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Nickel(II) and Copper(II) Dicyanoargentate Complexes with Ethylenediamine and 4,4'-Bipyridyl Ligands

D. R. Pashnin[a], D. P. Shevchenko[a, *], V. V. Sharutin[a], and O. K. Sharutina[a]

[a] *South Ural State University (National Research University), Chelyabinsk, Russia*

**e-mail: Shepher56@gmail.com*

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Abstract—The reactions of an aqueous solution of potassium dicyanoargentate with a mixture of nickel(II) or copper(II) chloride and ethylenediamine or 4,4'-bipyridyl in ethanol afford coordination polymers $[Ni(En)_2(Ag(CN)_2)][Ag(CN)_2]$ (**I**), $[Cu(En)_2(Ag(CN)_2)][Ag(CN)_2]$ (**II**), and $[Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2]$ (**III**) characterized by XRD (CIF files CCDC nos. 2225984 (**I**), 2214320 (**II**), and 2229270 (**III**)) and IR spectroscopy. According to the XRD data, the crystals of complexes **I** and **II** are formed by 1D chains $\{\cdot\cdot NC–Ag–CN–M(En)_2\cdot\cdot\}_n$ (M = Ni (**I**), Cu (**II**)) linked with each other by the dicyanoargentate anions via argentophilic contacts (Ag···Ag 3.288(8) Å (**I**), 3.1616(14) Å (**II**)). The crystal of compound **III** consists of independent interpenetrating 3D networks built of polymer layers $\{Cu[Ag(CN)_2]_2\}_n$ bound to each other by the 4,4'-bipyridyl molecules. The bipyridyl linkers connect the Cu centers with the Ag centers of the $[Ag(CN)_2]^-$ anions thus providing the tridentate coordination of the silver atoms. No Ag···Ag interactions are observed in the crystal of complex **III**.

Keywords: coordination polymers, dicyanoargentates, nickel(II), copper(II), ethylenediamine, 4,4'-bipyridyl

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INTRODUCTION

The design and synthesis of coordination polymers of various architecture are of interest due to their potential use in the very diverse areas (electroconducting and magnetically and optically active materials, catalysis, energy engineering, etc.) [1–3].

The main factor controlling the supramolecular topology and dimensionality of the structure in the design of coordination polymers is the choice of a ligand/metal/linker combination. In addition, various noncovalent interactions, for instance, hydrogen bonds, π–π stacking, metallophilicity, and others, also exert a significant effect on the crystal structures of these complexes.

Cyanometallate linkers based on silver, gold, platinum, and other transition metals play an important role among building blocks for coordination polymers. In particular, the dicyanoargentate derivatives have diverse potentially useful properties such as luminescence [4–9], spin crossover [10–15], and catalytic [16] and biological activity [17–19]. The strategical choice of counterions and auxiliary ligands makes it possible to modify these properties.

Continuing a number of studies on the dicyanoargentate complexes [20–22], in this work we describe the synthesis and specific structural features of the coordination polymers $[Ni(En)_2(Ag(CN)_2)][Ag(CN)_2]$ (**I**), $[Cu(En)_2(Ag(CN)_2)][Ag(CN)_2]$ (**II**), and $[Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2]$ (**III**), where En is ethylenediamine and 4,4'-Bipy is 4,4'-bipyridyl.

EXPERIMENTAL

Commercially available potassium dicyanoargentate (analytical grade, DTsM-Analitika), nickel(II) chloride (reagent grade, Profsnab), copper(II) chloride (98%, ABCR), copper(II) sulfate pentahydrate (analytical grade, Khimreaktivsnab), ethylenediamine (high-purity grade, Khimreaktivsnab), and 4,4'-bipyridyl (high-purity grade, Khimreaktivsnab) were used.

Synthesis of complex $[Ni(En)_2(Ag(CN)_2)][Ag(CN)_2]$ (I). A solution of anhydrous nickel(II) chloride (32 mg, 0.25 mmol) and ethylenediamine (30 mg, 0.50 mmol) in ethanol was added with stirring to a solution of potassium dicyanoargentate (100 mg, 0.50 mmol) in water (5 mL). A transparent violet solution was formed. The solvent was evaporated to isolate violet crystals of compound **I** with T_{decomp} = 199°C in a yield of 85 mg (69%).

