo|$; [b]$wR_2 = \{\sum[w (F_o^2 - F_c^2)^2]/ \sum[w (F_o^2)^2]\}^{1/2}$

Table S6 Selected bond lengths [Å] and angles [°] for complex **5**.

Complex **5**			
Sn(1)-C(9)	2.124(7)	C(11)-Sn(1)-C(9)	117.6(3)
Sn(1)-C(10)	2.117(6)	C(11)-Sn(1)-C(10)	123.0(3)
Sn(1)-C(11)	2.106(6)	O(2)#1-Sn(1)-O(1)	173.80(15)
Sn(1)-O(1)	2.389(5)	C(11)-Sn(1)-O(2)#1	93.8(2)
Sn(1)-O(2)#1	2.191(4)	C(10)-Sn(1)-O(2)#1	95.6(2)
O(2)-Sn(1)#2	2.191(4)	C(9)-Sn(1)-O(2)#1	88.7(2)
O(1)-C(8)	1.231(7)	C(11)-Sn(1)-O(1)	88.8(2)
O(2)-C(8)	1.278(7)	C(10)-Sn(1)-O(1)	87.8(2)
C(10)-Sn(1)-C(9)	118.7(3)	C(9)-Sn(1)-O(1)	85.1(2)

Symmetry code for complex **5**: #1 -x+2, y-1/2, -z+1/2; #2 -x+2, y+1/2, -z+1/2.

Table S7 Selected bond lengths [Å] and angles [°] for complex **6**.

Complex **6**			
Sn(1)-C(11)	2.092(6)	O(5)-C(13)	1.241(7)
Sn(1)-C(12)	2.103(7)	O(3)#1-Sn(1)-C(11)	107.2(2)
Sn(1)-O(3)	2.163(4)	O(3)#1-Sn(1)-C(12)	103.5(2)
Sn(1)-O(3)#1	2.057(4)	C(11)-Sn(1)-C(12)	148.0(3)
Sn(1)-O(4)	2.302(4)	O(3)#1-Sn(1)-O(3)	76.09(16)
O(3)-Sn(1)#1	2.057(4)	C(11)-Sn(1)-O(3)	96.5(2)
Sn(2)-C(9)	2.097(7)	C(12)-Sn(1)-O(3)	99.4(2)
Sn(2)-C(10)	2.103(7)	O(3)#1-Sn(1)-O(4)	88.87(15)
Sn(2)-O(2)	2.175(4)	C(11)-Sn(1)-O(4)	82.6(2)

Sn(2)-O(3)	2.001(4)	C(12)-Sn(1)-O(4)	89.3(2)
Sn(2)-O(5)#1	2.251(5)	O(3)-Sn(1)-O(4)	163.99(16)
O(5)-Sn(2)#1	2.251(5)	C(9)-Sn(2)-C(10)	135.4(3)
O(1)-C(8)	1.202(8)	O(3)-Sn(2)-O(2)	78.50(16)
O(2)-C(8)	1.281(8)	O(3)-Sn(2)-C(9)	112.2(3)
O(4)-C(13)	1.266(7)	O(3)-Sn(2)-C(10)	112.2(2)

Symmetry code for complex **6**: #1 -x, -y, -z.

Table S8 Selected bond lengths [Å] and angles [°] for complex **7**.

Complex **7**			
Sn(1)-C(1)	2.06(3)	C(1)-Sn(1)-O(1)	97.2(8)
Sn(1)-C(9)	2.12(3)	C(9)-Sn(1)-O(1)	96.6(8)
Sn(1)-C(5)	2.16(2)	C(5)-Sn(1)-O(1)	85.5(9)
Sn(1)-O(1)	2.182(16)	C(1)-Sn(1)-O(4)#1	86.4(8)
Sn(1)-O(4)#1	2.513(17)	C(9)-Sn(1)-O(4)#1	85.9(8)
O(4)-Sn(1)#2	2.513(17)	C(5)-Sn(1)-O(4)#1	87.0(8)
Sn(2)-C(21)	2.09(3)	O(1)-Sn(1)-O(4)#1	172.5(6)
Sn(2)-C(17)	2.12(2)	C(21)-Sn(2)-C(17)	123.4(10)
Sn(2)-C(13)	2.18(2)	C(21)-Sn(2)-C(13)	120.5(10)
Sn(2)-O(3)	2.190(17)	C(17)-Sn(2)-C(13)	114.1(10)
Sn(2)-O(2)	2.492(18)	C(21)-Sn(2)-O(3)	98.3(8)
O(1)-C(25)	1.30(3)	C(17)-Sn(2)-O(3)	95.8(8)
O(2)-C(25)	1.18(3)	C(13)-Sn(2)-O(3)	89.7(8)
O(3)-C(33)	1.28(3)	C(21)-Sn(2)-O(2)	84.1(8)
O(4)-C(33)	1.16(3)	C(17)-Sn(2)-O(2)	87.5(7)
C(1)-Sn(1)-C(9)	122.1(10)	C(13)-Sn(2)-O(2)	84.3(8)
C(1)-Sn(1)-C(5)	121.0(11)	O(3)-Sn(2)-O(2)	173.9(6)
C(9)-Sn(1)-C(5)	115.7(11)		

