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# Insight into systematic formation of hexafluorosilicate during crystallization *via* self-assembly in a glass vessel†

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Formation of the unexpected hexafluorosilicate ( $\text{SiF}_6^{2-}$ ) anion during crystallization *via* self-assembly in glassware is scrutinized. Self-assembly of  $\text{M}(\text{BF}_4)_2$  ( $\text{M}^{2+} = \text{Cu}^{2+}$  and  $\text{Zn}^{2+}$ ) with tridentate N-donors (L) in a mixture solvent including methanol in a glass vessel gives rise to an  $\text{SiF}_6^{2-}$ -encapsulated  $\text{Cu}_3\text{L}_4$  double-decker cage and a  $\text{Zn}_2\text{L}_4$  cage, respectively. Induced reaction of  $\text{CuX}_2$  ( $\text{X}^- = \text{PF}_6^-$  and  $\text{SbF}_6^-$ ) instead of  $\text{Cu}(\text{BF}_4)_2$ , with the tridentate ligands, produces the same species. The formation time of  $\text{SiF}_6^{2-}$  is in the order of anions  $\text{BF}_4^- < \text{PF}_6^- < \text{SbF}_6^-$  under the given reaction conditions. The  $\text{SiF}_6^{2-}$  anion, acting as a cage template or cage-to-cage bridge, seems to be formed from the reaction of polyatomic anions containing fluoride with the  $\text{SiO}_2$  of the surface of the glass vessel.

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## Introduction

Anion-related chemistry is a rapidly burgeoning field owing to the timeliness and importance including environmental pollution, industrial chemicals, biological processes, ionic liquids, lithium batteries, templates, ion-pairing, and health.<sup>1–12</sup> Some anions play a significant role in the construction and behaviors of desirable molecular architectures based on negative charge, size, shape, solvents, and pH.<sup>13–18</sup> In particular, F-containing polyatomic anions such as  $\text{BF}_4^-$ ,  $\text{PF}_6^-$ , and  $\text{SbF}_6^-$  have been extensively employed for various purposes such as important chemical phenomena, cage-templates, coordination, and the Hofmeister series;<sup>19–26</sup> however, they are known to be not thermodynamically stable depending on conditions<sup>27,28</sup> relative to the F-free polyatomic anions  $\text{NO}_3^-$ ,  $\text{ClO}_4^-$ ,  $\text{CH}_3\text{CO}_2^-$ , and  $\text{SO}_4^{2-}$ . For instance, the  $\text{PF}_6^-$  anion could be converted to  $\text{PF}_n(\text{OH})_{6-n}^-$  during the complexation of  $\text{Pd}(\text{II})\text{-L}$ .<sup>29</sup> Furthermore,  $\text{BF}_4^-$  is known to be changed to the  $\text{SiF}_6^{2-}$  anion *via* subsequent reaction of dissociated  $\text{F}^-$  with the Si–O moieties of a glass vessel or stoneware.<sup>30–35</sup> Hexafluorosilicate ( $\text{SiF}_6^{2-}$ ) is a stable octahedral anion with six Si–F bond distances of 1.71 Å,<sup>36</sup> and its solubility is significantly dependent on cations.<sup>37</sup> Furthermore, the dianion species have seen the following diverse uses: leather and wood preservation agents, fluoridation agents for drinking water, two-solution

fluoride mouth rinse, commercial laundry, enamels/enamel frits for china and porcelain, opalescent glass, metallurgy of aluminum and beryllium, glue, ore flotation, insecticides and rodenticides, fluorinating agent in organic synthesis, and water fluoridation.<sup>38–47</sup>

In this context, systematic research on the unusual formation process and recognition of  $\text{SiF}_6^{2-}$  is very much in demand. Thus, herein, formation of hexafluorosilicate *via* conversion of  $\text{PF}_6^-$  and  $\text{SbF}_6^-$  beside  $\text{BF}_4^-$  during self-assembly or recrystallization in a glass vessel is scrutinized. This paper reports the unique  $\text{SiF}_6^{2-}$ -encapsulated cages constructed *via* self-assembly of  $\text{M}^{2+}$  ( $\text{M} = \text{Cu}^{2+}$  and  $\text{Zn}^{2+}$ ) with tridentate N-donor ligands in a glass vessel. To our knowledge, this article presents clear systematic research on the formation of hexafluorosilicate by reactions of glassware with F-containing polyatomic anions.