IR (ν, cm^{-1}): 3343 s, 3302 w, 3273 s, 3154 w, 2976 m, 2963 m, 2941 s, 2884 m, 2156 s, 2137 s, 1630 w, 1597 s, 1452 m, 1396 w, 1368 w, 1321 m,

1277 m, 1136 m, 1084 m, 1074 w, 1005 s, 970 s, 872 w, 662 s, 581 w, 513 s, 420 m.

For $C_8H_8N_8NiAg_2$		
Anal. calcd., %	C, 19.58	H, 1.65
Found, %	C, 19.48	H, 1.70

Complex II was synthesized according to a procedure similar to that of complex **I** using $CuCl_2$ instead of $NiCl_2$.

Complex **II**: blue-violet crystals, 77% yield, T_m = 204°C.

IR (ν, cm^{-1}): 3335 s, 3256 s, 3130 w, 2984 w, 2972 m, 2955 w, 2893 w, 2137 s, 1580 s, 1456 m, 1392 w, 1363 w, 1317 w, 1281 w, 1267 m, 1153 w, 1084 m, 1024 s, 976 m, 881 w, 696 s, 604 w, 530 m, 453 w.

For $C_8H_8N_8CuAg_2$		
Anal. calcd., %	C, 19.39	H, 1.63
Found, %	C, 19.30	H, 1.69

Synthesis of complex $[Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2]$ (III). A solution of copper(II) sulfate pentahydrate (62 mg, 0.25 mmol) in ethanol was added with stirring to a solution of potassium dicyanoargentate (100 mg, 0.50 mmol) and 4,4'-bipyridyl (78 mg, 0.50 mmol) in water (5 mL). A brown-green precipitate was formed and dissolved by the addition of several droplets of a concentrated aqueous solution of ammonia. The evaporation of the solvent gave blue crystals of complex **III** with T_{decomp} = 184°C in a yield of 50 mg (29%).

IR (ν, cm^{-1}): 3044 w, 2168 m, 2126 m, 1612 m, 1599 s, 1531 m, 1516 w, 1487 m, 1458 w, 1427 w, 1410 m, 1342 w, 1323 w, 1217 m, 1139 w, 1125 w, 1109 w, 1072 m, 1043 w, 1018 w, 1003 m, 976 w, 957 w, 866 w, 851 w, 839 w, 810 s, 745 w, 729 m, 629 m, 569 m, 559 w, 492 m, 455 m, 420 w.

For $C_{24}H_{16}N_8CuAg_2$		
Anal. calcd., %	C, 41.43	H, 2.32
Found, %	C, 41.31	H, 2.37

The IR spectra of compounds **I**–**III** were recorded on a Shimadzu IRAffinity-1S FT-IR spectrometer, and the samples were prepared by pelleting with KBr (absorption range 4000–400 cm^{-1}).

XRD of the crystals of complexes **I**–**III** was carried out on a D8 QUEST Bruker diffractometer (MoK_α radiation, λ = 0.71073 Å, graphite monochromator). Data were collected and edited, unit cell parameters were refined, and an absorption correction was applied using the SMART and SAINT-Plus programs [23]. All calculations on structure determination and refinement were performed using the SHELXL/PC [24] and OLEX2 [25] programs. The structures were determined by a direct method and refined by least squares in the anisotropic approximation for non-hydrogen atoms.

The full tables of the atomic coordinates, bond lengths, and bond angles were deposited with the Cambridge Crystallographic Data Centre (CIF files CCDC nos. 2225984, 2214320, and 2229270 for complexes **I**–**III**, respectively; deposit@ccdc.cam.ac.uk; http://www.ccdc.cam.ac.uk).

