1,3-Dithianes as Assembling Ligands for the Construction of Copper(I) Coordination Polymers. Investigation of the Impact of the RC(H)S2C3H6 Substituent and Reaction Conditions on the Architecture of the 0D–3D Networks
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1,3-Dithianes as assembling ligands for the construction of Cu(I) coordination polymers.

Investigation of the impact of the $RC(H)S_2C_3H_6$ substituent and reaction conditions on the architecture of the 0D-3D networks

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ABSTRACT

The parent compound 1,3-dithiane L1 was reacted with CuI providing the 1D coordination polymer \([\{\text{Cu(µ-2-I)}_2\text{Cu}\}(µ_2-L1)_2]\)_n CP1, an isostructural compound \([\{\text{Cu(µ-2-Br)}_2\text{Cu}\}(µ_2-L1)_2]\)_n CP2 was isolated upon treatment of CuBr with L1. In contrast, treatment of L1 with CuCl results in the formation of 2D polymeric \([\{\text{Cu(µ-2-Cl)}_2\text{Cu}\}(µ_2-L1)_2]\)_n CP3, in which each sulfur atom acts as a 4-electron donor. The 1D compounds \([\{\text{Cu(µ-2-X)}_2\text{Cu}\}(µ_2-L2)_2]\)_n CP7 (X = Br) and CP8 (X = Cl) resulting from treatment of 2-methyl-1,3 dithiane L2 with CuBr and CuCl are isostructural with their CuI homologue \([\{\text{Cu(µ-2-I)}_2\text{Cu}\}(µ_2-L2)_2]\)_n--CP5, reported previously. Using CuCN, a 2D CP of composition \([\{\text{Cu(µ-2-CN)}_2\text{Cu}\}(µ_2-L2)_2]\)_n CP9 has been isolated. Complexation of 2-isobutyl-1,3-dithiane L3 on CuI generates a 2D material \([\{\text{Cu}_3(µ_3-I)(µ_2-I)_2(µ_2-L3)_2\}]_n\) CP10, incorporating usual trinuclear µ3-I-capped Cu clusters as SBUs, whereas 2D-polymeric compounds \([\{\text{Cu(µ-2-Br)}_2\text{Cu}\}(µ_2-L3)_2]\)_n CP11 and \([\{\text{Cu(µ-2-Cl)}_2\text{Cu}\}(µ_2-L3)_2]\)_n CP12 were obtained with CuBr and CuCl. Treatment of 2-Me₃Si-1,3-dithiane L4 with CuX yields the series \([\{\text{Cu}_2(µ_4-X)(µ_2-X)}_2(µ_2-L4)_2]\)_n CP13–CP15. With 2-phenyl-1,3-dithiane L5, the outcome of the reaction with CuI depends on the reaction conditions. Reaction with CuI in MeCN provides a 1D ribbon \([\{\text{Cu(µ-2-I)}_2\text{Cu}(\text{MeCN})_2(µ_2-L5)_2\}]_n\) CP16, whereas treatment of CuI with L5 in hot EtCN yields 2D-polymeric \([\{\text{Cu}_3(µ_3-I)(µ_2-I)_2(µ_2-L5)_2\}]_n\) CP17. A reversible phase transition from triclinic P-1 to monoclinic P2₁/m is observed when recording the structure of CP16 at 5 different temperatures in the 100-300 K range. Ligand L6 containing a ferrocenyl function at the 2-position was also probed as organometallic dithioether ligand. Reaction of L6 with 1 equiv. of CuI produces the 0D dinuclear complex \([\{\text{Cu(µ-2-I)}_2\text{Cu}(η^1-L6)_2(\text{MeCN})_2\}]_n\) (D1), whereas treatment with 2 equiv. of CuI affords the novel 1D CP \([\{\text{Cu(µ-3-I)}_2\text{Cu}(µ-L6)_2\}]_n\) CP18, in which both S atoms of one L6 molecule span two copper centers of the infinite (CuI)_n ribbon. Some selected results of thermal analyses and luminescence measurements are also presented.
INTRODUCTION

Polydentate macrocyclic thiacrown ethers ligands are able to coordinate a wide range of transition metal complexes both in endocyclic and exocyclic manner yielding discrete molecular complexes. They have also been used as assembling ligands to construct 1D and 2D coordination polymers and 3D MOFs. The less flexible six-membered dithiahetarecycle 1,3-dithiane L1 (also named 1,3-dithiaacyclohexane) has also been used in the past as mono- and bidentate ligand to coordinate to a series of early and late transition metal complexes. Crystallographically characterized examples include mono- and dinuclear compounds \([(C_{5}H_{4})Cr(CO)_{2}(\kappa^{1}-L1)]^{11}, [Fe(CO)_{4}(\kappa^{1}-L1)]^{12}, [(C_{5}H_{3})Ru(PPh_{3})_{2}(\kappa^{1}-L1)][CF_{3}SO_{3}], [((C_{5}Me_{5})IrCl_{2}(\kappa^{1}-L1)) and [(C_{2}Me_{3})IrCl_{2}]_{2}(\mu_{2}-L1)]^{14}\) as well as polynuclear clusters such as \([(\mu_{2}-H)_{2}Ru_{3}(CO)_{6}Cl(\mu_{3}-\eta^{3}-L1)]^{15} \text{and} [H_{3}Ru_{4}(CO)_{10}(\mu_{2}-L1)]^{16}\). The propensity of 1,3-dithiane to act even as a \(\mu_{2}-S,S\) 4-electron donor has been evidenced for \([\text{Os}_{6}CO_{16}(\mu_{2}-L1)]\), where L1 is bridging across an Os–Os edge via one of the sulfur atoms. The use of 1,3-dithiane as assembling ligand for the construction of coordination polymers (CPs) has been first demonstrated by the crystallographic characterization of 1D polymeric 1,3-dithiane-dimercury(l) dinitrate. Several CPs have been built up by treatment of 1,3-dithiane with AgNO\(_{3}\), AgBF\(_{4}\) and AgPF\(_{6}\), respectively. More recently, Keller and Knaust reacted \([\text{Cu(MeCN)}_{4}]BF_{4}\) with \(L1\) and obtained four coordination networks depending on metal-to-ligand ratio and solvent conditions used.

We have previously shown that the isomeric 1,2-dithiane heterocycle is formed upon treatment of 1,4-butanedithiol in the presence of CuI yielding the luminescent 1D material \([\{\text{Cu}(\mu_{2}-1)_{2}\text{Cu}_{1}(1,2\text{-dithiaenecycl}_{2})\}_{n}\) featuring rhomboid \(\text{Cu}(\mu_{2}-1)_{2}\text{Cu}\) clusters, which are linked through the S-atoms of six-membered 1,2-dithiane heterocycles. In contrast to \([\text{Cu(MeCN)}_{4}]^{+}\) salts, CuI and CuBr form upon complexation with thioethers readily halide-bridged polynuclear aggregates, whose nuclearities and geometries are almost unpredictable. We and other research groups encountered after ligation of aliphatic and aromatic dithioethers \(\text{RS(CH}_{2})_{n}\text{SR} (n = 1-8)\) and \(\text{RSCH}_{2}\text{C=CH}_{2}\text{SR}\) a panoply of discrete molecular compounds, CPs and MOFs of varying dimensionality incorporating as connecting nodes the \(\text{Cu}(\mu_{2}-X)_{2}\text{Cu}\) rhomboid, the tetranuclear closed-cubane \(\text{Cu}_{4}\text{I}_{4}\) cluster, the prismane-shaped \(\text{Cu}_{6}\text{I}_{6}\) cluster and the fused octanuclear \(\text{Cu}_{8}\text{I}_{8}\) cluster. Apart from the fascinating structural richness of these compounds, their photophysical properties, often associated with intense photoluminescence and luminescence thermochromism, intrigued us to investigate in
details the coordination chemistry of 1,3-dithiane \textbf{L1} and 2-substituted derivatives such as 2-methyl-1,3-dithiane \textbf{L2}, 2-isobutyl-1,3-dithiane \textbf{L3}, 2-Me$_3$Si-1,3-dithiane \textbf{L4}, 2-phenyl-1,3-dithiane \textbf{L5} and 2-ferrocenyl-1,3-dithiane \textbf{L6} \textit{vis-à-vis} CuI, CuBr and CuCl. This study completes our recent investigation on the coordination of 2-methyl-1,3-dithiane \textbf{L2} on CuI where, depending on the reaction conditions, both topological isomers of composition [{\text{Cu}(\mu_2\text{-I})_2}{\text{Cu}}]_n or the luminescent 3D material [{\text{Cu}_8(\mu_3\text{-I})_8}(\mu_2\text{-L2})_4]_n, exhibiting an unprecedented octanuclear Cu$_8$I$_8$ SBU, have been prepared and structurally characterized.\textsuperscript{48} The chemical structures of the investigated ligands with the dimensionalities and nuclearities of the secondary building units of the resulting CPs are shown in Chart 1.

\textbf{Chart 1.} Ligands and coordination polymers investigated

<table>
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<tr>
<th>Ligand</th>
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<th>CPs</th>
<th>SBU</th>
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<tr>
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RESULTS AND DISCUSSION

Synthesis and X-Ray diffraction characterization

Treatment of 1,3-dithiane $L_1$ with CuX ($X = I, Br, Cl$). In continuation of our previous work on the coordination chemistry of cyclic and acyclic dithioether ligands on CuX salts and to complete the series of ionic Cu(I) networks obtained by Keller and Knaust by treatment of $[\text{Cu(MeCN)}_4]\text{BF}_4$ with 1,3-dithiane $L_1$, we reacted this heterocycle with CuI in a 1:1 ratio. After heating in EtCN, a colorless crystalline material of composition $\{\text{Cu}(\mu_2\text{-I})_2\text{Cu}(\mu_2\text{-L}_1)_2\}_n$ was obtained in over 90% yield (Scheme 1).
Scheme 1. Synthesis of the 1D CPs [{Cu(\(\mu_2\)-I)\(_2\)Cu}\(\mu_2\)-L1\(_2\)] \(_n\) CP1 (X = I) and CP2 (X = Br) and the 2D CP [{Cu(\(\mu_2\)-Cl)\(_2\)Cu}\(\mu_2\)-L1\(_2\)] \(_n\) CP3.

An X-ray diffraction study revealed formation of ribbon-like 1D coordination polymer, in which rhomboid Cu(\(\mu_2\)-I)\(_2\)Cu units are linked through bridging dithiane cycles using both S atom as donor sites (Figures 1 and S1). Let us first compare the structural features of [{Cu(\(\mu_2\)-I)\(_2\)Cu}\(\mu_2\)-L1\(_2\)] with those of its 1D isomer [{Cu(\(\mu_2\)-I)\(_2\)Cu}(1,2-dithiane)\(_2\)] \(_n\). This latter is assembled by rhomboid Cu(\(\mu_2\)-I)\(_2\)Cu clusters, which are linked through the S-atoms of six-membered 1,2-dithiane heterocycles, thus generating an infinite ribbon. But in contrast to
[{Cu(μ₂-I)₂Cu}{μ₂-L1}₂], where the centrosymmetric Cu(μ₂-I)₂Cu units are arranged roughly perpendicular with respect to the 1,3-dithiane cycles, those of [{Cu(μ₂-I)₂Cu}{1,2-dithiane}₂]ₙ are approximately coplanar. Another striking difference concerns the Cu····Cu distances within the Cu(μ₂-I)₂Cu rhomboids, which are far longer in the 1,3-dithiane isomer than in 1,2-dithiane one (2.8904(6) vs. 2.6843(18) Å).

The coordination mode of [Cu(μ₂-I)₂Cu]{μ₂-L1}₂ is more reminiscent to that encountered in 1D CP [{Cu(μ₂-I)₂Cu}_2{μ-PhS(CH₂)₂SPh}_2]ₙ, displaying a Cu····Cu separation of 2.8058(11) Å. Other complexes exhibiting a rhomboidal Cu₂I₂ unit and weak Cu····Cu interactions close to the values of [{Cu(μ₂-I)₂Cu}{μ-PhS(CH₂)₅SPh}_2]ₙ (m = 2,3,5) have been reported for the 3D CP [Cu₂I₂[16]aneS₄]ₙ ([16]aneS₄ = 1,5,9,13-tetrathiaacyclohexadecane) (2.8079(12) Å and dinuclear [{MeSi(CH₂SMe)₃}CuI]₂ (2.862(2) Å).5,19,50

**Figure 1.** View of the 1D ribbon of [{Cu(μ₂-I)₂Cu}]{μ₂-L1}₂ CP1 running along b axis. Selected bond lengths (Å) and angles (°): Cu····Cu# 2.8904(6), Cu–I 2.5989(4), Cu–I# 2.6492(3), Cu–S1 2.3312(7), Cu–S2 2.3262(6); Cu–I–Cu# 66.829(11), S1–Cu–S2 103.93(2), S1–Cu–I 111.443(3), S1–Cu–I# 109.053(18), S2–Cu–I 110.461(18), S2–Cu–I# 108.333(18).