## Experimental

### Materials and measurements

All of the chemicals, including copper(II) tetrafluoroborate ( $\text{Cu}(\text{BF}_4)_2$ ), copper(II) nitrate ( $\text{Cu}(\text{NO}_3)_2$ ), copper(II) chloride ( $\text{CuCl}_2$ ), silver(I) hexafluorophosphate ( $\text{AgPF}_6$ ), silver(I) hexafluoroantimonate ( $\text{AgSbF}_6$ ), and zinc(II) tetrafluoroborate ( $\text{Zn}(\text{BF}_4)_2$ ), were purchased from Aldrich and used without further purification. (1*S*,1'*S*,1''*S*,2*R*,2'*R*,2''*R*)-(Benzenetricarbonyltris(azanediyl))tris(2,3-dihydro-1*H*-indene-2,1-diyl)triisonicotinate ( $\text{L}^1$ ) and 1,3,5-tris(isonicotinoyloxy-methyl)benzene ( $\text{L}^2$ ) were synthesized according to the literature,<sup>48,49</sup> respectively. Glass vessels (Hubena Co, Seongnam, Korea) were employed in all of the self-assembly reactions. The  $^1\text{H}$  and  $^{19}\text{F}$  NMR spectra were recorded on a Varian Mercury Plus operating at 400 MHz. The infrared (IR) spectra were obtained on a Nicolet 380 FT-IR spectrophotometer with samples prepared as

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KBr pellets. Elemental microanalyses (C, H, N) were performed on solid samples at the Pusan Center, KBSI, using a Vario-EL III. Thermal analyses were carried out under a dinitrogen atmosphere at a scan rate of 10 °C min<sup>-1</sup> using a Labsys TGA-DSC 1600.

### [(SiF<sub>6</sub>)<sub>2</sub>@Cu<sub>3</sub>L<sup>1</sup><sub>4</sub>](SiF<sub>6</sub>)·16CH<sub>3</sub>OH

**Method 1.** A methanol solution (2.0 mL) of copper(II) tetrafluoroborate (4.7 mg, 0.02 mmol) was carefully layered onto a dichloromethane solution (2.0 mL) of L<sup>1</sup> (18.4 mg, 0.02 mmol). After 2 weeks, blue crystals suitable for single crystal X-ray structure determination were obtained in an 83% yield.

**Method 2.** A methanol solution (1.0 mL) of silver(I) hexafluorophosphate (10.1 mg, 0.04 mmol) was added to copper(II) chloride (2.7 mg, 0.02 mmol) dispersed in methanol at room temperature. The reaction mixture was stirred for 30 min, after which, the precipitated silver chloride was filtered off. The methanol solution of Cu(PF<sub>6</sub>)<sub>2</sub> was carefully layered onto a dichloromethane solution (2.0 mL) of L<sup>1</sup> (18.4 mg, 0.02 mmol). After 4 weeks, blue crystals suitable for single crystal X-ray structure determination were obtained in a 78% yield.

**Method 3.** A methanol solution (1.0 mL) of silver(I) hexafluoroantimonate (13.7 mg, 0.04 mmol) was added to a suspension of copper(II) chloride (2.7 mg, 0.02 mmol) dispersed in methanol at room temperature. The reaction mixture was stirred for 30 min, after which, the precipitated silver chloride was filtered off. The methanol solution of Cu(SbF<sub>6</sub>)<sub>2</sub> was carefully layered onto a dichloromethane solution (2.0 mL) of L<sup>1</sup> (18.4 mg, 0.02 mmol). After 6 weeks, blue crystals suitable for single crystal X-ray structure determination were obtained in a 66% yield.

**Method 4.** A methanol solution (2.0 mL) of copper(II) nitrate (2.8 mg, 0.015 mmol), a dichloromethane solution (4.0 mL) of L<sup>1</sup> (18.4 mg, 0.02 mmol), and an aqueous solution (0.1 mL) of (NH<sub>4</sub>)<sub>2</sub>SiF<sub>6</sub> (3.6 mg, 0.02 mmol) were left at room temperature, and after 1 day, blue crystals suitable for single crystal X-ray structure determination were obtained in a 62% yield. m. p. 280 °C (dec). Anal. Calcd for: C, 58.55; H, 4.65; N, 7.19%. Found: C, 58.40; H, 4.52; N, 7.23%. IR (KBr pellet, cm<sup>-1</sup>): 3294(br), 1733(s), 1661(s), 1524(s), 1425(m), 1329(m), 1286(s), 1179(w), 1127(s), 1063(m), 1032(m), 859(w), 756(s), 705(s), 472(w).

