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Synthesis and characterization of organotin complexes with dithiocarbamates and crystal structures of $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ and $(2\text{-}ClC_6H_4CH_2)_2Sn(Cl)S_2CNBz_2$

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Ten organotin derivatives with dithiocarbamates of the formulae $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (1), $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (2), $(4\text{-}NCC_6H_4CH_2)_2Sn[S_2CN(CH_2CH_2)_2NCH_3]_2$ (3), $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (4), $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (5), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CNEt_2$ (6), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CNBz_2$ (7), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CN(CH_2CH_2)_2NCH_3$ (8), $(2\text{-}ClC_6H_4CH_2)_2Sn(Cl)S_2CNEt_2$ (9) and $(2\text{-}ClC_6H_4CH_2)_2Sn(Cl)S_2CNBz_2$ (10) have been prepared. All complexes were characterized by elemental analyses, IR and NMR. The crystal structures of complexes 1 and 10 were determined by X-ray single crystal diffraction. For complex 1, the central tin atom exists in a skew-trapezoidal planar geometry defined by two asymmetrically coordinated dithiocarbamate ligands and two 4-cyanobenzyl groups. In addition, because of the presence of close intermolecular non-bonded contacts, complex 1 is a weakly-bridged dimer. In complex 10, the central tin atom is rendered pentacoordinated in a distorted trigonal bipyramidal configuration by coordinating with S atoms derived from the dithiocarbamate ligand. *In vitro* assays for cytotoxicity against five human tumor cell lines (MCF-7, EVSA-T, WiDr, IGROV and M226) furnished the significant toxicities of the title complexes. Copyright © 2006 John Wiley & Sons, Ltd.

KEYWORDS: organotin; dithiocarbamate; synthesis; crystal structure

INTRODUCTION

Interest in dithiocarbamate complexes of organotin species arises because of their variety of structures and biological activities.[1–14] Crystallographic studies have revealed that the coordination at the tin atom depends not only on factors such as structure of the organic groups, but also on whether the 1,1-dithiolates behave as monodentate or bidentate ligands and whether the complexes are monomeric or oligomeric. In the diorganotin series $R'_2Sn(Cl)S_2CNR_2$, the tin atom is effectively 5-coordinate as in complexes $(4\text{-}FC_6H_4CH_2)_2Sn(Cl)S_2CN(CH_2CH_2)_2O$,[15] $Ph_2Sn(Cl)S_2CO^iPr$,[16] $Ph_2Sn(Cl)S_2CNEt_2$[17] and $^tBu_2Sn(Cl)S_2CNEt_2$,[17] whereas in $R'_2Sn(S_2CNR_2)_2$ the tin atom appears to be 6-coordinate, for example, complexes $^tBu_2Sn(S_2CNEt_2)_2$,[17] $Ph_2Sn(S_2CNEt_2)_2$,[18] $(4\text{-}ClC_6H_4CH_2)_2Sn[S_2CN(CH_2CH_2)_2NCH_3]_2$,[19] $Ph_2Sn(S_2COEt)_2$,[20] $Ph_2Sn(S_2COPr^i)_2$,[21] $Me_2Sn[S_2P(OMe)_2]_2$[22] and $Me_2Sn(S_2COEt)_2$.[23] In order to continue exploring relationships between their biological activity and structure, and as part of an ongoing study of dithiocarbamate complexes of main group elements and of the coordination chemistry of tin(IV) compounds,[24–33] we have synthesized and characterized 10 organotin(IV) complexes with dithiocarbamate ligands: $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (**1**), $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (**2**), $(4\text{-}NCC_6H_4CH_2)_2Sn[S_2CN(CH_2CH_2)_2NCH_3]_2$ (**3**), $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (**4**), $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (**5**), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CNEt_2$ (**6**), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CNBz_2$ (**7**), $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CN(CH_2CH_2)_2NCH_3$ (**8**), $(2\text{-}ClC_6H_4CH_2)_2Sn(Cl)S_2CNEt_2$ (**9**) and $(2\text{-}ClC_6H_4CH_2)_2Sn(Cl)S_2CNBz_2$ (**10**). The

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crystal structures of complexes **1** and **10** were determined by X-ray single crystal diffraction. Moreover, all the complexes were tested for *in vitro* cytotoxicity against six human tumor cell lines and the results are also reported.

EXPERIMENTAL

General

Anhydrous sodium dithiocarbamates were prepared in the way of method described in the literature.[34] $(4\text{-}NCC_6H_4CH_2)_3SnCl$ and $(2\text{-}ClC_6H_4CH_2)_2SnCl$ were synthesized according to reported papers.[35,36] IR spectra were recorded on a Nicolet-460 spectrophotometer, using KBr disks. NMR spectra were obtained with Mercury Plus-400 NMR spectrometer and the chemical shifts are given in ppm relative to Me_4Si and Me_4Sn in $CDCl_3$. Elemental analyses were performed on PE-2400-II elemental analyzer.