The homogeneity of the phase was ascertained by recording the PXRD spectrum (Figure S17). Previous studies from our group have shown that the CuI-to-ligand ratio may have a crucial impact on the architecture as well as on nuclearity within the (CuI)ₙ clusters of the resulting network.48 For example, mixing CuI and PhS(CH₂)₅SPh in a 2:1 ratio results in formation of [Cu₄I₄{μ-PhS(CH₂)₅SPh}₂]ₙ in which cubane-like Cu₄(μ₃-I)₄ cluster are linked by the bridging dithioether ligand giving rise to a 1D necklace structure.37 However, a 1D-chain with composition [{Cu(μ₂-I)₂Cu}]{μ-PhS(CH₂)₅SPh}_2]ₙ, incorporating rhomboid Cu₂I₂ units,
is produced upon treatment of CuI with 1,5-bis(phenylthio)pentane in a 1:1 ratio. Therefore, we reacted 1,3-dithiane also with two equivalents of CuI in MeCN solution. However, a comparison of the PXRD spectra (Figure S17) revealed that no other species is present in the precipitated colorless bulk material. Note also, that in this case and in contrast to L2 (see below), the order of addition of the reactants does not affect the outcome of the reaction.

We reacted under analogous condition L1 also with CuBr. Again a colorless, sparingly soluble material of composition \([{\text{Cu}(\mu_2-\text{Br})_2\text{Cu}}(\mu_2-L1)_2]_n\) CP2 was formed (Figure 2 and Figure S2), crystallizing like \([{\text{Cu}(\mu_2-\text{L})_2\text{Cu}}(\mu_2-L1)_2]_n\) in the orthorhombic space group Pnma. Compared with the latter, the Cu····Cu contact of 2.9143(3) Å is looser and matches well with that of 1D CP \([{\text{Cu}(\mu_2-\text{Br})_2\text{Cu}}(\mu_2-\text{PhSCH}_2\text{SPh})_2]_n\) (2.9192(8) Å).

![Figure 2. View of the 1D ribbon of \([{\text{Cu}(\mu_2-\text{Br})_2\text{Cu}}(\mu_2-L1)_2]_n\) CP2. Selected bond lengths (Å) and angles (°): Cu····Cu# 2.9143(3), Cu–Br 2.4478(2), Cu–Br# 2.5088(2), Cu–S1 2.2989(3); Cu–S2 2.3009(3), Cu–Br–Cu# 72.011(6), S1–Cu–S2 105.170(11), S1–Cu–Br 112.192(9), S1–Cu–Br# 109.151(9), S2–Cu–Br 113.089(8), S2–Cu–Br# 109.169(9).](image)

Tan and Ang reported that L1 reacts readily with CuCl\(_2\) to form a paramagnetic species \([\text{CuCl}_2L1]\) undergoing spontaneously reduction to give finally \([\text{Cu}_2\text{Cl}_2L1]\) according to elemental analysis and magnetic measurements. We repeated this experience using CuCl\(_2\)\cdot2\text{H}_2\text{O} as starting material and noticed also progressive discoloration of the initially green solution to yellowish with precipitation of a colorless powder, which was analyzed to have indeed a composition \([\text{Cu}_2\text{Cl}_2L1]\).

Note that other examples of the reduction of CuCl\(_2\) in the presence of thioethers have been reported previously. In an alternative approach, we added a twofold amount of CuCl to a MeCN solution of L1, causing rapid precipitation of a microcrystalline solid in over 85% yield (Scheme 1). This latter was analyzed to have also a
2:1 Cu:L1 composition, different from the 1:1 Cu:L1 composition found for CP1 and CP2. By recrystallization of a sample from hot EtCN, small single-crystals crystallizing in the monoclinic space group $P2(1)/c$ could be grown. Examination of the X-ray data of [{Cu(μ₂-Cl)₂Cu}{μ₂-L1}]ₙ CP3 (Figure 3) reveals that the dimensionality of the network has changed to 2D. Like in CP1 and CP2, rhomboid Cu(μ₂-X)₂Cu SBUs are present, but they are composed of two crystallographically distinct Cu atoms with Cu1····Cu2 separation of 2.809(2) Å. Apart from the dimensionality, the second salient feature concerns the bonding mode of the S atoms. Whereas in CP1 and CP2 all S-atoms act as 2-electron donors, in CP3 both lone pairs of the S-donors are engaged in bonding as schematically shown in Scheme 1. The propensity of 1,3-dithiane to act as a μ₂-S,S 4-electron donor has been previously evidenced for the cluster [Os₆CO₁₆(μ₂-L1)], where L1 is bridging across an Os–Os edge via one of the sulfur atoms.¹⁷
Figure 3. (top) Perspective view down the c axis on the a,b plane of the 2D network of \([\{\text{Cu}(\mu_2-\text{Cl})_2\text{Cu}\}(\mu_2-\text{L1})]_n\text{ CP3.} (bottom) View on the h,c plane of the 2D network of CP3. Selected bond lengths (Å) and angles (°): Cu1⋅⋅⋅Cu2 2.809(2), Cu1–Cl1 2.302(2), Cu1–Cl2 2.339(2), Cu1–S1 2.294(2), Cu1–S2 2.317(4); Cu2–S2 2.263(2); Cu1–Cl1–Cu2 92.68(7), Cu1–Cl2–Cu2 73.33(7), S1–Cu1–S1 106.97(8), S1–Cu–S2 108.21(8), S1–Cu1–Cl1 123.18(8), S2–Cu2–Cl2 124.64(8). Symmetry transformations used to generate equivalent atoms: \(1\)–X,1–Y,1–Z; \(2\)–X,+Y,–1+Z; \(3\)–X,3/2–Y,1/2+Z; \(4\)–X,3/2–Y,–1/2+Z; \(5\)–X,+Y,1+Z.

The comparison of the PXRD pattern of the material obtained by reduction of CuCl₂ and direct complexation of L1 confirms that (i) both compounds have the identical composition and (ii) the experimental diffractogram of CP3 matches with the calculated one (Figure 4).
Treatment of 2-methyl-1,3-dithiane \( \text{L2} \) with \( \text{CuX} \) (\( \text{X=I, Br, Cl} \)) and \( \text{CuCN} \). In contrast to \( \text{L1} \), its derivative 2-methyl-1,3-dithiane \( \text{L2} \) bearing a sterically more crowded substituent at the 2-position of the dithiane cycle, has been very scarcely probed as ligand in coordination chemistry. The few representatives, whose fluxional behavior has been investigated by NMR techniques in solution, are \([\text{M(CO)}_5\text{L2}]\) and \([\text{Fe(CO)}_4\text{L2}]\).\(^{55,56}\) According to a survey of the CSD data base, there are no examples of crystallographically characterized coordination compounds ligated with alkyl- or aryl-substituted dithianes. Recently, we investigated in depth the reactivity of \( \text{L2} \) toward \( \text{CuI} \). When \( \text{L2} \) and \( \text{CuI} \) were reacted in a 1:1 ratio, we evidenced the formation of two topological 1D (\( \text{CP5} \)) and 2D (\( \text{CP4} \)) isomers of formula \([\{\text{Cu}_2\text{I}_2\}(\text{L2})_2)_n\] featuring dinuclear \( \{\text{Cu}_2(\mu_2-\text{I})_2\} \) rhomboids.\(^{48}\) We also demonstrated that the network dimensionality can be controlled by the order of reactants addition. More interestingly, when 2 eq. of \( \text{L2} \) were used, a strongly luminescent non-porous 3D coordination polymer \([\{\text{Cu}_8(\mu_3-\text{I})_8\}(\mu_2-\text{L2})_4)_n\] \( \text{CP6} \), incorporating unprecedented \( \text{Cu}_8\text{I}_8\text{S}_8 \) clusters (built upon two side-fused open cubanes) was obtained (Scheme 2). We have furthermore shown that \( \text{CP4} \) and \( \text{CP5} \) can be converted in hot butyronitrile to strongly luminescent \( \text{CP6} \). For comparison, we extended our study on the coordination chemistry of \( \text{L2} \) toward \( \text{CuBr} \) and \( \text{CuCl} \) vs \( \text{CuI} \).
Addition of a slight excess of \( \text{L2} \) to MeCN solutions of CuBr and CuCl resulted in fast deposition of large amounts of microcrystalline solids. X-ray suitable single crystals crystallizing in both cases in the monoclinic space group \( C2/m \) were obtained from dissolution of solid samples in hot EtCN or by slow partial evaporation of MeCN solutions. The crystal structures of the resulting 1D CPs \([\{\text{Cu}(\mu_2-\text{Br})_2\text{Cu}\}(\mu_2-\text{L2})_2]\) \(\text{CP7}\) and \([\{\text{Cu}(\mu_2-\text{Br})_2\text{Cu}\}(\mu_2-\text{L1})_3]\) \(\text{CP8}\).
Cl$_2$Cu$_2$(μ$_2$-L2)$_2$)$_n$ CP8 shown in Figures 5 and 6 (Figures S3 and S4) are isostructural with their iodo analogue [{Cu(μ$_2$-I)Cu$_2$(μ$_2$-L2)$_2$}]$_n$ CP5, constituting thus a unique case allowing a comparative description. The non-bonding Cu⋯⋯Cu# contacts of the centrosymmetric [{Cu(μ$_2$-X)$_2$Cu$_2$}] rhomboids shorten systematically from 3.367 to 3.176 Å going from I to Br and reach 3.0517(8) Å for X = Cl. The Cu–X–Cu angles are not much affected by this shrinking of the Cu⋯⋯Cu# contacts and evolve from 79.042(10)° (X = I), 79.165(16)° (X = Br) to 79.851(16)° (X = Cl). Within this series, the Cu–S bond length falls with increasing electronegativity of the bridging halide from 2.3316(4), 2.3097(6), to 2.3060(4) Å. We are not aware of other complete literature-known [{S$_2$Cu(μ$_2$-X)$_2$Cu}]$_2$ series. Note that an opposite evolution of the Cu⋯⋯Cu separation is noticed in the case of the L1-ligated compound [{Cu(μ$_2$-X)$_2$Cu}(μ$_2$-L1)$_2$]$_n$ CP1 and CP2 (X = I, Br; see above). The same tendency has been reported for the isomorphous molecular compounds [{Cu(μ$_2$-X)$_2$Cu}(μ-$\text{PhCH}_2\text{SCH}_2\text{C}≡\text{CCH}_2\text{SCH}_2\text{Ph})$_2$], where in the case of X = I the Cu⋯⋯Cu distance is shorter than for X = Br [2.9279(5) vs. 3.0075(5) Å].\textsuperscript{57} The opposite trend has been noticed by Bowmaker et al. for 1:1:1 adducts of copper(I) halides with phosphine and amine donor ligands, [{CuX[PPh$_2$(C$_6$H$_4$Me-o)](cpy)$_2$}] (cpy = 4-cyanopyridine; X = Cl, Br or I). In this latter series, the Cu⋯⋯Cu distances increase from 3.119(3) to 3.201(2) to 3.304(2) Å.\textsuperscript{58} Currently, we have no explanation to rationalize these findings.

**Figure 5.** View of a segment of the 1D ribbon of [{Cu(μ$_2$-Br)$_2$Cu}(μ$_2$-L2)$_2$]$_n$ CP7. Selected bond lengths (Å) and angles (°): Cu⋯⋯Cu# 3.176, Cu–Br 2.4393(6), Cu–Br# 2.5428(5), Cu–S 2.3097(6), Cu–S# 2.3098(6), Cu–Br–Cu# 79.165(16), Br–Cu–Br# 100.835(16), S–Cu–Br 118.096(18), S–Cu–Br# 107.533(18), S#–Cu–Br 118.096(18), S–Cu–S# 103.97(3).
Figure 6. View of a segment of the 1D ribbon of \([\{\text{Cu}({\mu}_2-\text{Cl})_2\text{Cu}\}({\mu}_2-\text{L}_2)_2\}]_n\) \textbf{CP8}. Selected bond lengths (Å) and angles (°): Cu····Cu\# 3.0517(8), Cu–Cl 2.3133(7), Cu–Cl\# 2.4393(7), Cu–S 2.3060(4), Cu–Cl–Cu\# 79.851(16), Cl–Cu–Cl\# 100.148(15), S–Cu–Cu\# 126.738(10), S–Cu–S\# 104.13(2), S\#–Cu–Cl 118.741(11), S–Cu–Cl\# 106.997(13).