Compound **I**: violet crystals, triclinic, space group $P\bar{1}$, a = 6.576(17), b = 8.354(18), c = 8.44(2) Å, α = 102.13(13)°, β = 109.60(14)°, γ = 108.67(9)°, V = 386.7(17) $Å^3$, Z = 1, ρ_{calc} = 2.107 g/cm^3; μ = 3.709 mm^{-1}, $F(000)$ = 234.0. Total number of measured reflections 20117, independent reflections 4402 (R_{int} = 0.0521), refinement parameters 91: R_1 = 0.0457, wR_2 = 0.1245.

Compound **II**: blue-violet crystals, orthorhombic, space group $Immm$, a = 6.323(3), b = 9.033(4), c = 13.217(6) Å, α = 90°, β = 90°, γ = 90°, V = 754.9(6) $Å^3$, Z = 2, ρ_{calc} = 2.215 g/cm^3; μ = 3.963 mm^{-1}, $F(000)$ = 486.0. Total number of measured reflections 6097, independent reflections 557 (R_{int} = 0.0280), refinement parameters 46: R_1 = 0.0182, wR_2 = 0.0414.

Compound **III**: blue crystals, monoclinic, space group $P2_1/n$, a = 8.952(5), b = 11.505(4), c = 12.608(5) Å, α = 90°, β = 106.42(2)°, γ = 90°, V = 1245.4(9) $Å^3$, Z = 2, ρ_{calc} = 1.855 g/cm^3; μ = 2.432 mm^{-1}, $F(000)$ = 678.0. Total number of measured reflections 62964, independent reflections 9831 (R_{int} = 0.0396), refinement parameters 160: R_1 = 0.0401, wR_2 = 0.0900.

RESULTS AND DISCUSSION

Polymer complexes **I** and **II** in the single-crystal form were prepared by the reaction of an aqueous solution of potassium dicyanoargentate with a mixture of ethylenediamine and nickel(II) chloride (**I**) or copper(II) chloride (**II**) (2 : 2 : 1 mol/mol/mol) in ethanol

$$2K[Ag(CN)_2] + 2(En) + MCl_2 \xrightarrow[-2KCl]{H_2O/EtOH} [M(En)_2(Ag(CN)_2)][Ag(CN)_2],$$
$$M = Ni\ (\mathbf{I}),\ Cu\ (\mathbf{II}).$$

Note that the structure of complex **II** has already been determined previously but in other space group (*Pnnm*) [26].

Attempts to isolate crystals of the copper(II) complex with 4,4'-bipyridyl using a similar procedure were unsuccessful because of the very fast formation of a fine precipitate of the product insoluble in water and available organic solvents (acetone, acetonitrile, chloroform, THF, DMSO, and DMF) for subsequent crystallization. The addition of several droplets of a concentrated aqueous solution of ammonia to the

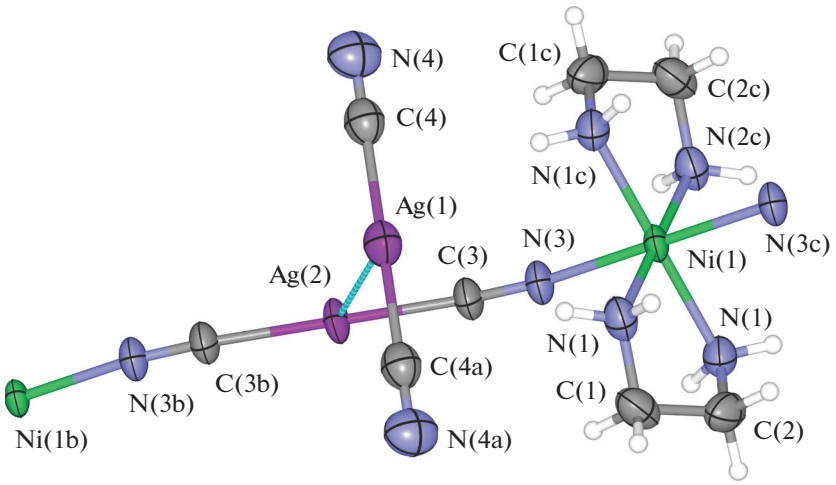

Fig. 1. Structure of the fragment of complex **I**.