Syntheses of complexes 1–10

*Synthesis of $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (**1**)*

Anhydrous sodium *N,N*-diethyldithiocarbamate (2.2 mmol) was added to 40 mL 95% ethanol solution of tris(4-cyanobenzyl)tin chloride (1.0 mmol). Then the mixture was heated under reflux for 10 h. The precipitated sodium chloride was removed by filtration and the filtrate was concentrated to about 5 mL under reduced pressure. When hexane (5 mL) was added to this solution, a precipitate was immediately formed. The product was recrystallized from ethanol to give colorless crystals: yield 72%; m.p.133–134 °C. ^{1}H-NMR ($CDCl_3$): δ 7.27–7.45 (8H, m, Ar–H), 1.23 (12H, t, CH_3), 3.68 (8H, m, NCH_2), 2.42 (4H, s, $J_{Sn-H} = 81$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 30.9 (CH_2Ph, $^1J_{Snc} = 686$ Hz), 146.0, 132.3, 129.6, 107.8 (Ar–C, $^2J_{Snc} = 34$ Hz, *i*–C; $^3J_{Snc} = 48$ Hz, *o*–C; $^4J_{Snc} = 31$ Hz, *m*–C; $^5J_{Snc} = 25$ Hz, *p*–C), 117.5 (CN) 197.2 (CS_2), 49.7, 13.6 (NCH_2CH_3) ppm. ^{119}Sn-NMR δ − 491.4 ppm. IR (KBr, cm^{-1}): 2223 (s, C≡N), 1486 (s, C–N), 1120, 995 (s, CS_2), 577 (m, Sn–C), 428 (m, Sn–S). Anal. calcd for $C_{26}H_{32}N_4S_4Sn$: C, 48.32; H, 5.09; N, 8.74; S,19.75. Found: C, 48.23; H, 4.98; N, 8.65; S, 19.81%.

*Synthesis of $(4\text{-}NCC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (**2**)*

The method of synthesis of complex **2** was similar to that described for **1**. The product was recrystallized from ethanol to give colorless crystals: yield 68%. m.p.167–169 °C. ^{1}H-NMR ($CDCl_3$): δ 7.06–7.41(28 H, m, Ar–H, Ph–H), 4.70 (8H, s, $PhCH_2N$), 2.53 (4H, s, $J_{Sn-H} = 84$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$):δ 31.6 (CH_2Ph, $^1J_{Snc} = 684$ Hz), 147.2, 133.1, 128.8, 109.1 (SnAr–C, $^2J_{Snc} = 33$ Hz, *i*–C; $^3J_{Snc} = 49$ Hz, *o*–C; $^4J_{Snc} = 30$ Hz, *m*–C; $^5J_{Snc} = 24$ Hz, *p*–C), 132.0, 131.5, 130.6, 129.0 (NCH_2Ph–C), 115.2 (CN), 68.2 (CH_2N), 196.3 (CS_2) ppm. ^{119}Sn-NMR δ − 497.3 ppm. IR (KBr, cm^{-1}): 2225 (s, C≡N), 1490 (s, C–N), 1129, 994 (s, CS_2), 571 (m, Sn–C), 435 (m, Sn–S). Anal. calcd for $C_{46}H_{40}N_4S_4Sn$: C, 61.68; H, 4.50; N, 6.25; S,14.32. Found: C, 61.53; H, 4.57; N, 6.31; S, 14.42%.

*Synthesis of $(4\text{-}NCC_6H_4CH_2)_2Sn[S_2CN(CH_2CH_2)_2NCH_3]_2$ (**3**)*

The method of synthesis of complex **3** was similar to that described for **1**. The product was recrystallized from ethanol to give colorless crystals: yield 67%; m.p. 211–213 °C. ^{1}H-NMR ($CDCl_3$): δ 7.21–7.47 (8H, m, Ar–H), 4.01 (16H, m, NCH_2CH_2N), 2.57 (4H, s, $J_{Sn-H} = 79$ Hz, $ArCH_2Sn$), 2.46 (3H, s, NCH_3) ppm. ^{13}C-NMR ($CDCl_3$): δ 30.5 (CH_2Ph, $^1J_{Snc} = 685$ Hz), 145.3, 131.3, 129.0, 108.5 (Ar–C, $^2J_{Snc} = 34$ Hz, *i*–C; $^3J_{Snc} = 49$ Hz, *o*–C; $^4J_{Snc} = 32$ Hz, *m*–C; $^5J_{Snc} = 24$ Hz, *p*–C), 116.4 (CN) 195.8 (CS_2), 56.3, 53.8, 45.2 (NCH_2, NCH_3) ppm.^{119}Sn-NMR δ − 488.7 ppm. IR (KBr, cm^{-1}): 2220 (s, C ≡ N), 1487 (s, C–N), 1130, 993 (s, CS_2), 575 (m, Sn–C), 431 (m, Sn–S). Anal. calcd for $C_{28}H_{34}N_6S_4Sn$: C, 47.94; H, 4.88; N, 11.98; S, 18.28. Found: C, 48.03; H, 4.81; N, 11.94; S, 18.09%.