Although less common than CuX thioether adducts, the pseudohalide salt CuCN is also known to form both discrete molecular complexes and coordination polymers with varying dimensionalities upon treatment with thioether ligands. Examples are the dinuclear species \([\{9S3\}\text{Cu}({\mu}_2-\text{CN})(9S3)]\text{BF}_4\) (9S3 =1,4,7-trithiacyclononane) or an 3D network of formula \([(\text{Cu}({\mu}_2-\text{CN})(\mu_2-\text{SMe}_2))]_n\). Another example of a 3D network assembled by tetrahydrothiophene ligands is \([(\text{Cu}({\mu}_2-\text{CN})(\mu_2-\text{THT})])_n\). When adding a slight excess of \textbf{L2} to hot suspension of CuCN in MeCN a greyish microcrystalline solid precipitated rapidly. We failed to obtain acceptable elemental analysis or PXRD data for this compound, which seems to lose progressively the somewhat volatile \textbf{L2} ligand upon drying. The facile release of CuCN-bound ligands yielding CuCN has been evidenced by means of thermal analysis elsewhere.
Scheme 3. Synthesis of \([\text{Cu(\(\mu_2\)-CN)(\(\mu_2\)-L2)}\] \(_n\) CP9.

Characteristic in the ATR-IR spectrum of CP9 is the presence of an intense v(C≡N) vibration occurring at 2121 cm\(^{-1}\) indicative for a covalently bound cyanide ligand (Fig S33 ESI). As in other CuCN CPs ligated by donor ligands, the v(C≡N) stretch is markedly red-shifted compared to that of uncoordinated CuCN (2170 cm\(^{-1}\)). Due to its poor solubility, a small amount was re-dissolved in hot benzyl cyanide at 180 °C in the presence of L2 and then allowed to reach ambient temperature forming a product crystallizing in the orthorhombic space group \(Cmc2_1\). A view of the corrugated 2D sheets of \([\text{Cu(\(\mu_2\)-CN)(\(\mu_2\)-L2)}\] \(_n\) CP9 is shown in Figure 7. The layers are constructed by two crystallographically different tetrahedral Cu1 and Cu2 centers, each one ligated by one C-bound cyanide, one N-bound cyanide from a neighbored Cu atom and the S atoms of two L2 ligands. A view down the \(b\) axis on a 2D sheet of CP9 is given in Figure S5.
Figure 7. View down the $a$ axis of the 2D layer of $[\{\text{Cu(}$\mu_2\text{-CN}$)\text{Cu}1(\mu_2\text{-L2})\text{Cu}2\}]_n$ CP9. Selected bond lengths (Å) and angles (°): Cu1–C5 1.935(3), Cu2–C6 1.920(3), Cu1–S1 2.3469(6), Cu2–S2 2.4032(6), Cu1–N2 2.006(6), Cu2–N1 2.015(3), C5–N1 1.142(4), C6–N2 1.153(4); S1–Cu1–S1 99.39(3), S2–Cu2–S2 95.64(3), S1–Cu1–S1 104.92(5), N1–Cu2–S2 102.35(6).

Treatment of 2-isobutyl-1,3-dithiane L3 with CuX ($X = I, Br, Cl$). Intrigued by the striking differences concerning the dimensionalities and nuclearities of the polymeric materials obtained from reaction of CuX with L1 and L2, we investigated also in detail the effect of the substitution at the 2-position by a bulkier isobutyl group. We therefore reacted first CuI with 2-isobutyl-1,3-dithiane L3 in a 1:1 ratio (Scheme 4). A white precipitate immediately formed at room temperature. Dissolution of a small amount of this powder into hot acetonitrile led to the formation of the 2D CP10 of composition $[\{\text{Cu}_3(\mu_3-\text{I})(\mu_2-\text{I})_2(\mu_2-\text{L3})\}]_n$, which crystallizes in the triclinic space group $P\bar{1}$. Here, again, addition of an excess of L3 (ratio 1:2) led also to CP10 as proven by PXRD (Figure S21). The most salient feature in the crystal structure is the occurrence of triangular Cu$_3$I$_3$ SBUs, capped by a $\mu_3$-iodo ligand and two $\mu_2$-bond I atom spanning two edges (Figures 8 and S6). All Cu····Cu contacts are quite different ranging between weakly bonding (Cu2–Cu3 2.7625(3) Å), to clearly non-bonding Cu1····Cu3 2.9554(3) Å and Cu1····Cu2 3.336 Å. The structure presents four non-equivalent sulfur atoms. The particularity is that the S3 atom acts as 4-electron donor while the others are only two electrons donors. Thus, one isobutyl-1,3 dithiane ligand acts solely as a $\kappa_1S$-$\kappa_1S$ ligand while
the second one acts as a $\kappa_1S_{12}S$ ligand. The first dimension is maintained through the coordination of one ligand to two Cu$_3$I$_3$ SBUss thus forming Cu$_1$S$_1$S$_2$-Cu$_2$ ribbons. The coordination of S3 to Cu1 and Cu2 and of S4 to Cu3 led to the second dimension, thus generating 19-membered macrocycles.

Scheme 4. Synthesis of the 2D CPs CP10, CP11 and CP12 obtained by treatment of CuX with L3.
Figure 8. View down the c axis of the 2D network of \([\{\text{Cu}_3(\mu_3-I)(\mu_2-I)_2(\mu_2-L3)_2\}\]_n CP10. Selected bond lengths (Å) and angles (°): Cu1···Cu3 2.9554(3), Cu2–Cu3 2.7625(3), Cu1···Cu2 3.336 Cu1–I1 2.5910(2), Cu3–I1 2.6643(2), Cu1–I2 2.8034(2), Cu2–I2 2.8340(2), Cu3–I2 2.6486(2), Cu2–I3 2.5875(2), Cu3–I3 2.6481(2), Cu1–S1 2.3132(3), Cu1–S3 2.3179(3), Cu2–S3 2.3190(3), Cu2–S2 2.2976(3), Cu1–I1–Cu3 68.423(6), Cu1–I2–Cu2 72.560(6), Cu1–I2–Cu3 65.578(6), Cu2–I2–Cu3 60.400(6), Cu2–I3–Cu3 63.681(7), Cu1–S1–Cu2 93.047(12), S1–Cu1–S3 132.568(13), S2–Cu2–S3 136.460 (13).

Several other examples of CPs incorporating trinuclear Cu3I6S3 (X = 3,4) motifs such as catena-[tris(μ3-I)-(μ2-I)-(ethyl-(N-ethyl-4-pyridinio)sulfido)-tricopper(I)] (EtS-4-C5H4NEt)[Cu3I4], constructed of Cu3I4 and EtS-C5H4N2Et components, are literature-known. The assembly of a 3D CP \([(\text{Cu}_3\text{I}_3)\text{(thiacrown) • (MeCN) • (CH}_2\text{Cl}_2 • (2H}_2\text{O})\]_n by mixing calix[4]-bis-thiacrown with CuI in CH2Cl2 and MeCN has been reported by Lee et al. Upon removal of the coordinated solvent molecules by heating, the initial solvent-coordinated CP undergoes a single-crystal-to-single-crystal transformation to the desolvated polymer \([(\text{Cu}_3\text{I}_3)\text{(thiacrown) • (0.5H}_2\text{O})\]_n. For other Cu3I3 containing compounds, see also: There is also a report on the molecular compound [Cu3I4(dodecylMeS)](dodecylMe2S) containing an anionic iodocuprate Cu3I4− cluster with short Cu–Cu distances of 2.657 to 2.704
Å and a dodecyltrimethylsulphonium cation as counterion. However, the structural features of CP10 differ considerably from those examples. Although the iodocuprates [Cu3I4(dodecylMeS)][dodecylMe2S] and (EtS-4-C5H4NEt)[Cu3I4] incorporate like CP10 triangular Cu clusters, those triangles are far more symmetric with mean Cu–Cu distances below 2.8 Å. The SBUs of [(Cu3I3)(thiacrown) • (MeCN) • (CH2Cl2) • (2H2O)]n do not form triangles, but are described as three-runged ladder type Cu3I3 units bearing exclusively μ2-bound iodo ligands. Although the two latter materials own also a Cu3I3S4 composition like CP10, there is one CuI unit without any Cu–S bond and two CuI units connected each to two S-donor sites.

The treatment of L3 with CuBr under analogous reaction conditions gives also rise to a 2D network but, in contrast to that of CP10, the topology of this colorless material crystallizing in the monoclinic space group P21/c is rather trivial (Scheme 4). Figures 9 and S7 show that the 2D layers of [{Cu(μ2-Br)2Cu}(μ2-L3)]n CP11 are composed of rhomboid Cu(μ2-Br)2Cu SBUs, whose Cu–Cu distance matches with that of CP2 (2.9057(2) vs 2.9143(3) Å). Unlike the Cu(μ2-Br)2Cu SBUs of CP2 and CP7, the two Cu atoms of CP11 are crystallographically different.
Figure 9 View on the $b,c$ plane of the 2D network of $\text{[Cu}$(\mu_2$-$\text{Br})_2$Cu$(\mu_2$-$\text{L3)}}_2$, CP11. Selected bond lengths (Å) and angles (°): Cu1–Cu2 2.9057(2), Cu1–Br1 2.5636(2), Cu1–Br2 2.4136(2), Cu2–Br1 2.4834(2), Cu2–Br2 2.4872(2), Cu1–S1 2.3882(3), Cu1–S2 2.3161(3), Cu2–S3 2.2724(3), Cu2–S4 2.3249(3); Cu1–Br1–Cu2 70.279(6), Cu1–Br2–Cu2 72.710(7), Br1–Cu1–Br2 108.328(7), Br1–Cu2–Br2 108.578(7), S1–Cu1–S2 105.945(11), S3–Cu2–S4 108.523(12).

The isostructural 2D CP $\text{[Cu}$(\mu_2$-$\text{Cl})_2$Cu$(\mu_2$-$\text{L3)}}_2$, CP12 shown in Figures 10 and S8 results from treatment of a solution of CuCl in MeCN with L3. Compared with the Cu1····Cu2 distance of the Cu$(\mu_2$-$\text{X})_2$Cu rhomboid of its bromo analogue CP11, that of CP12 shrinks somewhat (2.9057(2) vs. 2.8715(9) Å), in line with the trend noticed for CP7 and CP8 within the $\text{[Cu}$(\mu_2$-$\text{X})_2$Cu$(\mu_2$-$\text{L2)}}_2$, series (see above).
Figure 10. View down the a axis on the bc plane of the 2D network of \([\{\text{Cu}(\mu_2-\text{Cl})_2\text{Cu}\}(\mu_2-\text{L3})_2]\)_{\text{CP12}}. Selected bond lengths (Å) and angles (°): Cu1–Cu2 2.8715(9), Cu1–Cl1 2.3813(13), Cu1–Cl2 2.38106(13), Cu2–Cl1 2.2890(13), Cu2–Cl2 2.4413(13), Cu1–S1 2.33231(13), Cu1–S2 2.2624(13), Cu2–S3 2.2992(13), Cu2–S4 2.3829(12); Cu1–Cl1–Cu2 75.85(4), Cu1–Cl2–Cu2 73.08(4), Cl1–Cu1–Cl2 104.968(5), Cl1–Cu2–Cl2 105.94(5), S1–Cu1–S2 108.70(5), S3–Cu2–S4 106.81(15).

Treatment of 2-Trimethylsilyl-1,3-dithiane L4 with CuX (X = I, Br, Cl). In order to evaluate the impact of a heteroelement at the 2-position of the dithiane cycle, we extended our systematic investigation on 2-trimethylsilyl-1,3-dithiane bearing a bulky SiMe3 group. A survey of the CSD data base revealed that apart from the dinuclear complex \([\text{Ag}(\text{Me3Si}-\text{dithiane})_2(\text{CF}_3\text{SO}_3)_2]\) obtained by complexation of 2-trimethylsilyl-1,3-dithiane on silver triflate, no other examples of crystallographically characterized coordination compounds ligated with L4 have been reported so far.

Addition of a stoichiometric amount of L4 to a MeCN solution of Cul caused fast precipitation of colorless solid, which, surprisingly had composition \([\{\text{Cu}_2\text{I}\}(\text{L4})]\) indicating a 2:1 metal-to-ligand ratio (Scheme 5). Indeed, recrystallization of a sample of the collected material from hot MeCN afforded fine needle-shaped crystals whose crystallographic characterization confirmed this \([\{\text{Cu}_2\text{I}\}(\text{L4})]\) composition. Note that this compound \([\{\text{Cu}_2(\mu_4-\text{I})(\mu_2-\text{I})\}(\mu_2-\text{L4})]\)_{\text{CP13}} is markedly more soluble than \text{CP1, CP4} and \text{CP5}, probably due the presence of the SiMe3 substituent.