reaction mixture until the precipitate was dissolved completely followed by solvent evaporation gave blue single crystals of product **III** suitable for XRD.

$$2K[Ag(CN)_2] + 2(4,4'\text{-Bipy}) + CuSO_4\cdot 5H_2O \xrightarrow[-K_2SO_4,\ -5H_2O]{\substack{(1)\ H_2O/EtOH \\ (2)\ NH_3}} [Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2].$$

(III)

A similar approach has previously been described [27] for the polymer dicyanoaurate complexes $[M(Bpym)(NH_3)_2(Au(CN)_2)_2]$ (M = Co, Ni, Cu; Bpym is 2,2'-bipyrimidine). However, thus synthesized complex **III** contains no ammonia molecules in the coordination sphere of the Cu^{2+} cations, most likely, due to a higher affinity to the 4,4'-Bipy ligand.

The presence of cyano groups in organic and inorganic compounds can rather easily be found using IR spectroscopy: the corresponding absorption bands lie in a sufficiently narrow frequency range from 2200 to 2000 cm^{-1} [28]. Cyanide ligands in the dicyanoargentate (as well dicyanoaurate) complexes are divided into terminal and bridging ligands, and rather certain frequency range in the IR range corresponds to each type. The absorption bands lying lower than 2150 cm^{-1} indicate the presence of the terminal Ag–C≡N fragment, and the values higher than 2150 cm^{-1} indicate the presence of the Ag–C≡N–M bridges and polymer character of the complex [29]. Thus, the IR spectra are important for understanding the structures of the dicyanoargentate derivatives and often allow one to propose their structures before performing XRD.

For instance, for complexes **I**–**III**, the absorption bands of stretching vibrations of the C≡N bonds in the $[Ag(CN)_2)]^-$ anion are highly intense and lie at 2156 and 2137 (**I**), 2137 (**II**), and 2168 and 2126 cm^{-1} (**III**), which assumes that complexes **I** and **III**, unlike product **II**, contain both the terminal and bridging C≡N groups.

The IR spectra of ethylenediamine-containing compounds **I** and **II** also distinctly exhibit absorption bands of NH_2 group vibrations: at 3343, 3273 cm^{-1} (**I**) and 3335, 3256 cm^{-1} (**II**) for stretching vibrations and at 1597 cm^{-1} (**I**) and 1580 cm^{-1} (**II**) for bending vibrations [28].

According to the XRD data, nickel- and copper-containing complexes **I** and **II** have polymer structures similar to each other and are presented in the crystal by weakly bent 1D chains built of the μ_2-bridging dicyanoargentate anions and octahedrally coordinated M^{2+} cations (M = Ni (**I**), Cu (**II**)). The axial positions of the latter are occupied by the nitrogen atoms of the $[Ag(CN)_2]^-$ ions. The equatorial plane around the Ni and Cu centers is formed by four nitrogen atoms from two chelate ethylenediamine molecules. Charge compensation occurs due to the uncoordinated dicyanoargentate anions that join the $\{\cdot\cdot NC–Ag–CN–M(En))_2\cdot\cdot\}_n$ chains into *pseudo*-2D massifs using argentophilic interactions Ag···Ag (3.288(8) Å (**I**) and 3.1616(14) Å (**II**)). The doubled van der Waals radius of the silver(I) atom is 3.44 Å [30] and, hence, these contacts in products **I** and **II** can be considered significant. The structure of complex **I** and the fragment of its crystal organization are shown in Figs. 1 and 2, respectively.

Both bridging and free $[Ag(CN)_2]^-$ ions in complexes **I** and **II** have the typical linear geometry. The Ag–C and C≡N bond lengths in the free anions are 2.042(5), 1.106(5) (**I**) and 2.054(3), 1.125(5) Å (**II**), respectively. Those in the bridging anions are 2.080(6), 1.154(4) (**I**) and 2.064(4), 1.124(6) Å (**II**), respectively.