*Synthesis of $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNEt_2)_2$ (**4**)*

The method of synthesis of complex **4** was similar to that described for **1**. The product was recrystallized from ethanol to give colorless crystals: yield 70%; m.p.132–134 °C. ^{1}H-NMR ($CDCl_3$): δ 6.75–7.40 (8H, m, Ar–H), 1.30 (12H, t, CH_3), 3.75 (8H, m, NCH_2), 2.52 (4H, s, $J_{Sn-H} = 80$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 36.2 (CH_2Ph, $^1J_{Snc} = 688$ Hz), 137.5, 134.2, 133.0, 132.7, 129.8, 126.7 (Ar–C, J_{Snc}: 47, 34, 30, 28, 29, 26 Hz), 196.4 (CS_2), 50.2, 13.8 (NCH_2CH_3) ppm. ^{119}Sn-NMR δ − 482.2 ppm. IR (KBr, cm^{-1}): 1489 (s, C–N), 1131, 1002 (s, CS_2), 565 (m, Sn–C), 436 (m, Sn–S). Anal. calcd for $C_{24}H_{32}Cl_2N_2S_4Sn$: C, 43.26; H, 4.84; N, 4.20; S, 19.24. Found: C, 43.38; H, 4.90; N, 4.13; S, 19.19%.

*Synthesis of $(2\text{-}ClC_6H_4CH_2)_2Sn(S_2CNBz_2)_2$ (**5**)*

The method of synthesis of complex **5** was similar to that described for **1**: yield 74%; m.p.152–154 °C. ^{1}H-NMR ($CDCl_3$): δ 6.77–7.43(18 H, m, Ar–H, Ph–H), 4.77 (4H, s, $PhCH_2N$), 2.54 (4H, s, $J_{Sn-H} = 83$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 33.8 (CH_2Ph, $^1J_{Snc} = 687$ Hz), 138.2, 133.5, 132.4, 130.5, 129.8, 126.0 (SnAr–C, $J_{Snc} = 46$, 32, 31, 30, 27, 26 Hz), 135.8, 134.5, 129.5,131.8 (NCH_2Ph–C) 67.3 (CH_2N), 199.3 (CS_2), ppm. ^{119}Sn-NMR δ − 482.4 ppm. IR (KBr, cm^{-1}): 1488 (s, C–N), 1127, 1000 (s, CS_2), 551 (m, Sn–C), 438 (m, Sn–S). Anal. calcd for $C_{44}H_{40}Cl_2N_2S_4Sn$: C, 57.78; H, 4.41; N, 3.06; S, 14.02. Found: C, 57.61; H, 4.50; N, 3.02; S, 14.13%.

*Synthesis of $(4\text{-}NCC_6H_4CH_2)_2Sn(Cl)S_2CNEt_2$ (**6**)*

Sodium *N,N*-diethyldithiocarbamate (1.0 mmol) was dissolved in 15 mL dichloromethane and added dropwise to the solution of bis(4-cyanobenzyl)tin dichloride (1.0 mmol) in the same solvent. The mixture was stirred for 10 h at 30 °C. It was then filtered to remove the white solid. The solvent was removed *in vacuo* and a white precipitate was obtained. Then the product was dissolved in hot acetone and a few drops of methanol were added to give colorless crystals: yield 68%; m.p.101–102 °C. ^{1}H-NMR ($CDCl_3$): δ 7.20–7.47 (8H, m, Ar–H), 1.26 (6H, t, CH_3), 3.78 (4H, m, NCH_2), 2.98 (4H, s, $J_{Sn-H} = 75$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$):

δ 31.3 (CH_2Ph, $^1J_{Snc} = 453$ Hz), 148.3, 135.4, 129.8, 110.3 (Ar–C, $^2J_{Snc} = 34$ Hz, *i*–C; $^3J_{Snc} = 45$ Hz, *o*–C; $^4J_{Snc} = 31$ Hz, *m*–C; $^5J_{Snc} = 25$ Hz, *p*–C), 116.2 (CN) 196.2 (CS_2), 49.1, 13.8 (NCH_2CH_3) ppm. ^{119}Sn-NMR δ − 315.3 ppm. IR (KBr, cm^{-1}): 2220 (s, C ≡ N), 1494 (s, C–N), 1120, 999 (s, CS_2), 571 (m, Sn–C), 443 (m, Sn–S). Anal. calcd for $C_{21}H_{22}ClN_3S_2Sn$: C, 47.17; H, 4.15; N, 7.86; S, 11.99. Found: C, 47.25; H, 4.19; N, 7.82; S, 11.86%.