![Scheme 5. Synthesis of the 1D CPs \([\{\text{Cu}_3(\mu_4-\text{X})(\mu_2-\text{X})\}(\mu_2-\text{L4})]\)_{\text{n}} \text{CP13, CP14 and CP15}](image-url)
The crystal structure of the resulting 1D ribbon is shown in Figures 11 and S9 and diverges much from the Cu(μ2-I)2Cu rhomboid containing 1D architectures of CP1 and CP5. The array of the crystallographically non-equivalent Cu1 and Cu2 atoms may be considered as meander-shaped (when neglecting the long Cu2····Cu2 separation of 3.362 Å), with Cu1–Cu1 and Cu1–Cu2 distances of 2.8203(12) and 2.9838(9) Å, respectively. Each Cu1–Cu2 bond is quite symmetrically bridged by a μ2-type I2 atom with Cu1–I2 and Cu2–I2 distances of 2.6139(7) and 2.5930(7) Å, respectively. Particularly noteworthy is the capping of each Cu1–Cu1–Cu2–Cu2 segment by a μ4-type I1 ligand, with Cu–I distances ranging from 2.6139(7) to 2.7005(7) Å. The two sulfur atoms of L4 span additionally two remote Cu1 and Cu2 atoms with Cu1–S1 and Cu2–S2 bond lengths of 2.3053(11) and 2.3131(11) Å, respectively. Figure 11 shows also the alignment of the L4 ligands adopting a chair conformation with the SiMe3 groups pointing away from the inorganic [{Cu2(μ4-I)(μ2-I)}]n ribbon.

Figure 11. View of a segment of the 1D ribbon of [{Cu2(μ4-I)(μ2-I)}(μ2-L4)], CP13 running along the b axis. Selected bond lengths (Å) and angles (°): Cu1–Cu1# 2.8203(12), Cu1–Cu2# 2.9838(9), Cu2····Cu2# 3.362, Cu1····Cu2 3.975, Cu1–I1 2.6345(7), Cu1–I1# 2.7005(7), Cu1–I2 2.6139(7), Cu2–I2 2.5930(7), Cu2–I1 2.6594(7), Cu2–I1# 2.6594(7), Cu1–S1 2.2922(13), Cu2–S2 2.2939(14); Cu1–Cu1#–Cu2 104.49(2), Cu1–I1–Cu1# 63.81(2), Cu1–I2–Cu2 69.92(2), Cu2–I2–Cu2# 76.89(2), I1–Cu1–I2 104.49(2), I1–Cu2–I2 103.61(2), S1–Cu1–I1 116.83(4), S1–Cu1–I1# 97.76(4), S1–Cu1–I2 114.06(4), S2–Cu2–I2 113.89(4).

With CuBr and L4, invariantly of the metal-to-ligand ratio, formation of [{Cu2(μ4-Br)(μ2-Br)} μ2-L4]n CP14 occurred, crystallizing like its CuI homologue CP13 as transparent
needles in the monoclinic space group $P2_1/n$ (Scheme 5). At first glance, the overall topology is very reminiscent to that of CP13 consisting of a 1D ribbon featuring both $\mu_4$-type and $\mu_2$-type halide ligands. However, a closer inspection of the structure shown in Figure 12 reveals that the symmetry is lowered since now 4 crystallographically different Cu atoms as well as 4 different S donor sites are present. The averaged Cu ⋯Cu distances are now somewhat longer than those of CP13 (3.063 vs. 3.055 Å), ranging from bonding (Cu2–Cu3 2.8159(3) Å) up to clearly non-bonding (Cu1····Cu4 3.409 Å). A perspective view of the packing down the $c$ axis is presented in Figure S10.

Figure 12. View of the 1D ribbon of $[\{\text{Cu}_2(\mu_4-\text{Br})(\mu_2-\text{Br})_2(\mu_2-\text{L}4)\}_n]$ CP14 running along the $b$ axis. Selected bond lengths (Å) and angles (°): Cu1····Cu2 3.0074(3), Cu2–Cu3 2.8159(3), Cu3····Cu4 3.0199(3), Cu1–Br1 2.5007(3), Cu1–Br3 2.6941(3), Cu1–Br2 2.4297(3), Cu2–Br1 2.4704(3), Cu2–Br2 2.4331(3), Cu2–Br3 2.6634(3), Cu3–Br1 2.6765(3), Cu3–Br3 2.4583(3), Cu3–Br4 2.4311(3), Cu4–Br1 2.6748(3), Cu4–Br3 2.5018(3), Cu4–Br4 2.4364(2), Cu1–S1 2.2597(4), Cu2–S2 2.2570(4), Cu3–S3 2.2533(4), Cu4–S4 2.2623(4), Cu1–Br1–Cu3 126.680(8), Cu2–Br1–Cu1 95.756(9), Cu2–Br1–Cu3 66.196(8), Cu3–Br3–Cu2 66.565(8), Cu3–Br3–Cu4 95.509(9), Cu4–Br3–Cu2 126.140(8), Br1–Cu2–Br3 113.643(9), Br1–Cu2–Cu3 60.418(7), Br2–Cu2–Br1 106.680(9), Br2–Cu2–Br3 101.557(9), Br2–Cu2–Cu3 116.231(10), Br3–Cu2–Cu3 53.225(7), Br1–Cu3–Cu2 53.386(7), Br3–Cu3–Br1 113.595(9), Br3–Cu3–Cu2 60.209(7), Br4–Cu3–Br1 100.806(9), Br4–Cu3–Br3 107.349(9), Br4–Cu3–Cu2 115.971(10).
A structural quite similar 1D ribbon $\left[ \{ \text{Cu}_2(\mu_4-\text{Cl})(\mu_2-\text{Cl})\}_{\mu_4-\text{L4}} \right]_{n}$ CP15 crystallizing in the triclinic space group $P\bar{1}$ was also isolated upon stoichiometric treatment of CuCl with L4 in MeCN solution. Whereas the Cu1–Cu1 distance of 2.883(3) Å is only slightly superior to that of CP12, both the Cu1···Cu2 and Cu2···Cu2 separations of 3.105 and 3.341 Å do no longer allow describing the connectivity between the Cu atoms as meander-shaped. A description as discreet Cu1–Cu1 pairs, which are connected to isolated Cu2 atoms through $\mu_2$-bound Cl2 atoms and capping $\mu_4$-bound Cl2 atoms, appears more appropriate. The metric parameters are presented in the caption of Figure 13 and a perspective view is shown in Figure S11.

**Figure 13.** View of the 1D ribbon of $\left[ \{ \text{Cu}_2(\mu_4-\text{Cl})(\mu_2-\text{Cl})\}_{\mu_4-\text{L4}} \right]_{n}$ CP15 running along the $a$ axis. Selected bond lengths (Å) and angles (º): Cu1–Cu1# 2.883(3), Cu1–Cl 2.325(2), Cu1–Cl1# 2.681(2), Cu1–Cl2 2.294(2), Cu2–Cl2 2.306(2), Cu2–Cl1 2.342(2), Cu2–Cl1# 2.671(2), Cu1–S1 2.239(2), Cu2–S2 2.249(2); Cu1–Cl1–Cu1# 69.62(7), Cu1–Cl2–Cu2 84.91(7), Cu2–Cu1–Cu2# 83.30(7), Cl1–Cu1–Cl2 112.42(8), Cl1–Cu2–Cl2 111.20(7), S1–Cu1–Cl1 122.91(8), S1–Cu1–Cl1# 92.70(7), S1–Cu1–Cl2 116.62(8), S2–Cu2–Cl2 115.64(8).

*Treatment of 2-phenyl-1,3-dithiane L5 with CuX (X = I, Br, Cl)*. We then investigated the effect of a bulkier and rigid phenyl substituent at the 2-position of the dithiane cycle on the structural features of the anticipated CP. For this, we treated first CuI with 2-phenyldithiane L5 in MeCN solution using a 1:1 metal-to-ligand ratio (Scheme 6).
Scheme 6. Synthesis of 1D [{\text{Cu}(\mu_2-I)_{2}Cu}(\text{MeCN})_{2}(\mu_2-L5)]_n \text{CP16} and 2D [{\text{Cu}_3}(\mu_3-I)(\mu_2-I)_2(\mu_2-L5)_2)]_n \text{CP17 and CP18.}

After mixing the two reactants, the resulting colorless poorly soluble precipitate was heated shortly till complete dissolution by further addition of MeCN. Upon cooling, the onset of a crystal growth on the wall was noticed. Surprisingly, elemental analysis of the resulting needle-shaped material indicated a 2:1 CuI-to-L5 composition as well as the presence of MeCN molecules. Indeed, employing a 2:1 metal-to-ligand ratio allowed to improve the yield up to 90%. An X-ray analysis of a single-crystal confirmed this composition revealing also the existence of Cu-coordinated MeCN molecules. Figure 14 shows that an undulated 1D ribbon [{\text{Cu}(\mu_2-I)_{2}Cu}(\text{MeCN})_{2}(\mu_2-L5)]_n \text{CP16} has been formed consisting of rhomboidal-shaped Cu$_2$I$_2$ SBUs linked by a L5 heterocycle via the S1 and S2 atoms. Noteworthy is the
alternating occurrence of two different types of centrosymmetric rhomboids featuring slightly different metric parameters. In the Cu1–Cu1 SBU the metal-metal bond 2.6555(10) Å is particularly short, whereas within the Cu2–Cu2 SBU the bond distance reaches 2.7014(10) Å.

Two $\mu_2$-spanning iodo ligands and a datively bound MeCN ligand with Cu–N distances of 1.967(4) and 1.982(4) Å complete the coordination of each copper center, respectively. A perspective view down the c axis is shown in Figure S12 (ESI).

**Figure 14.** View of the 1D ribbon of [{Cu($\mu_2$I)2Cu}(MeCN)2($\mu_2$L5)]n CP16 running along the c axis. Selected bond lengths (Å) and angles (°) at 100 K: Cu1–Cu1# 2.6588(3), Cu2–Cu2# 2.7086(3), Cu1–II 2.6339(2), Cu1#–II 2.6764(2), Cu2–II 2.6187(2), Cu2#–I2 2.6897(2), Cu1–S1 2.3193(3), Cu1–N1 1.9716(10), Cu2–S2 2.3324(3), Cu2–N2 1.9775(10); Cu1–II–Cu1# 60.085(6), Cu2–I2–Cu2# 61.343(6), S1–Cu1–II 98.984(11), S2–Cu2–I2 102.224(10).

Examples of CPs incorporating two different types of Cu($\mu_2$-X)2Cu rhomboids within the same array are quite rare. We have encountered such a case in 1D CP [{Cu($\mu_2$-Br)2Cu}($\mu$-p-MeC6H4SCH2C≡CCH2SC6H4Me-p)]n, showing a regular alternation of Cu($\mu_2$-Br)2Cu SBUs (2.9662(14) Å) with a second type featuring somewhat shorter contacts (2.9306(14) Å). However, the difference in the Cu–Cu distance in CP16 is clearly more significant with $\Delta$(Cu–Cu 0.0489 Å). We therefore subjected a single-crystal stemming from another probe to a structural analysis at 5 different temperatures in a 100-300 K range. Whereas the metric parameters at 100 K are almost identical with those presented in the caption of Figure 14, raising the temperature to 200 K causes a moderate lengthening of Cu1–Cu1 to 2.6731(7) Å and that of Cu2–Cu2 to 2.7114(7) Å. A phase transition (PT) occurs upon further heating to 26
250 K, resulting in a change of the space group from triclinic $P\bar{1}$ to monoclinic $P2_1/m$. This change impacts the symmetry of the (MeCN)SCu($\mu_2$-I)$_2$CuS(CNMe) units, which are now all crystallographically identical with Cu–Cu distance of 2.6965(5) Å. Finally, an elongation of the latter bond distance to 2.7003(6) Å was observed when recording the structure at 300 K. The reversibility of this PT was evidence by a fast scan recording at 100 K confirming reestablishment of the triclinic space group $P\bar{1}$. Some relevant metric parameters are gathered in Table 1, illustrations of the ribbons of CP16 at 100 and 300 K are shown as Figure S13 in the ESI. Although we have already observed a PT for the 1D CP $[\{Cu_4(\mu_3-I)_4\}\{\mu-PhSCH_2SPh\}]_n$ from C2/c to $P2_1/c$ upon heating, the PT in the case of CP16 accompanied by an harmonization of the metric parameters is to the best of our knowledge unique. To confirm the occurrence of the PT, DSC analysis were performed from 20°C to -80°C (Figure S36). Upon cooling/heating, a pair of exothermic/endothermic peaks was observed at -52/-58°C, indicating a reversible phase transition, in line with the PT observed by variable-temperature X-Ray diffraction analysis in the 200-250 K range.