### [(SiF<sub>6</sub>)@Zn<sub>2</sub>L<sup>2</sup><sub>4</sub>](SiF<sub>6</sub>)·2C<sub>4</sub>H<sub>8</sub>O·4CH<sub>2</sub>Cl<sub>2</sub>

A mixture of tetrahydrofuran with a methanol solution (3.0 mL/1.0 mL) of zinc(II) tetrafluoroborate (9.6 mg, 0.04 mmol) and a dichloromethane solution (3.0 mL) of L<sup>2</sup> (14.5 mg, 0.04 mmol) were left at room temperature, and after 2 weeks, blue crystals suitable for single crystal X-ray structure determination were obtained in a 67% yield. m. p. 260 °C (dec). Anal. Calcd for: C, 50.88; H, 3.84; N, 5.93%. Found: C, 50.79; H, 3.81; N, 5.97%. IR (KBr pellet, cm<sup>-1</sup>): 3425(br), 1729(s), 1616(w), 1564(w), 1409(m), 1373(w), 1326(m), 1280(s), 1224(w), 1122(s), 1062(m), 1024(w), 862(m), 759(s), 705(s), 468(w).

### Single crystal X-ray structure determination

The X-ray diffraction data for [(SiF<sub>6</sub>)<sub>2</sub>@Cu<sub>3</sub>L<sup>1</sup><sub>4</sub>](SiF<sub>6</sub>)·16CH<sub>3</sub>OH were measured at 100 K with synchrotron radiation (λ = 0.76000

**Table 1** Selected bond lengths (Å) and angles (°) for [(SiF<sub>6</sub>)<sub>2</sub>@Cu<sub>3</sub>L<sup>1</sup><sub>4</sub>](SiF<sub>6</sub>)·16CH<sub>3</sub>OH, and [(SiF<sub>6</sub>)@Zn<sub>2</sub>L<sup>2</sup><sub>4</sub>](SiF<sub>6</sub>)·2C<sub>4</sub>H<sub>8</sub>O·4CH<sub>2</sub>Cl<sub>2</sub>

[(SiF <sub>6</sub> ) <sub>2</sub> @Cu <sub>3</sub> L <sup>1</sup> <sub>4</sub> ](SiF <sub>6</sub> )·16CH <sub>3</sub> OH		[(SiF <sub>6</sub> )@Zn <sub>2</sub> L <sup>2</sup> <sub>4</sub> ](SiF <sub>6</sub> )·2C <sub>4</sub> H <sub>8</sub> O·4CH <sub>2</sub> Cl <sub>2</sub>	
Cu(1)–N(6)	2.007(4)	Zn(1)–N(1)	2.115(4)
Cu(1)–N(3)	2.019(3)	Zn(1)–F(4)	2.122(5)
Cu(1)–F(5)	2.317(2)	Zn(1)–F(3)	2.361(5)
N(6) <sup>a</sup> –Cu(1)–N(6)	87.5(2)	N(1)–Zn(1)–N(1) <sup>a</sup>	89.952(6)
N(6) <sup>a</sup> –Cu(1)–N(3) <sup>a</sup>	176.4(3)	N(1) <sup>a</sup> –Zn(1)–N(1) <sup>b</sup>	176.7(2)
N(6)–Cu(1)–N(3) <sup>a</sup>	91.2(2)	N(1) <sup>a</sup> –Zn(1)–N(1) <sup>c</sup>	89.953(6)
N(6)–Cu(1)–N(3)	176.4(2)	N(1)–Zn(1)–F(4)	91.6(1)
N(3) <sup>a</sup> –Cu(1)–N(3)	90.3(3)	N(1)–Zn(1)–F(3)	88.4(1)
		F(4)–Zn(1)–F(3)	180.0

<sup>a</sup> x – 1, y + 1, z, x + 1, y – 1, z. <sup>b</sup> x + 1, y, z – 1. <sup>c</sup> –x + 1/2, –y + 1/2, z