*Synthesis of (4-NCC$_6$H$_4$CH$_2$)$_2$Sn(Cl)S$_2$CNBz$_2$ (**7**)*

The method of synthesis of complex **7** was similar to that described for **6**: yield 73%; m.p.132–134 °C. ^{1}H-NMR ($CDCl_3$): δ 7.11–7.45(18 H, m, Ar–H, Ph–H), 4.81 (4H, s, $PhCH_2N$), 2.87 (4H, s, $J_{Sn-H} = 78$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 32.4 (CH_2Ph, $^1J_{Snc} = 457$ Hz), 148.6, 133.9, 129.3, 110.5 (SnAr–C, $^2J_{Snc} = 36$ Hz, *i*–C; $^3J_{Snc} = 44$ Hz, *o*–C; $^4J_{Snc} = 30$ Hz, *m*–C; $^5J_{Snc} = 26$ Hz, *p*–C), 131.7, 131.0, 131.5, 129.7 (NCH_2Ph–C), 115.1 (CN), 68.7 (CH_2N), 197.2 (CS_2) ppm. ^{119}Sn-NMR δ − 317.9 ppm. IR (KBr, cm^{-1}): 2222 (s, C ≡ N), 1496 (s, C–N), 1122, 998 (s, CS_2), 575 (m, Sn–C), 441 (m, Sn–S). Anal. calcd for $C_{31}H_{26}ClN_3S_2Sn$: C, 56.52; H, 3.98; N, 6.38; S, 9.73. Found: C, 56.44; H, 4.03; N, 6.42; S, 9.70%.

*Synthesis of (4-NCC$_6$H$_4$CH$_2$)$_2$Sn(Cl)S$_2$CN (CH$_2$CH$_2$)$_2$NCH$_3$ (**8**)*

The method of synthesis of complex **8** was similar to that described for **6**: yield 67%; m.p.156–158 °C. ^{1}H-NMR ($CDCl_3$): δ 7.24–7.45 (8H, m, Ar–H), 4.05 (8H, m, NCH_2CH_2N), 2.85 (4H, s, $J_{Sn-H} = 75$ Hz, $ArCH_2Sn$), 2.47 (3H, s, NCH_3) ppm. ^{13}C-NMR ($CDCl_3$): δ 31.2 (CH_2Ph, $^1J_{Snc} = 456$ Hz),147.0, 132.7, 129.5, 109.1 (Ar–C, $^2J_{Snc} = 33$ Hz, *i*–C; $^3J_{Snc} = 45$ Hz, *o*–C; $^4J_{Snc} = 33$ Hz, *m*–C; $^5J_{Snc} = 27$ Hz, *p*–C), 116.1 (CN), 197.2 (CS_2), 56.7, 54.2, 45.0 (NCH_2, NCH_3) ppm.^{119}Sn-NMR δ − 310.7 ppm. IR (KBr, cm^{-1}): 2223 (s, C ≡ N), 1493 (s, C–N), 1124, 1002 (s, CS_2), 577 (m, Sn–C), 440 (m, Sn–S). Anal. calcd for $C_{22}H_{23}ClN_4S_2Sn$: C, 47.04; H, 4.13; N, 9.97; S, 11.42. Found: C, 47.20; H, 4.15; N, 9.91; S, 11.37%.

*Synthesis of (2-ClC$_6$H$_4$CH$_2$)$_2$Sn(Cl)S$_2$CNEt$_2$ (**9**)*

The method of synthesis of complex **9** was similar to that described for **6**: yield 75%; m.p.103–105 °C. ^{1}H-NMR ($CDCl_3$): δ 6.70–7.43 (8H, m, Ar–H), 1.32 (6H, t, CH_3), 3.74 (4H, m, NCH_2), 2.83 (4H, s, $J_{Sn-H} = 74$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 36.8 (CH_2Ph, $^1J_{Snc} = 454$ Hz), 138.8, 134.6, 133.6, 132.1, 130.4, 125.5 (Ar–C, J_{Snc}: 49, 36, 33, 32, 30, 25 Hz), 197.2 (CS_2), 51.4, 13.5 (NCH_2CH_3) ppm. ^{119}Sn-NMR δ − 312.6 ppm. IR (KBr, cm^{-1}): 1490 (s, C–N), 1129, 1008 (s, CS_2), 561 (m, Sn–C), 444 (m, Sn–S). Anal. calcd for $C_{19}H_{22}Cl_3NS_2Sn$: C, 41.23; H, 4.01; N, 2.53; S, 11.58. Found: C, 41.15; H, 4.08; N, 2.59; S, 11.48%.