**Table 1. Evolution of bond distances and angles with temperature for CP16.**

<table>
<thead>
<tr>
<th></th>
<th>100 K</th>
<th>150 K</th>
<th>200 K</th>
<th>250 K</th>
<th>300 K</th>
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<tr>
<td>Cu1–Cu1#</td>
<td>2.6588(3)</td>
<td>2.6642(4)</td>
<td>2.6731(7)</td>
<td>2.6965(5)</td>
<td>2.7003(6)</td>
</tr>
<tr>
<td>Cu2–Cu2#</td>
<td>2.7086(3)</td>
<td>2.7105(4)</td>
<td>2.7114(7)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu1–I1</td>
<td>2.6339(2)</td>
<td>2.6317(2)</td>
<td>2.6317(4)</td>
<td>2.6230</td>
<td>2.6191(4)</td>
</tr>
<tr>
<td>Cu1#–I1</td>
<td>2.6764(2)</td>
<td>2.6762(3)</td>
<td>2.6793(4)</td>
<td>2.6948(3)</td>
<td>2.6942(4)</td>
</tr>
<tr>
<td>Cu2–I2</td>
<td>2.6187(2)</td>
<td>2.6167(2)</td>
<td>2.6175(4)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu2#–I2</td>
<td>2.6897(2)</td>
<td>2.6910(3)</td>
<td>2.6954(4)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu1–S1</td>
<td>2.3193(3)</td>
<td>2.3205(4)</td>
<td>2.3250(7)</td>
<td>2.3330(5)</td>
<td>2.3344(6)</td>
</tr>
<tr>
<td>Cu2–S2</td>
<td>2.3324(3)</td>
<td>2.3322(4)</td>
<td>2.3347(8)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu1–I1–Cu1#</td>
<td>60.085(6)</td>
<td>60.249(8)</td>
<td>60.431(13)</td>
<td>60.920(10)</td>
<td>61.071(12)</td>
</tr>
<tr>
<td>Cu2–I2–Cu2#</td>
<td>61.343(6)</td>
<td>61.399(8)</td>
<td>61.353(13)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Intrigued by both the phase transition and the preference to ligate a labile MeCN donor in CP16 instead of coordination of a second L5 ligand, we repeated this reaction under more forcing conditions in hot EtCN employing a 2:1 stoichiometry. After reflux for two hours, a
homogeneous material crystallizing like CP16 in the triclinic space group P-1 was isolated in over 90% yield. In contrast to CP16 exhibiting in the IR spectrum two weak peaks at 2309 and 2275 cm$^{-1}$ due to the v(C≡N) vibration, the IR spectrum of this compound was silent in this region. In line with this finding the crystal structure of this air-stable polymeric material shown in Figure 15 revealed formation of 2D network of composition [{Cu$_3$(μ$_3$-I)(μ$_2$-I)$_2$(μ$_2$-L$_5$)$_2$}] CP17, which is very reminiscent to CP10. Again, triangular Cu$_3$I$_3$ clusters capped by a μ$_3$-iodo ligand and two μ$_2$-bond I atom spanning two edges constitute the SBUs. But in contrast to CP10, all Cu····Cu distances are now above the sum of the Van der Waals radii of two Cu atoms and range from weakly bonding (Cu1–Cu3 2.8302(4), Cu2–Cu3 2.8948(4) Å) to clearly non-bonding (Cu1····Cu2 3.297 Å). Thus, the mean Cu····Cu distance of the Cu$_3$I$_3$ triangle shortens from 3.0178 in CP10 to 3.007 Å in CP17. A view of the unit cell showing the stacking of the layers is presented in the ESI as Figure S14.

**Figure 15.** View on the a,b plane of the 2D network of [{Cu$_3$(μ$_3$-I)(μ$_2$-I)$_2$(μ$_2$-L$_5$)$_2$}]$_n$ CP17. Selected bond lengths (Å) and angles (°): Cu1–Cu3 2.8302(4), Cu2–Cu3 2.8948(4), Cu1····Cu2 3.297, Cu1–I1 2.5905(3), Cu3–I1 2.6591(3), Cu1–I3 2.7817(3), Cu2–I3 2.7803(3), Cu3–I3 2.6483(3), Cu2–I2 2.5842(3), Cu3–I2 2.6621(3), Cu1–S1 2.3050(3), Cu1–S3 2.3122(3), Cu2–S2 2.2876(5), Cu2–S3 2.2917(5), Cu3–S4 2.3393(5), Cu1–I1–Cu3 65.235(8), Cu2–I2–Cu3 66.961(8), Cu1–I3–Cu2 72.702(8), Cu1–I3–Cu3 62.771(8), Cu2–I3–Cu3 64.397(8), Cu1–S3–Cu2 91.461(16).
An isomorphic 2D network with that of CP17 (triclinic, P-1) results also from addition of L5 to a MeCN solution of CuBr (Figures 16 and S15). Again, each trinuclear Cu cluster is linked to 4 adjacent Cu3Br3 SBUs through the S1 and S2 atoms of one L5 molecule acting as κ1S-κ1S ligand and the S3 and S4 atoms of a second L5 heterocycle linking in a κ1S-μ2S bonding mode, thus securing the 2-dimensional character of each layer featuring 20-membered macrocycles. Compared to CP17, the mean Cu····Cu distance of the Cu3X3 triangle shrinks only insignificantly (3.007 vs. 2.989 Å). A survey of the CSD database reveals another rare example of a Cu3Br3 cluster ligated by a thioether catena-(bis(μ3-Br)-bis(μ3-diallylsulﬁdo)-tris(μ2-Br)-pentacopper(I), whose structure consists of infinite (Cu2Br2)n ribbons and Cu3Br3(diallylsulﬁde)2 fragments that are linked to them through Cu–S and π-olefinic C=C bonds.

Figure 16. View on the a,b plane of the 2D network of [{Cu3(μ1-Br)(μ2-Br)2(μ2-L5)2}]{CP18.}

Selected bond lengths (Å) and angles (°): Cu1–Cu3 2.8980(15), Cu2–Cu3 2.8194(14), Cu1····Cu2 3.249, Cu1–Br1 2.4199(13), Cu3–Br1 2.5173(14), Cu1–Br3 2.6135(13), Cu2–Br3 2.6862(13), Cu3–Br3 2.4744(14), Cu2–Br2 2.4225(13), Cu3–Br2 2.5064(13), Cu1–S1 2.266(2), Cu1–S3 2.263(2), Cu2–S2 2.270(2), Cu2–S3 2.270(2), Cu3–S4 2.293(2); Cu1–Br1–Cu3 71.85(4), Cu2–Br2–Cu3 91.57(7).
When attempting to complete the series by complexation of L5 on CuCl at room temperature, elemental analysis on the crude compound obtained indicates a 1:1 Cu: L5 ratio, different from the 3:2 Cu ratio expected for a compound related to CP17 and CP18. The crude product was further heated in hot MECN or EtCN and we noticed the formation of a small amount of a yellow product but we failed to grow crystals suitable for X-Ray analysis of the major product. Using CuCl2, surprisingly, a yellow material crystallizing as 3D polymer containing \(-\text{Cl}-\text{Cu}-\text{Cl}\)-chains assembled by five-membered 1,2-dithiolane ligands was isolated. Mechanistic details rationalizing this unexpected extrusion of a Ph-CH unit (most probably in form of benzaldehyde) and structure of this 3D network will be reported elsewhere.71, 72 Furthermore, the PXRD of the crude product obtained by reaction of CuCl2 and L5 matches perfectly with the one calculated from the single crystal of the CP containing 1,2 dithiolane ligand, confirming the formation of this compound as main product (Fig. S30).

Treatment of 2-ferrocenyl-1,3-dithiane L6 with CuI. The construction of polynuclear assemblies and coordination polymers featuring an organometallo-ligand, especially the electrochemically active and thermally robust ferrocenyl group in the main chain or as a pendant side-fragment has stimulated much interest in material sciences.73-81 Coordination polymers based upon ferrocenyltelluroethers or ferrocenylselenoethers are pre-catalysts promoting Ullmann C–N cross-coupling reactions in solution.82 Reaction of metal ions with ferrocenes functionalized with bis(thioether) substituents can give rise to the formation of discrete clusters.83, 84 Introduction of an additional donor site as in the case of 1,1-(4-dipyridinethio)ferroce led to the formation of 1D CP when reacted with Cu(I) salts.85 86 Recently, we reported on the complexation of the related five-membered ferrocenyl-dithiolane Fc-C(H)S2C2H4 on CuI and CuBr. A molecular heterometallic cluster \([\{\text{Cu}_5(\mu_2-\text{Br})_2(\mu_3-\text{Br})_2\}(\mu_2-\text{Fc-dithiolane})_2(\text{MeCN})_2]\) was obtained with CuBr, whilst 1D polymeric \([\{\text{Cu}_2(\mu_4-\text{I})(\mu_2-\text{I})(\mu_2-\text{Fc-dithiolane})\},n\) has been assembled with CuI. We were now intrigued to combine a ferrocenyl fragment with the 1,3-dithiane cycle to assemble coordination networks based on CuX salt to investigate their architecture and to compare the findings with our recent investigations using ferrocenyl-dithiolane.49

The synthesis of the heterocyclic dithioacetal Fc-C(H)S2C3H6 L6 has been first reported by treatment of ferrocenecarbaldehyde with 1,3-propanedithiol in the presence of HCl as catalyst.87 We have slightly modified the protocol using p-toluenesulfonic acid as catalyst. The crystal structure of this ferrocenyl-dithiane is shown in Figure S16, the crystallographic refinement
data are gathered in Table S7. The six-membered dithiane-heterocycle of L6 adopts the chair conformation as encountered in 2-phenyl-1,3-dithiane.88 Like the phenyl group in the latter thiaheterocycle, the ferrocenyl moiety occupies the equatorial position. The bond lengths and angles in L6 are normal for this kind of molecules and deserve no further comments.

As shown in Scheme 7, the outcome of the complexation of L6 on CuI in MeCN solution depends on the metal-to-ligand ratio and the order of reactant addition. A discrete molecular dinuclear species [{Cu(μ2-I)2Cu(κ1-L6)L2(MeCN)}2] D1 is formed employing a 1:1 ratio. The crystal structure of this dimer depicted in Figure 17 shows a centrosymmetric Cu2I2 rhomboid in which the two Cu atoms are connected through a quite short Cu–Cu bond of only 2.6897(4) Å. The coordination sphere around each Cu center is completed by a datively bound MeCN ligand and one S atom of L6. Surprisingly, the bonding mode of L6 is mono-hapto, with the second S atom prone for coordination of a second metal center. A bridging μ2-bonding of L6 can be achieved by performing the reaction in a 2:1 CuI-to-ligand ratio. Indeed, when L6 was added to 2 equivalent of CuI, PXRD analysis confirmed the formation of D1, whilst when adding 2 eq. of CuI to L6, an orange-colored crystalline solid [{Cu(μ3-I)2Cu(μ-L6)}n CP19 was isolated. The unusual 1D-polymeric architecture of CP19 is illustrated in Figure 18. The inorganic CuI ribbon of this material contains tetranuclear open Cu4I4 clusters as SBUs with a mean Cu–Cu distance of 2.7384 Å, below the sum of the Van der Waals radii of two Cu atoms. These tetranuclear units, capped by two μ3-type I2 atoms, are interconnected to adjacent ones through much looser Cu2⋯Cu2# contacts of 3.224(8) Å and two μ3-bridging I1 atoms with Cu–I1 bond distances ranging from 2.6555(8)-2.6844(8) Å. D1 exhibits in the IR spectrum two weak peaks at 2305 and 2275 cm⁻¹ due to the ν(C≡N) vibration (Figure S35). The structure of CP19 differs from that encountered in the CP obtained by reaction of 2 eq. of CuI with the less flexible 2-ferrocenyl-1,3-dithiolane ligand.49 In this latter case, the infinite ribbon was described as a meander-shaped array containing both μ4 and μ2-I ligands.
Scheme 7. Synthesis of L6 and its complexation on CuI yielding D1 and CP19.
Figure 17. View of the molecular structure of \([\{\text{Cu}(\mu_2\text{-I})_2\text{Cu}\}(\kappa_1\text{-L6})_2(\text{MeCN})_2]\) (D1). Selected bond lengths (Å) and angles (°): Cu–Cu# 2.6897(4), Cu–I 2.6362(3), Cu–I# 2.7102(3), Cu–N 1.9770(16), Cu–S 2.3010(5), C1–C11 1.493(2); N–Cu–S1 121.16(5), N–Cu–Cu# 123.71(5), N–Cu–I 111.95(5), I–Cu–I# 119.636(8), I–Cu–Cu# 61.214(9), S1–C11–S2 111.34(9). Symmetry transformations used to generate equivalent atoms: 1'1-X, 2-Y, 1-Z.