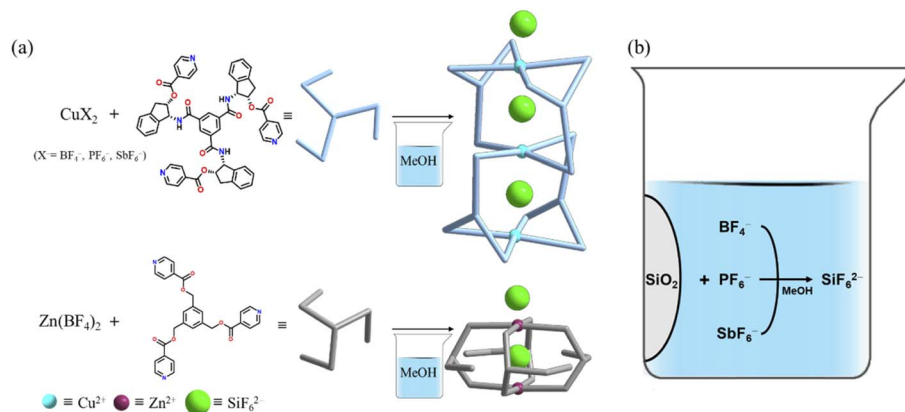
Å) on a Rayonix MX225HS detector at 2D SMC with a silicon (111) double-crystal monochromator (DCM) at the Pohang Accelerator Laboratory (PAL), Korea. The PAL BL2D-SMDC program<sup>50</sup> was used for data collection (detector distance: 66 mm, omega scan: Δω = 3°, exposure time: 1 s per frame), and HKL3000sm (ver. 703r)<sup>51</sup> was used for cell refinement, reduction, and absorption correction. X-ray data on [(SiF<sub>6</sub>)@Zn<sub>2</sub>L<sup>2</sup><sub>4</sub>](SiF<sub>6</sub>)·2C<sub>4</sub>H<sub>8</sub>O·4CH<sub>2</sub>Cl<sub>2</sub> were collected on a Bruker SMART automatic diffractometer with graphite-monochromated Mo Kα radiation (λ = 0.71073 Å). Thirty-six (36) frames of 2D diffraction images were collected and processed to obtain the cell parameters and orientation matrix. The data were corrected for Lorentz and polarization effects. The absorption effects were corrected using the multi-scan method (SADABS).<sup>52</sup> The structures were resolved using the direct method (SHELXS) and refined by full-matrix least squares techniques (SHELXL 2018/3).<sup>53</sup> The non-hydrogen atoms were refined anisotropically, and the hydrogen atoms were placed in calculated positions and refined only for the isotropic thermal factors. The crystal parameters and procedural information corresponding to the data collection and structure refinement are listed in Table 1.

## Results and discussion

### Synthesis aspects

Self-assembly of Cu(BF<sub>4</sub>)<sub>2</sub> with L<sup>1</sup> in a mixture of methanol and dichloromethane produced crystals consisting of [(SiF<sub>6</sub>)<sub>2</sub>@Cu<sub>3</sub>L<sup>1</sup><sub>4</sub>](SiF<sub>6</sub>)·16CH<sub>3</sub>OH suitable for single crystal X-ray structure determination after 2 weeks, as shown in Scheme 1. Moreover, the reactions with Cu(PF<sub>6</sub>)<sub>2</sub> and Cu(SbF<sub>6</sub>)<sub>2</sub> instead of Cu(BF<sub>4</sub>)<sub>2</sub> gave rise to the same product after significant durations, specifically 4 and 6 weeks, respectively. The reaction time may be owed to the stability of the BF<sub>4</sub><sup>–</sup> < PF<sub>6</sub><sup>–</sup> < SbF<sub>6</sub><sup>–</sup> anions under the given reaction conditions. As expected, self-assembly of Cu(BF<sub>4</sub>)<sub>2</sub> with L<sup>1</sup> in the presence of (NH<sub>4</sub>)<sub>2</sub>SiF<sub>6</sub> produced blue crystals within 1 day. In order to investigate the metal effects, self-assembly of Zn(BF<sub>4</sub>)<sub>2</sub> instead of Cu(BF<sub>4</sub>)<sub>2</sub> with L<sup>2</sup> was performed, which generated crystals of [(SiF<sub>6</sub>)@Zn<sub>2</sub>L<sup>2</sup><sub>4</sub>](SiF<sub>6</sub>)·2C<sub>4</sub>H<sub>8</sub>O·4CH<sub>2</sub>Cl<sub>2</sub> after 2 weeks, indicating that the central metal cation is not a significant factor in anion transformation in a glass vessel. For all of the reactions, the SiF<sub>6</sub><sup>2–</sup> anion acted





Scheme 1 Construction of cages (a) via  $\text{SiF}_6^{2-}$  formation (b) during self-assembly in a glass vessel.

either as a template by which to form the cage products or as a cage-to-cage bridge.