*Synthesis of (2-ClC$_6$H$_4$CH$_2$)$_2$Sn(Cl)S$_2$CNBz$_2$ (**10**)*

The method of synthesis of complex **10** was similar to that described for **6**: yield 71%; m.p.143–144 °C. ^{1}H-NMR ($CDCl_3$): δ 7.06–7.41(18 H, m, Ar–H, Ph–H), 4.73 (4H, s, $PhCH_2N$), 2.95 (4H, t, $J_{Sn-H} = 75$ Hz, $ArCH_2Sn$) ppm. ^{13}C-NMR ($CDCl_3$): δ 36.3 (CH_2Ar, $^1J_{Snc} = 453$ Hz), 136.7, 134.1, 132.0, 130.6, 129.7, 126.0 (SnAr–C, $J_{Snc} = 45$, 34, 32, 30, 27, 24 Hz), 133.5, 132.5, 131.5, 129.0 (NCH_2Ph–C), 69.7 (NCH_2) 198.9 (CS_2), 56.6 (NCH_2) ppm. ^{119}Sn-NMR δ − 302.2 ppm. IR (KBr, cm^{-1}): 1495 (s, C–N), 1123, 1003 (s, CS_2), 545 (m, Sn–C), 443 (m, Sn–S). Anal. calcd for $C_{29}H_{26}Cl_3NS_2Sn$: C, 51.34; H, 4.41; N, 2.10; S, 9.54. Found: C, 51.39; H, 3.87; N, 2.07; S, 9.46%.

In vitro *cytotoxicity assays*

The *in vitro* citotoxicity tests against five human tumoral cell lines (MCF-7 breast cancer, EVSA-T breast cancer, WiDr colon cancer, IGROV ovarian cancer and M226 non-small cell lung cancer) were measured using cisplatin and doxorubicin as reference drugs, implying the standard procedure.[29–33] According to literature method,[37] the inhibition rate of compounds against culture cells of Ehrlich ascites carcinoma was tested.

Crystallographic measurements

X-ray crystallographic data for **1** and **10** were collected on a Bruker smart-1000 CCD with graphite monochromated Mo-Kα radiation so that θ_{max} was 25.0°. The structures were solved by direct methods and difference Fourier maps using the SHELXL-97 program and refined by full-matrix least-squares on F^2. All non-H atoms were refined with anisotropic displacement parameters, H atoms were included in the riding model approximation, and using a weighting scheme of the form $w = 1/[\sigma^2(F_o^2) + (aP)^2 + bP]$ where $P = (F_o^2 + 2F_c^2)/3$). The crystallographic data, together with refinement details of complexes **1** and **10** are given in Table 2.

RESULTS AND DISCUSSION

Proposed mechanism for the formation of complexes 1–5

Various papers on the synthesis and structures of $R'_2Sn(S_2CNR_2)_2$ have been published,[22,23,28,35] but none have reported their formation from trialkyltin halides. When the reaction of $(ArCH_2)_3SnCl$ with NaS_2CNR_2 in 1:2 molar ratio occurred, five unexpected complexes $(ArCH_2)_2Sn(S_2CNR_2)_2$ **1–5** were obtained instead of the expected $(ArCH_2)_3SnS_2CNR_2$. A possible synthetic mechanism is a two-step process, as shown in Scheme 1. First, $(ArCH_2)_3SnCl$ reacts with NaS_2CNR_2 to form corresponding $(ArCH_2)_3SnS_2CNR_2$. Because tribenzyltin compounds are prone to oxidation with formation of dibenzyltin compounds and the appropriate aldehyde, refluxing for 10 h in an apparatus open to air may well lead to such oxidation.

$$(ArCH_2)_3SnCl + NaS_2CNR_2 \longrightarrow (ArCH_2)_3SnS_2CNR_2$$

$$(ArCH_2)_3SnS_2CNR_2 \xrightarrow{[O]} (ArCH_2)_2Sn(S_2CNR_2)_2 + ArCHO$$

Scheme 1.

IR and NMR spectroscopic properties

The assignment of IR bands of the 10 complexes has been made by comparison with the IR spectra of their related precursors. A new absorption band at 428–444 cm^{-1} for all complexes, which is absent from the spectra of the free ligands, can be assigned to the Sn–S stretching mode of vibration. The values are consistent with that detected for a number of organotin(IV)–sulfur derivatives.[38]

Of particular interest in the IR spectra are the C–N, C–S stretching frequencies that can be used to differentiate between mono- and bidentate modes of binding of dithiocarbamate ligands.[38] In the IR spectra of complexes **1–10**, the strong peaks that appear at 1120–1131 cm^{-1} have been attributed to the asymmetric absorption of $\nu(CS_2)_{as}$. And the 995–1008 cm^{-1} can be assigned to the symmetric $[\nu(CS_2)_s]$ absorption frequencies. According to the literature,[27,34,38,39] for complexes **1–10**, the $\Delta\nu$ values $[\nu(CS_2)_{as}-\nu(CS_2)_s]$ are 120–137 cm^{-1}, indicating that the sulfur atoms of the dithiocarbamate group are linked to the central tin in a bidentate fashion. The stretching vibration peaks of C–N are located at 1486–1496 cm^{-1}. The observed ν_{C-N} vibrations lie between the range for C–N single bonds (1250–1360 cm^{-1}) and C=N double bonds (1640–1690 cm^{-1}). This suggests that the C–N bonds in complexes **1–10** have some partial double bond character. Partial double bond character for the C–N bond would result in some partial double bond character for the C–S bonds.[27,28] The analyses are in agreement with X-ray single crystal diffraction results for complexes **1** and **10**.