Figure 18. View of the 1D ribbon of \([\{\text{Cu}(\mu_3\text{-I})_2\text{Cu}\}(\mu_2\text{-L6})\]_n CP19 running along the a axis. Selected bond lengths (Å) and angles (°): Cu1–Cu1$^1$ 2.7215(9), Cu1–Cu2$^1$ 2.7469(7), Cu2–Cu1$^1$
Thermal properties

All compounds were found to be stable for several months under ambient atmosphere. The thermal properties of some selected CPs containing L2 (CP5, CP7, CP8), L3 (CP10, CP11 and CP12) and Ferrocenyl L6 ligands (CP19) were studied by TGA under air up to 850°C. The first derivative plots of the TGA traces are given in ESI (Figures S37-44) Temperatures of decomposition corresponding to a 5% loss of the total mass are given in Table 2. The thermogravimetric traces depicted in Figure 19 show that CPs containing L2 and L3 ligands present relatively identical thermal behavior. As already encountered for others thioether-based CPs, all thermal profiles of CPs containing bromide (CP7 and CP11) or chlorine (CP8) atoms present three main losses while the thermal decomposition of CP5 and CP10 containing iodide presents only two well decomposition steps. The first major weight loss can be attributed to the loss of ligands based on the comparison between the theoretical and experimental values (see Table 2). The final residual contents values are also close to those calculated based on the formation of CuO. Comparison of the traces between CP7 and CP8 within the L2 series and between CP11 and CP12 within the L3 series indicates that, independently to the dimensionality (1D or 2D), a higher stability is always obtained for CP containing Cu2Br2 SBU than those containing Cu2Cl2 rhombooids. This observation is consistent with our previous studies. It was however more difficult to obtain a tendency for CPs containing iodide. Compare to CP7 and CP8, the 1D CP5 that contains Cu2I2 rhomboids present a lower thermal stability. Oppositely, in the L3 series, the thermal stability of CP10 is higher than those of CP11 and CP12. In this case, the highest stability might be due to the presence of a Cu3I3 core. Comparison of thermal degradation temperatures between CP7 and CP11 containing Cu2Br2 rhomboids and between CP8 and CP12 containing Cu2Cl2 rhombooids indicates that L2 containing CPs (CP7 and CP8) are more stable than L3 containing materials (CP11 and CP12). One explanation that has already been suggested for

2.7469(7), Cu1–I1 2.6555(8), Cu21–I1 2.6672(8), Cu22–I1 2.6844(8), Cu1–I2 2.6272(10), Cu1–I2 2.6748(8), Cu2–I2 2.6729(9), Cu1–I21 2.6748(8), Cu2–I21 2.6672(8), Cu1–S1 2.3069(11), Cu2–S2 2.3047(11); Cu1–I1–Cu21 62.138(11), Cu1–I1–Cu21 115.81(3), Cu1–I2–Cu11 61.763(16), Cu1–I2–Cu2 80.25(3), Cu2–I2–Cu11 61.817(14), Cu1–Cu1–Cu21 77.31(3), I1–Cu1–I21 113.515(16), I1–Cu1–Cu11 125.23(3), I2–Cu1–I1 101.03(3), I2–Cu1–I21 118.237(16), I2–Cu1–Cu11 58.25(2), I2–Cu1–Cu11 59.982(19), S1–Cu1–I1 106.06(3), S1–Cu1–I2 119.75(3), S2–Cu2–I2 118.56(3), I1–Cu2–I2 113.195(13), I1–Cu2–Cu11 58.722(19), I2–Cu2–I2 99.09(3), I2–Cu2–Cu11 59.126(19). Symmetry transformations used to generate equivalent atoms: 11-X, 1-Y,1-Z; 2-1+X,+Y,+Z; 31+X,+Y,+Z.
this behavior is the difference in the boiling point value of the ligand. However, in our case, the boiling point of \( \text{L}_3 \) (250°C) is higher than that of \( \text{L}_2 \) (224°C). The dimer compound \( \text{D}_1 \) presents the lowest stability with a first degradation step from 60°C to 130°C attributed to the loss of coordinated acetonitrile (Table 2). After that initial decomposition step, the thermal degradation profiles of \( \text{D}_1 \) and \( \text{CP}_{19} \) look alike. The final residues might include both FeO and CuO as evidenced by a comparison between theoretical and experimental values.

![Figure 19. TGA traces of a) \( \text{CP}_5, \text{CP}_7, \text{CP}_8 \) b) \( \text{CP}_{10}, \text{CP}_{11}, \text{CP}_{12} \) c) \( \text{D}_1 \) and \( \text{CP}_{19} \) under air flow (rate: 10 °C.min\(^{-1}\)).]
Table 2. TGA data for CP5, CP7-CP8, CP10-CP12, D1 and CP19.

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<tr>
<th>CP</th>
<th>T_{Dec} (°C)</th>
<th>T (°C)</th>
<th>Mass loss (%wt)</th>
<th>Residual mass (%wt)</th>
</tr>
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<tbody>
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<td></td>
<td></td>
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<td>Theo.</td>
<td>Exp</td>
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<tr>
<td>CP5</td>
<td>{Cu_2(μ-I)_2}(L2)_2</td>
<td>160</td>
<td>100-210</td>
<td>41^a</td>
</tr>
<tr>
<td>CP7</td>
<td>{Cu_2(μ-Br)_2}(L2)_2</td>
<td>187</td>
<td>100-350</td>
<td>48^a</td>
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<tr>
<td>CP8</td>
<td>{Cu_2(μ-Cl)_2}(L2)_2</td>
<td>173</td>
<td>100-350</td>
<td>57^a</td>
</tr>
<tr>
<td>CP10</td>
<td>{Cu_3(μ-I)(μ_2-I)_2(L3)_2}</td>
<td>165</td>
<td>100-240</td>
<td>38^a</td>
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<tr>
<td>CP11</td>
<td>{Cu_2(μ-Br)_2}(L3)_2</td>
<td>142</td>
<td>100-350</td>
<td>54^a</td>
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<tr>
<td>CP12</td>
<td>{Cu_2(μ-Cl)_2}(L3)_2</td>
<td>116</td>
<td>100-350</td>
<td>64^a</td>
</tr>
<tr>
<td>D1</td>
<td>{Cu_2(μ-I)_2}(κ_1-L6)_2(MeCN)_2</td>
<td>113</td>
<td>60-130</td>
<td>7.7^b</td>
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<tr>
<td>CP19</td>
<td>{Cu_2(μ_3-I)_2}(L6)_2</td>
<td>195</td>
<td></td>
<td>23^c / 44^d</td>
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</table>

^a values determined based on ligand loss
^b value determined based on CH_3CN loss
^c values determined based on the formation of CuO
^d values determined based on the formation of CuO and FeO

Luminescence Properties

(CuI)_n-containing coordination polymers are known for their interesting luminescence properties. Here, CP1, CP10, CP13 and CP17 composed of different SBUs and networks were found to be only weakly emissive under an UV lamp at 366 nm. In these cases, the mean Cu····Cu separation lies above the sum of the Van der Waals radii of two copper atoms. However, taking into account that both CP16 and CP19 present relatively short Cu-Cu distances (2.6555Å and 2.7215Å respectively), we were intrigued to measure their luminescence spectra. CP16 was found to be highly luminescent under UV irradiation. The luminescence spectrum of CP16 recorded at 298 K presents two emission bands at high energy (HE) and low energy (LE) with maxima at 435 nm and 554 nm (Figure 20 and Table 3). Other examples of CPs containing Cu_2I_2 rhomboids with...
luminescence spectra exhibiting a band at high energy around 430 nm with a long tail spreading over 550 nm have been reported before. This includes rhomboids obtained by reaction of CuI with (i) 1,4-bis(cyclohexylthio)butane, (ii) 1,5-bis(p-tolylthio)pentane or 1,5-bis(p-phenylthio)pentane and (iii) trans-1,4-bis(p-phenylthio)-2-butene. Our luminescence spectra, with two well separated emission bands looks much alike the one reported for a CP obtained by coordination of CuI with 1,2-dithiane ligand. At 77 K, only one emission band with maxima at 435 nm is observed and the intensity of this band is much higher than at room temperature (See Figure S45 ESI). The presence of a second band at low energy and the thermochromism phenomena observed was also described for cubane species such as Cu₄I₄(pyridine)₄ or other copper iodide clusters containing phosphine ligands.

Interestingly, we also found out that, as in the case of [Cu₄I₄(pyridine)₄], the LE and HE bands display different excitation spectra with reverse order: HE and LE missions correspond to the LE and HE excitation. We are not aware of any cubane CPs composed of thioether ligands showing disappearance of the low-energy band upon cooling. Thus, a plausible explanation that may come to mind is the contamination by another cubane species as reported in references 37 and 89. However, as stipulated before CP16 is highly luminescent under UV lamp and the crude powder can be considered as pure based on the comparison of experimental and simulated PXRD patterns (Fig S26) and elemental analysis results. We have shown above that CP16 undergoes a phase transition at around -50°C leading to a shortening of the Cu-Cu distance upon cooling. Currently, we are unable to conclude if this PT is responsible for the observed different luminescent properties at 298 and 77 K. Further computational studies, solid-state emission lifetimes are necessary to address this question to attribute the nature of the transitions involved.

The luminescence of CP19 presenting an unprecedented SBU is somehow different. The spectrum presents an intense band at HE, centered at 436 nm and a second broad band of lower intensity located at 536 nm. These two bands exhibit same excitation spectra. At 77 K, the luminescence profile remains the same even though the intensities of the two emission bands are stronger (Figure S46 in ESI). These spectra are thus more reminiscent to those reported for thioether-based CPs containing Cu₂I₂ rhomboids.

<p>| Table 3. Photoluminescence data for CP16 and CP19 measured in the solid state at 298 K and 77 K |</p>
<table>
<thead>
<tr>
<th>Compound</th>
<th>T (K)</th>
<th>$\lambda_{\text{ex}}$ (nm)</th>
<th>$\lambda_{\text{em}}$ (nm)</th>
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<tr>
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<td>298</td>
<td>347</td>
<td>554</td>
</tr>
<tr>
<td></td>
<td>77</td>
<td>375</td>
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<td></td>
<td>298</td>
<td>377</td>
<td>436, 536</td>
</tr>
<tr>
<td>CP19</td>
<td>77</td>
<td>360</td>
<td>436, 525</td>
</tr>
</tbody>
</table>

Figure 20. Solid-state excitation (blue lines) and emission spectra (red and green lines) of CP16 and CP19 recorded at room temperature (left) and 77 K (right)

CONCLUSION
In this project, we described a complete series of CPs obtained by reacting 2-substituted-1,3-dithiane with CuX salts, where X = I, Br and Cl. First, we have extended the work of Keller and Knaust on the coordination of 1,3-dithiane L1 on [Cu(MeCN)₄]BF₄ covering the complete Cu(I) halide series and shown that in this latter case, the resulting CPs contain invariable Cu(μ₂-X)₂Cu rhomboids as SBUs instead of single Cu(I) center as in the former case. Another novel finding is the aptitude of L1 to coordinate as μ₂-S,S 4-electron donor using the two non-bonding doublets of each S atom. The structural diversity of the architectures is further enriched when using dithiane derivatives that are monosubstituted at the 2-position of the thiaheterocycle. Even the “innocent” replacement of an H atom by a methyl group in L2 allows in the case of CuI to modulate the dimensionality of the network from 1D to 3D and the nuclearity of the (CuI)ₙ SBUs as a function of the reaction conditions and of CuI-to-L2 ratio. The crystallographic characterization of the isostructural series [(Cu(μ₂-X)₂Cu)(μ₂-L2)]₂n CP4, CP7 and CP8 allowed also for the first time to correlate the Cu⋯Cu distances with the nature of the bridging halide. Although cyano groups in CuCN compounds may adopt a bridging μ₂-bonding mode via the C atom, no such C≡N bonding occurs in [(Cu(μ₂-CN)₂Cu)(μ₂-L2)]₂n CP9 but instead a linear Cu–CN–Cu linking is preferred. The use of the bulkier L3 ligand bearing an iso-butyl group gives rise to a 2D material CP10 featuring a hitherto unknown [{Cu₃(μ₃-I)(μ₂-I₂)}₂S₄] cluster architecture. Similarly, the use of L5 bearing a phenyl group at the 2-position allows to generate 2D networks featuring similar unprecedented [{Cu₃(μ₃-I)(μ₂-I₂)}₂S₄] and [{Cu₃(μ₃-Br)(μ₂-Br₂)}₂S₄] cluster cores encountered in CP17 and CP18. In the case of L4 bearing a SiMe₃ function at the 2-position, independently to the halide nature, 1D ribbons featuring both μ₄-type and μ₂-type halide ligands were obtained.