The M–N distances in products **I** and **II** vary in different ranges. For complex **I**, the range is relatively

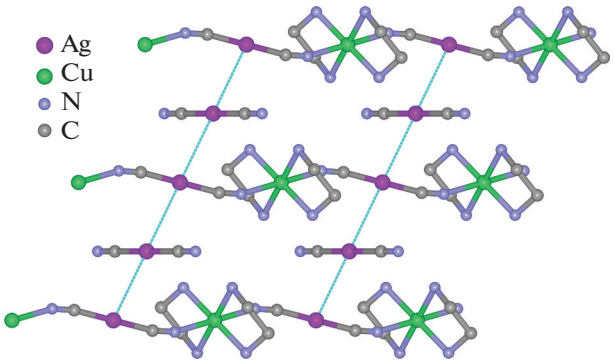

Fig. 2. Spatial organization of complex **I** (projection along the *b* axis; hydrogen atoms are omitted).

short and amounts to 2.088(6)–2.138(5) Å, and the longest distance of these values refers to the coordination sphere of the Ni center with the bridging $[Ag(CN)_2]^-$ anion (Ni(1)–N(3)). Another pattern is observed for the $[Cu(En)_2(Ag(CN)_2)][Ag(CN)_2]$ complex (**II**). The distances between the Cu^{2+} cations and nitrogen atoms of the $[Ag(CN)_2]^-$ bridges significantly exceed the distances between the Cu^{2+} cations and nitrogen atoms of the ethylenediamine molecules: 2.578 versus 2.029(2) Å.

Note that the closeness of the Ag–C and C≡N bond lengths for the coordinated and uncoordinated types of $[Ag(CN)_2]^-$ (2.064(4) and 1.124(6) versus 2.054(3) and 1.125(5) Å, respectively) and a significant elongation of the Cu–N_{ax} distances (2.578 Å) explain [26] why the presence of formally bridging cyano groups in the crystal of complex **II** gives no corresponding absorption band lower than 2150 cm^{-1} in the IR spectrum of this compound.

The zigzag character of the polymer chains in the crystals of compounds **I** and **II** is due to deviations from 180° of the AgCN and CNM angles that are equal to 171.3(3)° and 164.4(2)° (**I**) and 173.0(4)° and 150.6° (**II**), respectively. The octahedral coordination of the Ni and Cu centers is also somewhat distorted. The $N_{eq}MN_{ax}$ angles vary from 87.7(2)° to 92.3(2)° (**I**) and from 88.5° to 91.5° (**II**). The $N_{eq}MN_{eq}$ angles also vary in ranges of 82.4(2)°–97.6(2)° (**I**) and 84.4°–95.7° (**II**).

As compared to compounds **I** and **II**, complex **III** has a more complicated organization similar, on the whole, to those of some earlier described dicyanoargentate metal derivatives with 4,4'-bipyridyl $[M(4,4'\text{-}Bipy)_2(Ag(CN)_2)_2]$ (M = Fe [31], Cd [32]). In this