The ^{1}H-NMR spectra of complexes **1–10** show that the chemical shifts of the protons on the benzyl group exhibit two signals about 6.70–7.47 ppm as a complex pattern and 2.42–2.98 ppm as a singlet with 119-Sn satellites, the coupling constant J_{Sn-H} is equal to 74–84 Hz. The protons give rise to triplet signals at 3.68–4.05 ppm as expected in complexes **1, 3, 4, 6, 8** and **9**. For complexes **3** and **8**, the NCH_3 protons lead to a singlet signal at 2.46 and 2.47 ppm. The NCH_2Ph protons for complexes **2, 7** and **10** lead to a singlet signal at 4.70–4.81 ppm.

A comparison of the ^{13}C NMR spectra of the ligand with the corresponding organotin complexes **1–10** shows a downfield shift in the position of C_{C-N} and C_{C-O} signals and an upfield shift in the position of the C_{CSS} signal. These shifts indicate the bidentate behavior of the morpholindithiocarbamate moieties in all complexes.[40,41] The $^nJ(^{119}Sn-^{13}C)$ coupling constants were detected in the case of sufficiently soluble derivatives. In complexes **1–5,** the $^nJ(^{119}Sn-^{13}C)$ are close to those found for 6-coordinate skewed trapezoidal diorganotin complexes,[42,43] whereas in the case of derivatives **6–10**, the order of magnitude of the coupling constants is the same as those previously reported for analogous 5-coordinate derivatives.[43]

The ^{119}Sn chemical shift values in complexes **1–5** are found to be in the range −482 to −498 ppm, and the chemical shift for complexes **6–10** is −302 to −318 ppm. The appearance of chemical shift values in this region indicates a 5- and 6-coordination environment[39,40] around the central tin atoms in these complexes.

Table 1. *In vitro* cytotoxicity assays (ng/ml) of complexes **1–10** together with those of some reference drugs in clinical use

Complexes	MCF-7	EVSA-T	WiDr	IGROV	M226
1	35	23	20	31	37
2	33	22	19	29	36
3	30	22	17	27	34
4	40	31	25	36	45
5	46	38	35	42	53
6	28	41	32	35	30
7	20	16	19	30	24
8	8	14	34	11	16
9	16	23	16	14	29
10	13	26	21	12	18
Cisplatin	1450	480	720	360	960
Doxorubicin	180	83	44	73	170

Biological activity measurement

The *in vitro* cytotoxicity tests show that complexes **1–10** are significantly toxic in their biological activity screenings (Table 1). The inhibition rates (%) against culture cells of Ehrlich ascites carcinoma are uniformly in the range 50–70%, usually at the upper end, indicating that these complexes have a certain biological activity to Ehrlich ascites carcinoma compared with that of *cis*-platin (55%). Complex **8** is the most active. From the above experimental data, we can conclude that *in vitro* cytotoxicity of the complexes $(ArCH_2)_2Sn(Cl)S_2CNR_2$ is stronger than that of complexes $(ArCH_2)_2Sn(S_2CNR_2)_2$. The possible reason is that $(ArCH_2)_2Sn(Cl)S_2CNR_2$ can hydrolyze more easily and release $ArCH_2)_2Sn^{2+}$ in comparison with $(ArCH_2)_2Sn(S_2CNR_2)_2$.

Molecular structures of complexes 1 and 10

Selected bond distances and angles are given in Tables 3 and 4, and their molecular structures are shown in Figs 1 and 2.

Complex 1

From Fig. 1, it can be seen that the Sn atom exists in a skew-trapezoidal planar geometry in which the basal plane is defined by the four S atoms derived from two chelating dithiocarbamate ligands. The two remaining positions are occupied by two 4-cyanobenzyl groups, which lie over the weaker Sn–S bonds and define a C11–Sn–C19 angle of 147.7(3)°. The degree of asymmetry in the mode of coordination of each dithiocarbamate ligand, while comparable, is not equivalent. The first ligand forms Sn–S1 and Sn1–S2 bond distances of 2.537(2) and 2.879(2) Å, respectively, and the other forms Sn1–S3 and Sn1–S4 bond at 2.524(2) and 2.885(2) Å, respectively. These differences yield values of 0.342 and 0.361 Å, respectively for Δ(Sn–S), and are reflected in the associated C–S bond distances. Unexpectedly, the C–S bond distances [S1–C1 1.703(8) Å, S3–C6 1.712(9) Å]