Both crystalline products are stable under anaerobic condition at room temperature. The crystals are insoluble in common organic solvents such as acetone, chloroform, toluene, benzene and tetrahydrofuran, but are partially dissociated in dimethyl sulfoxide and *N,N*-dimethylformamide. Their compositions and structures were confirmed by elemental analyses, IR-spectral analysis (Fig. S1 and S2<sup>†</sup>), thermal analysis (Fig. S3<sup>†</sup>),  $^1\text{H}$  NMR (Fig. S4, as dissociated in  $\text{Me}_2\text{SO}-d_6$ ), and single-crystal X-ray crystallography. The characteristic IR bands of  $\text{SiF}_6^{2-}$  were easily assigned. The thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) showed  $[(\text{SiF}_6)_2@(\text{Cu}_3\text{L}^1_4)(\text{SiF}_6)] \cdot 16\text{CH}_3\text{OH}$  and  $[(\text{SiF}_6)@(\text{Zn}_2\text{L}^2_4)(\text{SiF}_6)] \cdot 2\text{C}_4\text{H}_8\text{O} \cdot 4\text{CH}_2\text{Cl}_2$  to be stable up to 277 and 257 °C, respectively. Evaporation of the solvate molecules of the two kinds of crystals occurred in the 10–60 and 20–135 °C temperature ranges, respectively (Fig. S3<sup>†</sup>).

### Crystal structures

The crystal structure of  $[(\text{SiF}_6)_2@(\text{Cu}_3\text{L}^1_4)(\text{SiF}_6)] \cdot 16\text{CH}_3\text{OH}$  is depicted in Fig. 1, and its bond lengths and angles are listed in Table 1. The geometry of each copper(II) ion is an octahedral  $\text{N}_4\text{F}_2$  coordination arrangement with four N donors from four  $\text{L}^1$ s and F donors from two  $\text{SiF}_6^{2-}$  anions ( $\text{Cu}-\text{N} = 2.007(4) - 2.019(3)$  Å;  $\text{Cu}-\text{F}(\text{encapsulated}) = 2.317(2), 2.300(3)$  Å;  $\text{Cu}-\text{F}(\text{bridged}) = 2.357(3)$  Å) in axial positions, resulting in the formation of the  $\text{Cu}_3\text{L}_4$  double-decker occupied by two  $\text{SiF}_6^{2-}$  anions. Concomitantly, for the nested  $\text{SiF}_6^{2-}$ , the equatorial Si–F bond lengths (1.628(7) – 1.684(7) Å) are comparable to the axial Si–F lengths (1.666(3) and 1.693(3) Å). Thus, the ligand is coordinated to two Cu(II) ions in a bidentate and a monodentate fashion, respectively. The intra-cage Cu...Cu distance is 7.968(2) Å. Its packing structure is in the linear double-decker... $\text{SiF}_6^{2-}$ ...double-decker... $\text{SiF}_6^{2-}$  mode (Fig. S5<sup>†</sup>). The crystal structure of  $[(\text{SiF}_6)@(\text{Zn}_2\text{L}^2_4)(\text{SiF}_6)] \cdot 2\text{C}_4\text{H}_8\text{O} \cdot 4\text{CH}_2\text{Cl}_2$  is a typical  $\text{Zn}_2\text{L}_4$  cage, as depicted in Fig. 2, and the coordination geometry of the Zn(II) ion is an octahedral arrangement with two  $\text{SiF}_6^{2-}$  groups in the *trans* position ( $\text{Zn}-\text{F} = 2.095(5) - 2.273(5)$  Å;  $\text{F}-\text{Zn}-\text{F}' = 180.0(0)^\circ$ ) and four pyridine N donors of four  $\text{L}^2$ s on the basal