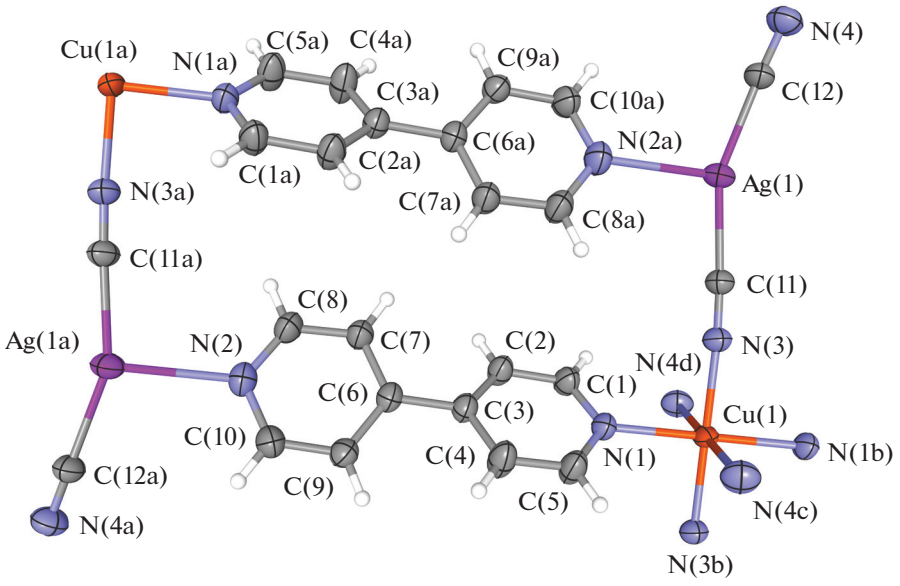

Fig. 3. Structure of the fragment of complex **III**.

product, all $[Ag(CN)_2]^-$ anions play the role of μ_2-bridges and join the Cu^{2+} cations into wavy 2D polymer layers $\{Cu[Ag(CN)_2]_2\}_n$. The 4,4'-bipyridyl molecules together with dicyanoargentate anions act as linear μ_2-bridging ligands: they coordinate to the copper cores of one $\{Cu[Ag(CN)_2]_2\}_n$ layer and thus penetrate the adjacent polymer layer and bind to the silver cores of the next polymer layer. Thus, the final crystal structure of complex **III** is presented by two independent interpenetrating 3D polymer networks. In this case, no Ag···Ag contacts are observed, since the dicyanoargentate anions are rather remote from each other. The structure of complex **III** and the fragment of independent interpenetrating 3D polymer networks are shown in Figs. 3 and 4, respectively.

The geometry of the $[Ag(CN)_2]^-$ ions in this complex significantly differs from the linear one due to bringing together the silver and nitrogen atoms of the 4,4'-bipyridyl ligands. Thus, the Ag centers are tricoordinated with Ag(1)–N(2a), Ag(1)–C(11), and Ag(1)–C(12) distances of 2.4841(18), 2.0955(16), and 2.0881(16) Å, respectively, and the C(11)Ag(1)C(12) angle decreases to 157.32(6)°. The lengths of the C(11)–N(3) and C(12)–N(4) triple bonds in the anions are not equivalent: 1.1453(19) and 1.137(2) Å. Nonuniformity of the Cu–N distances is also observed inside each $\{Cu[Ag(CN)_2]_2\}_n$ layer: the Cu(1)–N(3) bond length is 1.9615(14) Å, whereas the Cu(1)–N(4) distance is significantly longer and equal to 2.568 Å. The differences in the Ag–C, C≡N, and Cu–N bond lengths can explain the appearance of two absorption bands of cyano groups in the IR spectrum of the product, although the crystal of complex **III** formally contains dicyanoargentate anions of only one type. Two remained sites in the octahedral environment of the Cu^{2+} cations are occupied by the nitrogen atoms of two 4,4'-bipyridyl ligands: the Cu(1)–N(1) bond length is 2.0636(15) Å.

Thus, the reactions of potassium dicyanoargentate with nickel(II) and copper(II) chlorides in the presence of ethylenediamine or 4,4'-bipyridyl afforded the coordination polymers $[Ni(En)_2(Ag(CN)_2)][Ag(CN)_2]$, $[Cu(En)_2(Ag(CN)_2)][Ag(CN)_2]$, and $[Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2]$. The ethylenediamine derivatives contain dicyanoargentate anions of two types: bridging and free. The latter link the $\{\cdot\cdot NC–Ag–CN–M(En)_2\cdot\cdot\}_n$ chains into the *pseudo*-2D massifs using the Ag···Ag contacts with the bridging anions of the chains. The $[Cu(4,4'\text{-Bipy})_2(Ag(CN)_2)_2]$ complex contains only bridging anions linking the Cu^{2+} centers into the $\{Cu[Ag(CN)_2]_2\}_n$ layers. The 4,4'-Bipy ligands coordinate with the copper and silver cores to join the layers into the independent interpenetrating 3D networks without Ag···Ag interactions.