Table 2. Crystallographic data of complexes **1** and **10**

Compound	**1**	**10**
Molecular formula	$C_{26}H_{32}N_4S_4Sn$	$C_{29}H_{26}Cl_3NS_2Sn$
Formula weight	647.49	677.67
Temperature (K)	298(2)	273(2)
Crystal system	Monoclinic	Monoclinic
Space group	$P2_1/n$	$C2/c$
a (Å)	12.326(6)	22.737(4)
b (Å)	14.841(7)	10.4119(17)
c (Å)	17.085(8)	25.088(4)
β (deg)	104.838(7)	103.306(2)
V(Å^3)	3021(3)	5779.7(16)
Z	4	8
D_{cal}(g/cm^3)	1.424	1.558
μ (mm^{-1})	1.143	1.326
F(000)	1320	2720
Crystal size (mm)	0.31 × 0.37 × 0.55	0.25 × 0.32 × 0.41
Reflections collected	15193	14123
Independent reflections	5243	4915
R_{int}	0.072	0.037
Data with $I > 2\sigma(I)$	3248	3753
Goodness-of-fit	1.01	1.00
R_1/wR_2 (observed data)	0.060/0.146	0.044/0.125
a, b for weighting scheme	0.108, 1.953	0.099, 1.951
R_1/wR_2 (all data)	0.114/0.192	0.064/0.145
Largest residual peak and hole (e Å^{-3})	1.05/−0.64	1.38/−0.52
CCDC deposition no.	251 949	251 950

for the S atoms bound strongly to the Sn center are shorter than the C–S bonds [S2–C1 1.719(7) Å, S4–C6 1.723(9) Å] that involve the Sn atoms forming the weaker bonds to the Sn atom. The geometry of complex **1** is similar to those usually observed for $R_2Sn(S_2CNR'_2)_2$.[1,2]

In addition, a distinguishing feature, namely the presence of close intermolecular non-bonded [Sn···S2# 3.821(3) Å and S(2)···S(2)# 3.309(4) Å] contacts (from a centrosymmetrically related molecule) is noted in the crystallographic analysis of complex **1** (see Fig. 2). The contact of Sn(1) and S(2)# is significantly longer than the sum of the covalent radii of tin and sulfur atoms (2.42 Å) and less than the sum of the van der Waals radii for these atoms (4.0 Å),[44,45] and the S–S bond length is within the sum of the van der Waals radii of two sulfur atoms (3.70 Å).[46] From this, the structure of complex **1** is best described as a weakly bridged dimer (see Fig. 3).

Table 3. Selected bond distances (Å) and angles (deg) of complex **1**

Sn–C11	2.176(8)	Sn–S1	2.537(2)
Sn–C19	2.158(8)	Sn–S2	2.879(2)
S1–C1	1.703(8)	Sn–S3	2.524(2)
S2–C1	1.719(7)	Sn–S4	2.885(2)
S3–C6	1.712(9)	Sn···S2#	3.821(3)
S4–C6	1.723(9)	S2···S2#	3.309 (4)
C11–Sn–C19	147.7(3)	C19–Sn–S4	82.7(2)
C11–Sn–S1	100.9(2)	S1–Sn–S2	66.08(7)
C19–Sn–S1	102.8(2)	S1–Sn–S3	86.28(8)
C11–Sn–S2	82.5(2)	S1–Sn–S4	152.51(7)
C19–Sn–S2	87.3(2)	S2–Sn–S3	152.33(6)
C11–Sn–S3	102.5(2)	S2–Sn–S4	141.41(7)
C19–Sn–S3	100.6(3)	S3–Sn–S4	66.24(7)
C11–Sn–S4	86.4(2)		

Table 4. Selected bond distances (Å) and angles (deg) of complex **10**

Sn–C16	2.152(5)	S1–C1	1.743(5)
Sn–C23	2.160(6)	S2–C1	1.722(5)
Sn–S1	2.4695(14)	Sn–Cl1	2.4715(15)
Sn–S2	2.6574(13)		
C16–Sn–C23	116.9(3)	S1–Sn–Cl1	88.61(5)
C16–Sn–S1	116.35(17)	C16–Sn–S2	97.74(15)
C23–Sn–S1	126.5(2)	C23–Sn–S2	98.09(16)
C16–Sn–Cl1	94.36(15)	S1–Sn–S2	70.03(4)
C23–Sn–Cl1	92.21(17)	Cl1–Sn–S2	158.43(5)

*Complex **10***

As can be seen from Fig. 2, complex **10** possesses a monomeric structure, with no significant intermolecular interactions, as has been noted in an extensive study of related $R_2Sn(S^2CNR'^2)Cl$ structures.[39] The tin atom is rendered 5-coordination in a trigonal bipyramidal configuration [Sn–S1 2.4695(14) Å, Sn–S2 2.6574(13) Å, Sn–Cl1 2.4715(15) Å, Sn–C16 2.152(5) Å, Sn–C23 2.160(6) Å]. The structure is similar to those of complexes $Ph_2SnCl(S_2CNEt_2)$,[18] $^tBu_2SnCl(S_2CNEt_2)$[18] and $(4\text{-}F\text{-}Bz)_2Sn(Cl)S_2CN(CH_2CH_2)_2O$.[16]