Symmetry code for complex **7**: #1 x+1, y, z; #2 x-1, y, z.

Table S9 Selected bond lengths [Å] and angles [°] for complex **8**.

Complex **8**			
Sn(1)-C(9)	2.093(6)	O(2)-C(8)	2.296(5)
Sn(1)-C(9)#1	2.093(6)	C(9)#1-Sn(1)-O(2)	75.2(2)
Sn(1)-O(2)	2.130(4)	C(9)-Sn(1)-O(1)	90.7(2)
Sn(1)-O(2)#1	2.130(4)	C(9)#1-Sn(1)-C(9)	137.1(4)
Sn(1)-O(1)	2.557(3)	O(2)#1-Sn(1)-O(2)	79.48(18)
Sn(1)-O(1)#1	2.557(3)	O(1)#1-Sn(1)-O(1)	172.30(19)
O(1)-C(8)	1.185(7)	O(1)-Sn(1)-O(2)	54.1(3)

Symmetry code for complex **8**: #1 -x+2, y, -z+2.

3. Figures of crystal structure

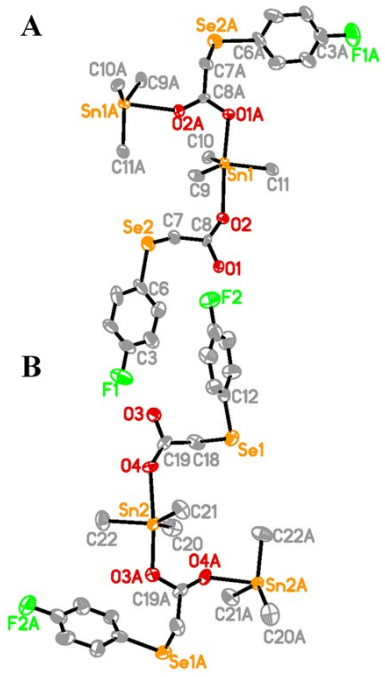

Figure S1 The Ortep picture of **1**. Hydrogen atoms are omitted for clarity.

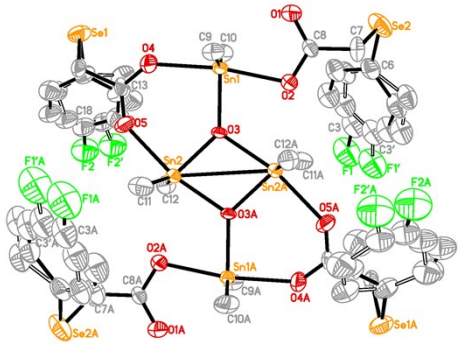

Figure S2 The Ortep picture of **2**. Hydrogen atoms are omitted for clarity.

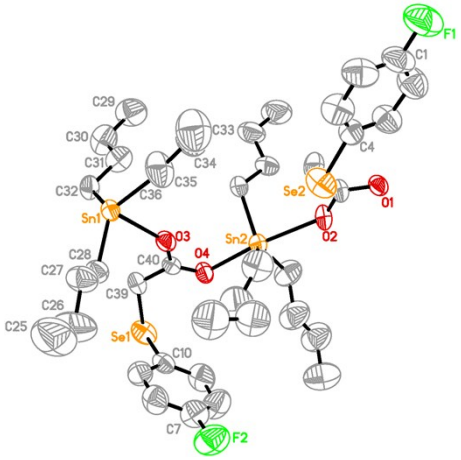

Figure S3 The Ortep picture of **3**. Hydrogen atoms are omitted for clarity.