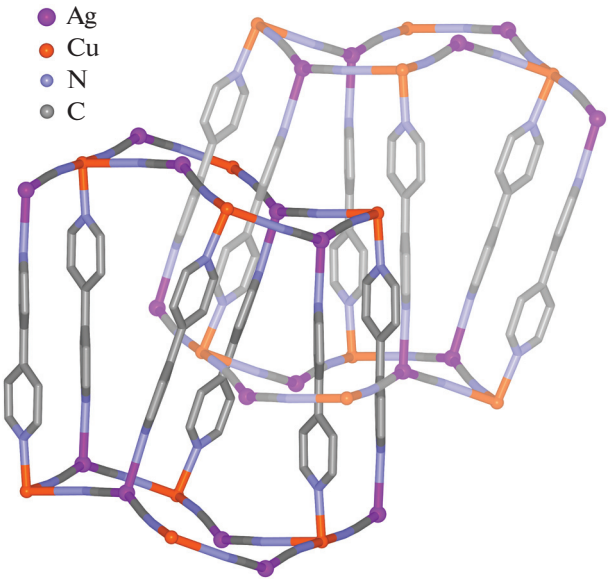

Fig. 4. Independent interpenetrating 3D polymer networks in the structure of complex **III**.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. Batten, S.R. and Champness, N.R., *Phil. Trans. R. Soc., A*, 2017, vol. 375, p. 20160032. https://doi.org/10.1098/rsta.2016.0032
2. Furukawa, H., Cordova, K.E., O'Keeffe, M., and Yaghi, O.M., *Science*, 2013, vol. 341, no. 6149, p. 1230444. https://doi.org/10.1126/science.1230444
3. Liu, J., Chen, L., Cui, H., Zhang, J., et al., *Chem. Soc. Rev.*, 2014, vol. 43, no. 16, p. 6011. https://doi.org/10.1039/C4CS00094C
4. Zhang, H., Cai, J., and Feng, X.L., et al., *Inorg. Chem. Commun.*, 2002, vol. 5, no. 9, p. 637. https://doi.org/10.1016/S1387-7003(02)00514-2
5. Lin, Y.-Y., Lai, S.-W., and Che, C.M., et al., *Inorg. Chem.*, 2005, vol. 44, no. 5, p. 1511. https://doi.org/10.1021/ic048876k