The geometry of complex **10** is loosely based on a trigonal bipyramid, with atoms C16, S1 and C23 occupying equatorial positions. The sum of the equatorial angles (359.75°) at the tin atom by the two coordinated carbon atoms and one sulfur atom [C23–Sn–S1 126.5(2)°, C16–Sn–S1 116.35(17)°, C16–Sn–C23 116.9(3)°] deviates only by 0.25° from 360°, so the atoms C16, S1, C23 and Sn1 are approximately on the same plane. The Cl atom occupies approximately one apical position of the trigonal bipyramid. Conversely, because of the constraint of the chelate [the angle of (S1–Sn–S2) is only 70.03(4)°], The S2 atom cannot exactly occupy the

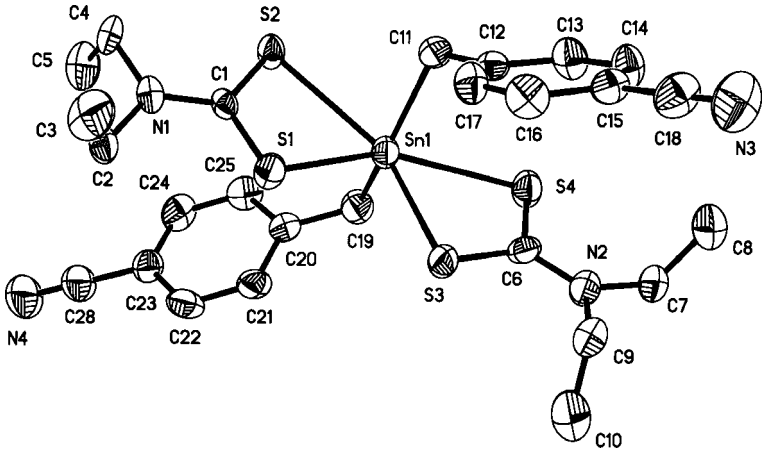

Figure 1. The molecular structure of **1**.

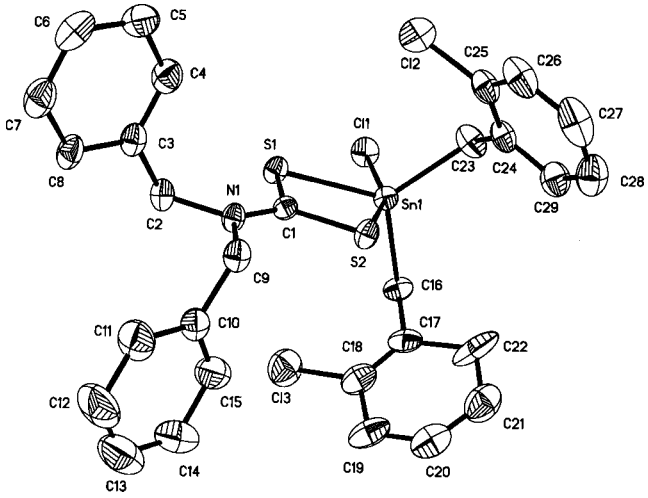

Figure 2. The molecular structure of **10**.

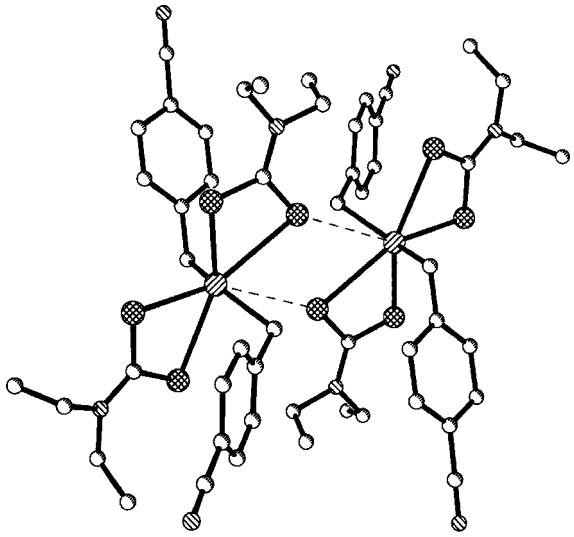

Figure 3. The weakly—associated dimeric structure of **1**.

corresponding trans axial position of the trigonal bipyramid, the angle Cl1–Sn–S2 being 158.43(5)°.

The S–C bond lengths [S1–C1 1.743(5) Å, S2–C1 1.722(5) Å] appear to be characteristic of the dithiocarbamate group and these four distances are all intermediate between the values expected for 'single' and 'double' bonds.[47] Therefore, in the crystal of compound **10**, the tin atom exists in a 5-coordinated trigonal bipyramidal geometry by coordinating with S atoms of dithiocarbamate group.

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