plane. Each L connects two zinc(II) ions in a bidentate mode with a free pyridyl donor. Concomitantly, for the nested  $\text{SiF}_6^{2-}$ , the equatorial Si–F bond lengths (1.637(4) Å) are slightly shorter than the axial Si–F lengths (1.733(5) – 1.746(6) Å). The intra-cage Zn...Zn distance is 8.113(2) Å. Its packing structure is in the linear cage... $\text{SiF}_6^{2-}$ ...cage... $\text{SiF}_6^{2-}$  mode (Fig. S5<sup>†</sup>). The solvate molecules of  $[(\text{SiF}_6)_2@(\text{Cu}_3\text{L}^1_4)(\text{SiF}_6)] \cdot 16\text{CH}_3\text{OH}$  were squeezed. The volumes of solvate molecules in  $[(\text{SiF}_6)_2@(\text{Cu}_3\text{L}^1_4)(\text{SiF}_6)] \cdot 16\text{CH}_3\text{OH}$  and  $[(\text{SiF}_6)@(\text{Zn}_2\text{L}^2_4)(\text{SiF}_6)] \cdot 2\text{C}_4\text{H}_8\text{O} \cdot 4\text{CH}_2\text{Cl}_2$  were 56.2% (10 282 Å<sup>3</sup>/18 304 Å<sup>3</sup>) and 37.8% (2093.4 Å<sup>3</sup>/5539.5 Å<sup>3</sup>), respectively, on the basis of a PLATON/SOLV calculation.<sup>54</sup>

### Discussion

Formation of  $\text{SiF}_6^{2-}$  during self-assembly of more than 2 weeks' duration requires some explanation, because the anion was not added to the self-assembly solution in a glass vessel. It should

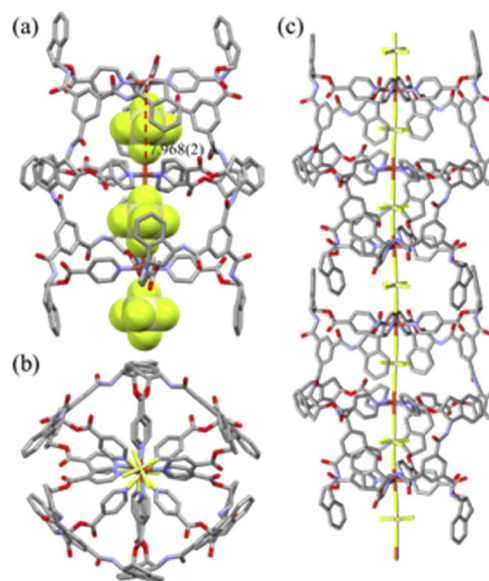


Fig. 1 Side view (a), top view (b), and packing structure (c) of double-decker,  $[(\text{SiF}_6)_2@(\text{Cu}_3\text{L}^1_4)(\text{SiF}_6)] \cdot 16\text{CH}_3\text{OH}$ . The nested and outside bridged  $\text{SiF}_6^{2-}$  anions were clearly depicted in light green color.



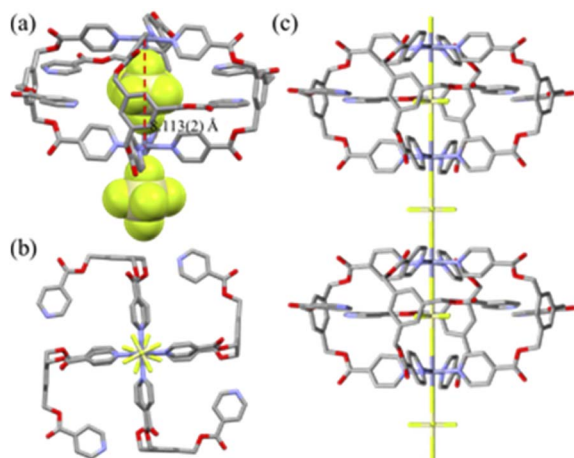
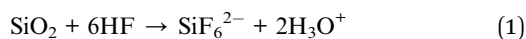


Fig. 2 Partial crystal structures of  $[\text{Ag}(s,r\text{-L})](\text{PF}_6) \cdot 3\text{C}_4\text{H}_8\text{O}_2 \cdot 0.5\text{H}_2\text{O}$  (a) and  $[\text{Ag}(r,s\text{-L})](\text{PF}_6) \cdot 3\text{C}_4\text{H}_8\text{O}_2 \cdot 0.5\text{H}_2\text{O}$  (b). The solvate molecules were omitted for clarity.