The observation that in several examples the S atoms of L1, L3 and L5 may act both as 2-electron and 4-electron donors also contributes certainly to the structural richness of the numerous architectures presented in this exhaustive study. Although the luminescent closed-cubane cluster of type [Cu₄(μ₃-I)₄L₄] is a wide-spread motif often obtained by treatment of CuI with N, P, As and Sb-donor ligands and also results by coordination of simple sulfides such as Pr-S-Pr, cyclic thioethers such as tetrahydrothiophene and tetrahydrothiopyran, as well as numerous dithioethers RS\(\cap\)SR, it is surprising that this cubane motif is not encountered using 1,3-dithianes. However, the formation of the
octanuclear cluster SBU in \(\{\text{Cu}_8(\mu_3-I)_8(\mu_2-L_2)_4\}_n\) \(\text{CP6}^{48}\) demonstrates that also in the case of dithianes, aggregation of CuX to clusters with a nuclearity > 3 can occur.

To conclude, despite the difficulty to anticipate the architecture generated by the self-assembly process between copper salts and dithianes, we have shown at least that: (i) using CuBr and CuCl, the resulting CPs show the same dimensionalities and SBUs (except in one case with \(L_1\)); (ii) using CuI, functionalization of the dithiane ligand at the 2-position with a bulky group (Phenyl, isobutyl) affords 2D CPs incorporating Cu₃I₃ SBUs. The bulkier ferrocenyl-derivative \(L_6\) also leads to the formation of a 1D CP with \(\mu_3-I\) capped Cu centers. Independently of the nature of the halide, the -SiMe₃ bearing ligand \(L_4\) led to the crystallogenesis of 1D CPs containing a \([\text{Cu}_2(\mu_4-X)(\mu_2-X)]\) SBU. We have also shown that the dimensionality of all compounds is quite variable ranging from 0D in the molecular ferrocenylic compound \([\{\text{Cu}(\mu_2-I)_2\text{Cu}\}(\kappa_1-L_6)_2(\text{MeCN})_2\] \(\text{D1}\) to 3D in \([\{\text{Cu}_8(\mu_3-I)_8(\mu_2-L_2)_4\}_n\) \(\text{CP6}\). We are convinced that further variation of the reaction conditions or substituent-pattern around the dithiane-framework may also permit to generate networks incorporating luminescent closed-cubane type \([\text{Cu}_4(\mu_1-I)_4\text{dithiane}_4]\) SBUs. We are currently extending these investigations to other functionalized dithianes bearing chromophores such as anthracenyl groups for photophysical studies and intend to investigate more in depth the electrochemical properties of our ferrocenyl-dithiane based materials.

**EXPERIMENTAL SECTION**

**Materials and methods.** The CuX salts, \(L_1-L_5\), 1,2-ethanediithiol and Ferrocene-carbaldehyde were commercial obtained from Acros, Alfa Aesar and Aldrich. The preparation of \(\text{CP4, CP5} \) and \(\text{CP6}\) has been recently described. \(^{48}\) The \(^1\text{H}\) and \(^{13}\text{C}\) NMR spectra were obtained on a Bruker AVANCE 400 HD instrument. \(^1\text{H}\) chemical shifts were referenced to the proton impurity of the NMR solvent and \(^{13}\text{C}\) chemical shifts to the NMR solvent. The solid-state emission and excitation spectra were recorded at room temperature or \(77\text{K}\) with a Jobin-Yvon Fluorolog-3 spectrometer using a cylindrical 5 mm diameter quartz capillary with a scan speed of 1 nm/s. Infrared spectra were recorded with a 2 cm\(^{-1}\) resolution on a Bruker vertex70 FTIR spectrometer using of a Platinum ATR accessory equipped with a diamond crystal. Thermogravimetric analysis (TGA) was carried out on a TA instruments Q600 in an alumina crucible under an air flow with a heating rate of 10°C min.\(^{-1}\) up to 850°C. Differential Scanning Calorimetry (DSC) measurements of phase-transition temperatures
were performed with a TA Instruments Q100. Samples of 5–10 mg were placed in a hermetically sealed aluminum pan; an empty pan was used as the reference. Pans were exposed to a N₂ flow atmosphere. The following measurement conditions were applied: (i) cooling from room temperature to -80 °C at a rate of 10 °C min⁻¹, (ii) heating to 25 °C at a rate of 10 °C min⁻¹.

**X-ray Crystallography.** X-ray powder patterns were obtained at 295 K on a D8 Advance Bruker diffractometer using Ni-filtered K-α radiation. Single crystals of CP1-CP19 and D1 were mounted on a Bruker D8 Venture four-circle diffractometer equipped with a nitrogen jet stream low-temperature system (Oxford Cryosystems). The X-ray source was graphite monochromated Mo-Kα radiation (λ = 0.71073 Å) from a microfocus sealed tube ΙμS by Incoatec. In the case of CP12, the X-ray source was a microfocus sealed tube ΙμS 3.0 by Incoatec. For CP1, CP2, CP3, CP7, CP8, CP13, CP19 and D1, a Photon 100 CMOS detector by Bruker was used. Data collection for CP9-CP12 and CP14-CP18 was conducted with a Bruker Photon II CPAD detector. All data collections have been carried out at 100 K, in the case of CP16 data were collected at five different temperatures: 100, 150, 200, 250 and 300 K, using the same crystal. The lattice parameters were obtained by least-squares fit to the optimized setting angles of the entire set of collected reflections. Intensity data were recorded as Φ and ω scans with κ offsets. No significant intensity decay or temperature drift was observed during data collections. Data were reduced by using SAINT v8.37A (Bruker, 2015) software and absorption correction was carried out by SADABS-2016/2 (Bruker, 2016). The structure was solved using SHELXT (Sheldrick, 2015) with intrinsic phasing. Refinements were carried out by full-matrix least-squares on F² using SHELXL program (Sheldrick, 2015) on the complete set of reflections. All non–hydrogen atoms were refined with anisotropic thermal parameters, whereas the H atoms were treated in a riding mode. The crystal structure determination of L6 was accomplished on an Oxford Xcalibur Sapphire3 diffractometer; data collection: CrysAlis CCD (Oxford Diffraction, 2006); cell refinement: CrysAlis RED (Oxford Diffraction, 2006); data reduction: CrysAlis RED; absorption correction: multi-scan (CrysAlis RED; Oxford Diffraction, 2006).

The crystal data, data collection and structure refinement of all compounds are presented in Tables S1–S7. Crystallographic data (excluding structure factors) have been deposited with the Cambridge Crystallographic Data Centre. The CIF files for the X-Ray structures presented in this publication have the following CCDC numbers: 1888353 for CP1, 1888455
for CP2, 1888456 for CP3, 1888460 for CP7, 1888477 for CP8, 1888478 for CP9, 1888479 for CP10, 1888480 for CP11, 1888481 for CP12, 1888483 for CP13, 1888487 for CP14, 1888489 for CP15, 1886853-1886857 for CP16 at 100, 150, 200, 250 and 300 K, 1888490 for CP17, 1888497 for CP18, 1888515 for CP19, 1888524 for D1, and 1888541 for L6. These data may be obtained free of charge from the Cambridge Crystallographic Data Center through www.ccdc.cam.ac.uk/data_request/cif.

Synthesis

Synthesis of L6. A toluene solution of ferrocenecarbaldehyde (428 mg, 2 mmol) and 1,3-propanedithiol (260 mg, 2.4 mmol) was stirred at 60 °C with p-toluenesulfonic acid monohydrate (38 mg, 0.2 mmol) as a catalyst. After 24 h the solvent was evaporated and the residue was purified by column chromatography on silica gel eluting with a gradient of hexane/dichloromethane (100:0 to 80:20) to give L6 as an orange solid (465 mg, 76%), mp. 115-116 °C. 1H NMR (CDCl3) δ (ppm): 1.79-1.86 (m, 1H), 2.05-2.09 (m, 1H), 2.75-5.80 (m, 2H), 2.91-2.98 (m, 2H), 4.08 (t, 3J = 2.0 Hz, 2H), 4.18 (s, 5H), 4.26 (t, 3J = 2.0 Hz, 2H), 4.90 (s, 1H). 13C{1H} NMR (CDCl3) δ (ppm): 25.7, 31.9, 47.3, 67.4, 68.0, 69.5, 86.9. IR (ATR): 3111 (w), 3092(w), 2931 (w), 2891 (w), 1410 (m), 1274 (w), 1238 (w), 1178 (w), 1106 (m), 1038 (w), 1021 (w), 1001 (m), 929 (w), 874 (w), 815 (m), 775 (m), 725 (m), 679 (m), 654 (w), 620 (w), 493 (s), 483 (s), 418 (w) cm⁻¹. Anal. Calc for C14H16FeS2 (304.25): C 55.27, H 5.30, S 21.08; found: C 55.63, H 5.36, S 21.12%.

Synthesis of CP1. To an EtCN solution of CuI (382 mg, 2.0 mmol) (40 mL) was added neat 1,3-dithiane (252 mg, 2.1 mmol). A white precipitate appeared within 2 min. The mixture was stirred for 3 h to complete the reaction and then heated to reflux for 5 min. After allowing to reach ambient temperature, the precipitate was filtered off, washed with 5 mL propionitrile and dried to give CP1 as a white microcrystalline solid (566 mg, 91%). Conducting the reaction in MeCN using a 2:1 CuI-to-L1 ratio afforded the same product. X-ray suitable crystals were grown by dissolution of a small amount of CP1 in refluxing EtCN and subsequent slow cooling in an oil bath. mp 241 °C; IR (ATR): 2985 (w), 2952 (w), 2913 (w), 2902 (w), 1428 (m), 1417 (s), 1405 (m), 1389(w), 1366 (m), 1283 (w), 1242 (w), 1164 (m), 1082 (m), 1012 (m), 923 (s), 914 (s), 891 (m), 889 (w), 817 (m), 746 (s), 738 (s), 664 (s), 637 (m), 476 (m) cm⁻¹. Anal. Calc for C14H16CuIS2 (310.66): C 15.46, H 2.60, S 20.64; found: C 15.05, H 2.24, S 20.35%.
Synthesis of CP2. To a solution of 1,3-dithiane (252 mg, 2.1 mmol) in 20 mL of acetonitrile was added CuBr (286 mg, 2.0 mmol) in several portions. A white precipitate appeared within 5 min. The mixture was stirred for 3 h to complete the reaction, then heated to reflux for 3 min till almost entire dissolution of the solid. Upon cooling, the onset of progressive growth of colorless crystals occurred on the wall of the Schlenk tube. A further crop of crystal of CP2 could be isolated after decanting the slight greenish mother liquor and storage at 5°C overnight in a fridge. Overall yield: (406 mg, 69%). mp 238 °C; IR (ATR): 2960 (m), 2934 (w), 2910 (w), 2896 (m), 1416 (m), 1365 (w), 1276 (w), 1234 (m), 1163 (m), 1090 (w), 1018 (m), 921 (s), 888 (m), 819 (m), 747 (m), 725 (m), 666 (m), 659 (m), 648 (m), 630 (m), 488 (m), 477 (m) cm⁻¹. Anal. Calc for C₄H₈BrCuS₂ (263.69): C 18.22, H 3.06, S 24.32; found: C 17.91, H 2.84, S 24.05 %.

Synthesis of CP3. To a solution of 1,3-dithiane (252 mg, 2.1 mmol) in 25 mL of acetonitrile containing 1 mL of MeOH was added CuCl (404 mg, 4.0 mmol) in several portions. A yellowish precipitate formed rapidly. The mixture was stirred for 3 h to complete the reaction, then heated to reflux for 3 min till almost entire dissolution of the solid. Upon cooling, the onset of progressive growth of yellowish crystals occurred on the wall of the Schlenk tube. A further crop of crystal of CP3 could be isolated by decanting the greenish mother liquor and storage at 5°C overnight in a fridge. Overall yield: (540 mg, 85%). IR (ATR): mp 241 °C; IR (ATR): 2961 (m), 2897 (m), 1424 (m), 1275 (w), 1234 (m), 1164 (m), 1148 (m), 1103(m), 1020 (m), 1001 (m), 920 (s), 889 (m), 821 (m), 775 (w), 729 (m), 652 (m), 634 (m), 490 (s), 419 (m) cm⁻¹ Anal. Calc. for C₄H₈ClCu₂S₂ (318.24): C 15.91, H 2.53, S 20.15; found: C 16.21, H 2.84, S 20.55 %.