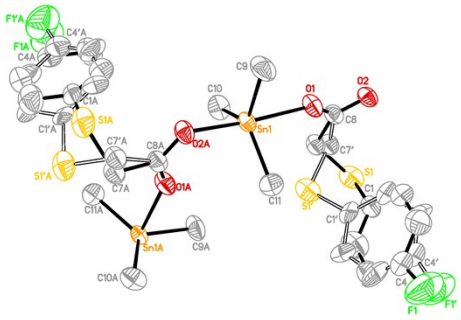

Figure S4 The Ortep picture of **5**. Hydrogen atoms are omitted for clarity.

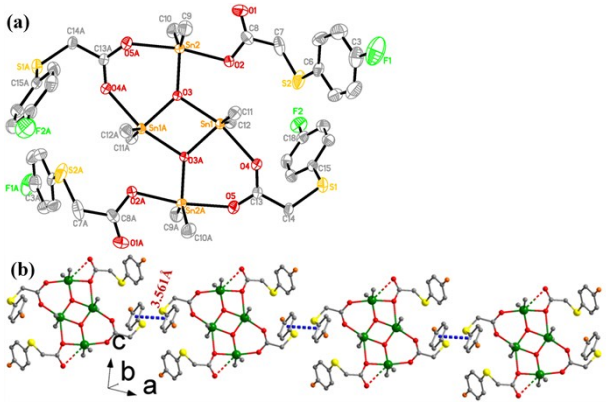

Figure S5 The Ortep picture (a) and 1D supermolecular structure constructed by π···π (blue dashes) interactions (b) of **6**. Hydrogen atoms are omitted for clarity.

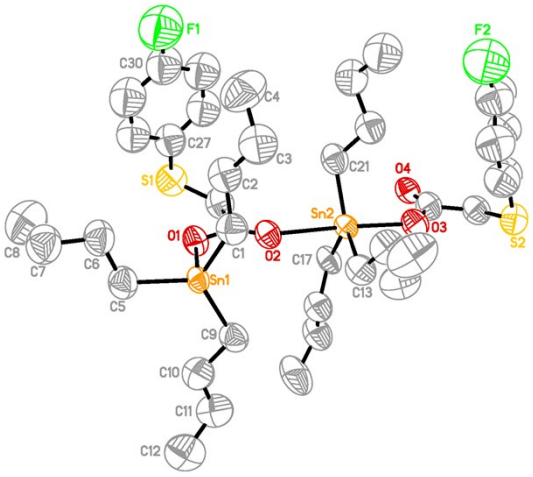

Figure S6 The Ortep picture of **7**. Hydrogen atoms are omitted for clarity.

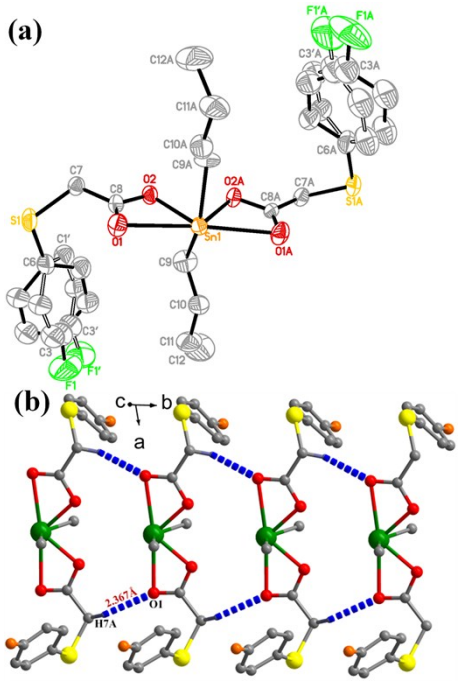

Figure S7 The Ortep picture (a) and 1D supermolecular structure constructed by C-H···O (blue dashes) interactions (b) of **8.** Hydrogen atoms are omitted for clarity.

4. The UV-vis Absorption and Fluorescence Spectra

Table S10 UV-Vis absorption and fluorescence data

	λ_{abs} (nm)		λ_{em} (nm)	
	DMF	culture medium	DMF	culture medium
solvent	/	/	329	343
1	272	247 (main), 298	332	345
2	272	249 (main), 296	329	342
3	272	250 (main), 298	329	344
4	272	249 (main), 297	331	345
Ligand	273	247 (main), 298	330	341