be noted that the  $\text{SiF}_6^{2-}$  anion replaces the starting  $\text{BF}_4^-$  anion in the self-assembly reaction and that it is formed after extracting  $\text{Si}^{4+}$  from the glass vessel in methanol solvent—a rare but well-known phenomenon.<sup>55</sup> The generation of  $\text{SiF}_6^{2-}$  by slow release of  $\text{Si}^{4+}$  from the glass vessel in the methanol solution was clearly confirmed, and the resultant anions were separated as counteranions. The  $\text{SiF}_6^{2-}$  anions appear to play significant roles as both encapsulator and bridge in the construction of the cage skeleton. The stable anion, by contrast, forms as a consequence of the hydrolysis of the  $\text{BF}_4^-$  anion and subsequent reaction of  $\text{F}^-$  with the Si–O moieties of the glass vessel<sup>56,57</sup> in which a methanol solution of  $\text{M}(\text{BF}_4)_2$  is kept for self-assembly or crystallization. The formation of  $\text{SiF}_6^{2-}$  seems to be promoted by the presence of a small quantity of  $\text{H}_2\text{O}$  in addition to a mixture solvent including methanol. Formation of  $\text{SiF}_6^{2-}$  from  $\text{BF}_4^-$  and  $\text{PF}_6^-$  in a glass vessel in water has been observed by other groups,<sup>30–32,56</sup> but that of  $\text{SiF}_6^{2-}$  from  $\text{SbF}_6^-$  heretofore has not been recorded. The present self-assembly of  $\text{MX}_2$  ( $\text{M}^{2+} = \text{Cu}^{2+}, \text{Zn}^{2+}$ ;  $\text{X}^- = \text{BF}_4^-, \text{PF}_6^-, \text{SbF}_6^-$ ) with each tridentate ligand in each glass vessel systematically transformed  $\text{BF}_4^-$ ,  $\text{PF}_6^-$  or  $\text{SbF}_6^-$  into the  $\text{SiF}_6^{2-}$  anion according to the following eqn (1):



Of course, formation of  $\text{SiF}_6^{2-}$  from  $\text{CF}_3\text{SO}_3^-$  (C–F compound) could not be carried out in a similar reaction performed in a polypropylene vessel instead of a glass one; that is, the reaction did not yield crystals containing the  $\text{SiF}_6^{2-}$  anion.

The presence of  $\text{SiF}_6^{2-}$  in  $\text{Me}_2\text{SO}-d^6$  was confirmed by  $^{19}\text{F}$  NMR spectra (Fig. S6†). The  $\text{SiF}_6^{2-}$  occurred as a singlet at  $\delta = -134$  ppm. Spectra taken of the sample preparation one month later indicated that almost all of the original  $\text{BF}_4^-$  anions had been converted to  $\text{SiF}_6^{2-}$  anions. As regards the formation of  $\text{SiF}_6^{2-}$  from  $\text{PF}_6^-$  and  $\text{SbF}_6^-$  anions,  $\text{PF}_6^-$  (−70.8 ppm) and  $\text{SbF}_6^-$  chemical shifts (−119.9 ppm) disappeared after 4 and 6 weeks, respectively, and appeared at the position of the  $\text{SiF}_6^{2-}$

anion. As for construction of the coordination architecture, insight into the stability and geometry of a specific anion as a template is useful to the tuning of the shape and topology of coordination species. In the present study, the encapsulated and bridged  $\text{SiF}_6^{2-}$  anions helped to stabilize the crystal structure of the cages. Certainly, transformation of polyatomic anions and their role is a topic worthy of further investigation.

## Conclusions

In summary, transformation of polyatomic anions  $\text{BF}_4^-$ ,  $\text{PF}_6^-$ , and  $\text{SbF}_6^-$  into  $\text{SiF}_6^{2-}$  during self-assembly or recrystallization in a glass vessel was systematically confirmed. This shows that the surface of regular laboratory glassware should be given serious consideration for long-duration reactions or self-assembly with  $\text{F}^-$  species. Further studies on other means of anion-bridging or -encapsulation of cage units will contribute to the development of task-specific polyatomic anions for recognition as well as environmental molecular materials such as adsorbents and sensing materials.

## Conflicts of interest

There are no conflicts to declare.

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