6. Marinescu, G., Madalan, A.M., and Andruh, M., *J. Coord. Chem.*, 2015, vol. 68, no. 3, p. 479. https://doi.org/10.1080/00958972.2014.997721
7. Wang, J.-Y., Zhang, L.-Z., Gu, W., et al., *J. Coord. Chem.*, 2006, vol. 59, no. 15, p. 1685. https://doi.org/10.1080/00958970600580142
8. Wang, J.-Y., Gu, W., Wang, W.Z., et al., *Chin. J. Chem.*, 2006, vol. 24, no. 4, p. 493. https://doi.org/10.1002/cjoc.200690095
9. Baril-Robert, F., Li, X., Katz, M.J., et al., *Inorg. Chem.*, 2011, vol. 50, no. 1, p. 231. https://doi.org/10.1021/ic101841a
10. Galet, A., Niel, V., Muñoz, M.C., and Real, J.A., *J. Am. Chem. Soc.*, 2003, vol. 125, no. 47, p. 14224. https://doi.org/10.1021/ja0377347
11. Wang, L.-F., Zhuang, W.-M., Huang, G.Z., et al., *Chem. Sci.*, 2019, vol. 10, no. 32, p. 7496. https://doi.org/10.1039/c9sc02274k
12. Gural'skiy, I.A., Shylin, S.I., Golub, B.O., et al., *New J. Chem.*, 2016, vol. 40, no. 11, p. 9012. https://doi.org/10.1039/C6NJ01472K
13. Arcís-Castillo, Z., Muñoz, M.C., Molnár, G., et al., *Chem.-Eur. J.*, 2013, vol. 19, no. 21, p. 6851. https://doi.org/10.1002/chem.201203559
14. Yoshida, K., Akahoshi, D., Kawasaki, T., et al., *Polyhedron*, 2013, vol. 66, p. 252. https://doi.org/10.1016/j.poly.2013.05.003
15. Liu, W., Peng, Y.-Y., and Wu, S.-G., *Angew. Chem. Int. Ed.*, 2017, vol. 56, no. 47, p. 14982. https://doi.org/10.1002/anie.201708973
16. Etaiw, S., El-din, H., and El-bendary, M.M., *Inorg. Chim. Acta*, 2015, vol. 435, p. 167. https://doi.org/10.1016/j.ica.2015.06.020
17. Karadağ, A., Korkmaz, N., Aydin, A., Tekin, Ş., Yanar, Y., Yerli, Y., Korkmaz, Ş.A., et al., *New J. Chem.*, 2018, vol. 42, no. 6, p. 4679. https://doi.org/10.1039/c7nj04796g
18. Korkmaz, N., Karadağ, A., Aydin, A., et al., *New J. Chem.*, 2014, vol. 38, no. 10, p. 4760. https://doi.org/10.1039/c4nj00851k
19. Korkmaz, N., *Turk. J. Chem.*, 2020, vol. 44, no. 4, p. 1110. https://doi.org/10.3906/kim-2004-42
20. Sharutin, V.V., Sharutina, O.K., Popkova, M.A., et al., *Russ. J. Inorg. Chem.*, 2019, vol. 64, no. 12, p. 1548. https://doi.org/10.1134/S0044457X19120158
21. Sharutin V.V. and Popkova M.A., *Vest. YuUrGU. Ser. Khim.*, 2019, vol. 11, no. 2, p. 5. https://doi.org/10.14529/chem190201
22. Popkova, M.A. and Sharutin, V.V., *Vest. YuUrGU. Ser. Khim.*, 2021, vol. 13, no. 4, p. 110. https://doi.org/10.14529/chem210409
23. *SMART. SAINT-Plus. V. 5.0. Data Collection, Processing Software for the SMART System*, Madison: Bruker AXS Inc., 1998.
24. *SHELXTL/PC. V. 5.10. An Integrated System for Solving, Refining, Displaying Crystal Structures from Diffraction Data*, Madison: Bruker AXS Inc., 1998.
25. Dolomanov, O.V., Bourhis, L.J., Gildea, R.J., et al., *J. Appl. Crystallogr.*, 2009, vol. 42, p. 339. https://doi.org/10.1107/S0021889808042726
26. Černak, J., Chomič, J., Gravereau, P., et al., *Inorg. Chim. Acta*, 1998, vol. 281, no. 2, p. 134. https://doi.org/10.1016/S0020-1693(98)00156-X
27. Suárez-Varela, J., Sakiyama, H., Cano, J., and Colacio, E., *Dalton Trans.*, 2007, no. 2, p. 249. https://doi.org/10.1039/B611684A
28. Pretsch, E., Buhlman, P., and Affolter, C., *Structure Determination of Organic Compounds. Tables of Spectral Data*, Springer, 2000.
29. Nawaz, S., Ghaffar, A., Monim-ul-Mehboob, M., et al., *Z. Naturforsch., B: Chem. Sci.*, 2007, vol. 72, no. 1, p. 43. https://doi.org/10.1515/znb-2016-0154
30. Bondi, A., *J. Phys. Chem.*, 1964, vol. 68, no. 3, p. 441. https://doi.org/10.1021/j100785a001
31. Niel, V., Muñoz, M.C., Gaspar, A.B., et al., *Chem.-Eur. J.*, 2002, vol. 8, no. 11, p. 2446. https://doi.org/10.1002/1521-3765(20020603)8:11<2446::AID-CHEM2446>3.0.CO;2-K
32. Soma, T., Yuge, H., and Iwamoto, T., *Angew. Chem.*, 1994, vol. 106, nos. 15–16, p. 1746. https://doi.org/10.1002/ange.19941061547

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