Synthesis of CP7. This compound was prepared in a similar manner as detailed for CP2. Overall yield: 487 mg, 88%. mp 225 °C; IR (ATR): 2956 (w), 2940 (w), 2912 (w), 28962 (w), 1453 (w), 1425 (s), 1408 (m), 1376 (m), 1231 (m), 1181 (m), 1164 (m), 1126 (m), 1078 (w), 1064 (m), 966 (s), 902 (m), 872 (m), 8112 (m), 710 (m), 664 (s) cm⁻¹ Anal. Calc for C₅H₁₀BrCuS₂ (277.72): C 28.77, H 3.63, S 23.09; found: C 28.31, H 3.34, S 22.75 %.

Synthesis of CP8. This compound was prepared in a similar manner as detailed for CP3. Overall yield: 373 mg, 79%. mp 198 °C; IR (ATR): 2959 (m), 2918 (w), 2863 (w), 2829 (w), 1456 (w), 1427 (s), 1410 (m), 1376 (m), 1233 (m), 1183 (w), 1165 (s), 1128 (m), 1080 (m), 902 (s), 872 (m), 810 (m), 712 (m), 665 (s), 444 (w) cm⁻¹ Anal. Calc for C₅H₁₀ClCuS₂ (233.26): C 25.75, H 4.32, S 27.49; found: C 25.31, H 3.94, S 27.05 %.
Synthesis of CP9. This compound was prepared by refluxing a suspension of CuCN (179 mg, 2.0 mmol) during 3h in MeCN in the presence of an excess of L2. Overall yield: 348 mg, 78%. IR (ATR): 2957 (m), 2911(w), 2859 (w), 2810 (w), 2121 (s), 1442 (w), 1420 (w), 1407 (m), 1378 (w), 1272 (w), 1230 (w), 1180 (w), 1166 (m), 1119 (w), 1076 (w), 1057 (m), 1046 (w), 999 (w), 973 (w), 902 (m), 866 (w), 818 (w), 708 (m), 666 (m), 520 (w), 485 (w), 442 (w) cm\(^{-1}\). No satisfactory elemental analysis could be obtained for CP9.

Synthesis of CP10. L3 (0.3 mL, 1.7 mmol) was dissolved in 5 mL of acetonitrile and an MeCN solution (25 mL) of CuI (226 mg, 1.2 mmol was added dropwise. A white precipitate was observed within 5 minutes. The mixture was then stirred for 3 h to complete the reaction. The precipitate was filtered, washed with 2 × 10 mL acetonitrile and dried. CP10 was isolated as a white solid (173 mg, 46%). A small amount of this CP (20 mg) was dissolved in hot MeCN (10 mL). Overnight standing of the solution at 5°C provided single-crystals suitable for X-ray crystallography. IR (ATR): 3100 (s), 2907 (m), 2863 (w), 1464 (m), 1416 (s), 1384 (w), 1366 (w), 1271 (w), 1236 (w), 1187(s), 1169 (w), 1109 (w),1038 (w), 1005 (w), 946 (w), 907 (s), 881 (w), 819 (w), 744 (m), 655 (m), 623 (w), 501 (w), 467 (w), 421(w) cm\(^{-1}\). Anal. Calc for C\(_{16}\)H\(_{32}\)Cu\(_3\)I\(_3\)S\(_4\): C 30.05, H 5.86, S 23.29; found: C 30.15, H 4.84, S 19.47%.

Synthesis of CP11. This material was prepared by following the same protocol by mixing L3 (0.3 mL, 1.7 mmol) and CuBr (175 mg, 1.2 mmol) providing CP11 as a white solid (103 mg, 27%). mp 152 °C; IR (ATR): 2955 (s), 2899 (m), 2868 (w), 1464 (m), 1416 (s), 1384 (w), 1366 (w), 1271 (w), 1236 (w), 1187(s), 1169 (w), 1131 (w), 1109 (w),1038 (w), 1005 (w), 947 (w), 908 (s), 889 (w), 871 (w), 828 (w), 817 (w), 764 (m), 677 (m), 661 (w), 637 (w), 463 (m) cm\(^{-1}\) Anal. Calc for C\(_{16}\)H\(_{32}\)Cu\(_2\)Br\(_2\)S\(_4\): C 30.05, H 5.04, S 20.05; found: C 30.15, H 4.84, S 19.47%.

Synthesis of CP12. This material was prepared by addition of CuCl (200 mg, 2.0 mmol) to a MeCN solution of 1.2 equiv. of L3 providing CP12 as a pale yellow solid (369 mg, 67%). IR (ATR): 2956 (w), 2922 (w), 2899 (w), 2868 (w), 1489 (w), 1414 (m), 1253 (m), 1167(m), 1129 (w), 1083 (w), 1037 (w), 999 (w), 905 (m), 880 (m), 841 (s), 758 (m), 731 (m), 639 (w), 474 (w) cm\(^{-1}\). Anal. Calc for C\(_{16}\)H\(_{32}\)Cu\(_2\)Cl\(_2\)S\(_4\): C 32.90, H 5.60, S 21.91%.
Synthesis of CP13. This CP was prepared by addition of neat L4 (2.0 mmol) to a MeCN solution of CUl (382 mg, 2.0 mmol), affording a white solid (458 mg, 80%). mp 221 °C IR (ATR): 2953 (w), 2933 (w), 2909 (w), 2894 (w), 2854 (w), 1414 (w), 1251 (m), 1175 (w), 1089 (w), 999 (w), 902 (m), 881 (w), 843 (s), 759 (m), 728 (m), 638 (w) cm\(^{-1}\). Anal. Calc for C\(_7\)H\(_{16}\)Cu\(_2\)I\(_2\)Si (573.32): C 14.66, H 2.81, S 11.19; found: C 14.75, H 2.54, S 10.97%.

Synthesis of CP14. This CP was prepared in a similar manner as white solid (393 mg, 82%). mp 224 °C IR (ATR): 2942 (w), 2913 (w), 2862 (w), 1413 (w), 1249 (m), 1170 (w), 1084 (w), 998 (w), 902 (m), 880 (m), 840 (s), 756 (m), 730 (m), 637 (m), 570 (w), 473(w) cm\(^{-1}\). Anal. Calc for C\(_7\)H\(_{16}\)CuBr\(_2\)Si (479.32): C 17.54, H 3.36, S 13.38; found: C 17.25, H 2.99, S 12.98%.

Synthesis of CP15. This CP was obtained in a similar manner as a pale yellow solid (393 mg, 62%). IR (ATR): 2948 (w), 2921 (w), 2894 (w), 2857 (w), 1414 (w), 1253 (m), 1167 (w), 1083 (w), 998 (w), 904 (m), 881 (m), 840 (s), 757 (m), 731 (m), 639 (m), 574 (w), 474(w) cm\(^{-1}\). Anal. Calc for C\(_7\)H\(_{16}\)CuCl\(_2\)Si (390.42): C 21.53, H 4.13, S 16.43; found: C 21.25, H 3.98, S 16.06%.

Synthesis of CP16. This CP was obtained by dissolving CUl (191 mg, 1.0 mmol) in MeCN and subsequent addition of 1 equiv of neat L5 providing CP16 as a white solid (393 mg, 64%). IR (ATR): 2965 (w), 2915 (w), 2309 (w), 2275 (w), 1495 (w), 1453 (w), 1420 (m), 1366(w), 1272 (w), 1224 (w), 1171 (w), 1072 (w), 1027 (w), 904 (w), 879 (w), 738 (m), 696 (s), 669 (m), 6451 (w), 589 (w), 497 (w) cm\(^{-1}\). Anal. Calc for C\(_{14}\)H\(_{16}\)Cu\(_2\)I\(_2\)N\(_2\)S\(_2\) (659.34): C 25.50, H 2.75, N 4.25, S 9.73; found: C 25.17, H 2.25, N 3.99, S 10.10%.

Synthesis of CP17. This CP was obtained by dissolving CUl (382 mg, 2.0 mmol) in warm EtCN followed by addition of neat L5 (196 mg, 1 mmol) and subsequent refluxing the white precipitate. (520 mg, 90%). mp 237 °C; IR (ATR): 3055 (w), 3030 (w), 2967 (w), 2932 (w), 2902 (w), 1584 (w), 1494 (w), 1453 (w), 1407 (w), 1272 (w), 1222 (w), 1174 (w), 1157 (w), 1072 (w), 1030 (w), 1008 (w), 904 (w), 889 (w), 876 (w), 827 (w), 778 (w), 721 (m), 689 (s), 666 (w), 644 (m), 591 (w), 489 (w), 423 (w) cm\(^{-1}\). Anal. Calc for C\(_{20}\)H\(_{26}\)Cu\(_3\)I\(_3\)S\(_4\) (964.03): C 24.92, H 2.50, S 13.30; found: C 25.12, H 2.27, S 12.98%.

Synthesis of CP18. This CP was obtained dissolving CuBr (286 mg, 2.0 mmol) in MeCN and subsequent addition of neat L5 (196 mg, 1 mmol), affording a white precipitate. (400 mg, 83%). mp 186 °C; IR (ATR): 3057 (w), 3031 (w), 2988 (w), 2949 (w), 2904 (w), 2818 (w),
1584 (w), 1494 (w), 1452 (w), 1418 (m), 1273 (w), 1221 (w), 1158 (w), 1072 (w), 1032 (w), 1009 (w), 905 (w), 877 (w), 837 (w), 780 (w), 727 (m), 690 (s), 667 (w), 645 (w), 490 (w) cm⁻¹. Anal. Calc for C₂₀H₂₄Cu₃Br₃S₄ (823.02): C 29.19, H 2.93, S 15.58; found: C 28.82, H 2.67, S 15.18 %.

**Synthesis of CP19.** To a solution of L₆ (30 mg, 0.1 mmol) in CH₂Cl₂ (5 mL) was added a MeCN solution of CuI (38 mg, 0.2 mmol). After stirring for 2h, a yellow precipitate was obtained, which was dissolved by heating. The solution was cooled to room temperature and then kept at 5°C. Overnight standing gave orange crystals, which were filtered off and air-dried to give CP19. (45 mg, 66 % yield). mp 197 °C IR (ATR): 2955 (w), 2922 (w), 2900 (w), 2858 (w), 1468 (w), 1414 (m), 1270 (w), 1253 (m), 1167 (m), 1083 (w), 1042 (w), 999, 905 (m), 881 (m), 840 (s), 758 (m), 731 (w), 701 (w), 639 (w), 483 (w) cm⁻¹. Anal. Calc for C₁₄H₁₆FeCu₂I₂S₂ (685.16): C 35.87, H 3.57, N 2.61, S 11.97; found: C 35.47, H 3.50, N 2.41, S 12.10 %.

**Synthesis of D1.** To a solution of L₆ (30 mg, 0.1 mmol) in CH₂Cl₂ (5 mL) was added acetonitrile solution of CuI (38 mg, 0.2 mmol). After stirring for 2h, yellow precipitate was obtained. The precipitate was re-dissolved by heating. The solution was cooled to room temperature and then kept at 5°C. Overnight standing gave orange crystals, which were filtered off and air-dried to give D1. (50 mg, 70 % yield). mp 192 °C IR (ATR): 3092(w), 3080 (w), 2894 (w), 2305 (w), 2275 (w), 1421 (w), 1413 (w), 1364 (w), 1268 (w), 1229 (w), 1163 (w), 1105 (m), 1036 (w), 1021 (w), 998 (m), 936 (w), 905 (w), 874 (w), 817 (m), 776 (m), 722 (w), 618 (w), 501 (s), 485 (s) cm⁻¹. Anal. Calc for C₃₂H₃₈FeCu₂I₂N₂S₄ (1071.52): C 35.87, H 3.57, N 2.61, S 11.97; found: C 35.47, H 3.50, N 2.41, S 12.10 %.

**ASSOCIATED CONTENT**

**Supporting Information.** Crystallographic data in CIF file, summary of X-ray data collection and refinement for all structures studied, structure views of CP1, CP2, CP7-CP18, L₆, Powder X-Ray Patterns of CP1, CP2, CP7, CP8, CP10-CP14, CP17-CP19, D1, ATR-IR spectra of CP9, CP16, D1, DSC traces of CP16 and TGA traces of CP5, CP7, CP8, CP10-CP12 and D1. The following files are available free of charge on the ACS publication website at hppt://pubs.acs.org.

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