Electronic Supplementary Material (ESI) for ChemComm.

Electronic Supplementary Information

Non-covalent immobilisation of *p*-toluenesulfonic acid in a porous molecular crystal for size-specific acid-catalysed reactions

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Abbreviations

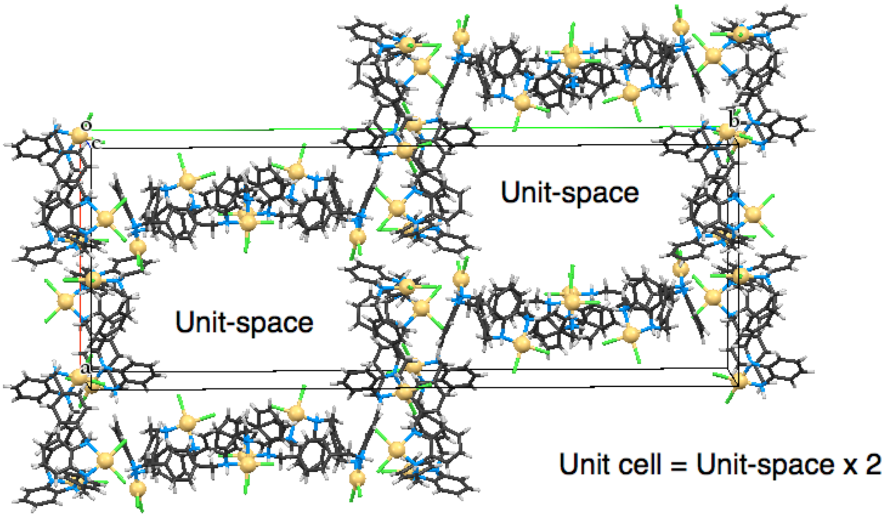
XRD: X-ray diffraction, MMF: metal–macrocycle framework, Bn: benzyl, Trt: trityl, NMR: nuclear magnetic resonance, DMSO: dimethyl sulfoxide, ESI-TOF: electrospray ionization-time-of-flight, IR: infrared, ATR: attenuated total reflection, CCDC: Cambridge crystallographic data centre, THF: tetrahydrofuran, HRMS: high-resolution mass spectrometry, HSQC: heteronuclear single quantum coherence, HMBC: heteronuclear multiple bond correlation, GOF: goodness of fit, IUCR: international union of crystallography, ORTEP: Oak Ridge thermal ellipsoid plot.

Materials and methods

MMF crystals were prepared according to our procedure previously reported.[1] BnOTrt (**2**) was synthesized and the analytical data of **2** were referred to a literature.[2] The precursor of compound **5**, 5-(4-carboxymethylphenyl)-10,15,20-triphenylporphyrin, was purchased from Tokyo Chemical Industry CO., LTD. *p*-Toluenesulfonic acid monohydrate ($\mathbf{1}\cdot H_2O$) was purchased from Wako Pure Chemicals CO., LTD. and used without further purification. 4-Chlorobenzenesulfonic acid hydrate and *p*-toluenesulfonamide were purchased from Tokyo Chemical Industry CO., LTD. and used without further purification. Other chemicals were commercially available and used without further purification. Column chromatography was performed using Merck Silica Gel 60 (230–400 mesh).

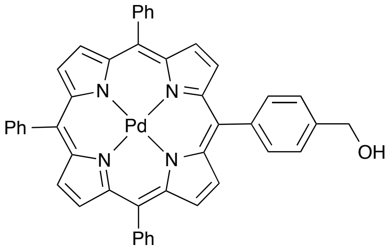
NMR spectroscopic measurements were performed using a Bruker AVANCE 500 spectrometer. NMR spectra are calibrated as below; $CDCl_3$: $Si(CH_3)_4$ = 0 ppm for ^1H, $CDCl_3$ = 77.16 ppm for ^{13}C. DMSO-d_6: $(CD_2H)CD_3SO$ = 2.50 ppm for ^1H. ESI-TOF mass spectra were recorded on Micromass LCT and Waters LCT Premier XE spectrometers. Melting points were measured using a Yanaco MP-500D apparatus. IR spectra were recorded on a JASCO FT/IR-4200 spectrometer using a ZnSe ATR method. Water contents were estimated by ^1H NMR analyses, and we also confirmed that this result was comparable to a result measured using a Mitsubishi CA-21 Karl Fischer apparatus. Single-crystal X-ray crystallographic analysis was performed using a Rigaku RAXIS-RAPID imaging plate diffractometer with MoK*a* radiation, and the obtained data were analyzed using a CrystalStructure crystallographic software package except for refinement, which was performed using a SHELXL-2013 program suite.[3] Solvent and guest molecules that are unbound to the molecular binding pockets are highly disordered in all crystal structures. Therefore the contribution of electron density of their highly-disordered molecules was removed by the SQUEEZE function[4] except for the crystal structure of *p*-TsOH@MMF. Several restraints (bond distances, angles and thermal parameters) were applied to $[Pd_3\mathbf{L}Cl_6]$ and guest molecules in all crystal structures. Complexes $[Pd_3\mathbf{L}Cl_6]$ were refined anisotropically except for disordered parts. Solvent and guest molecules were refined isotropically. Hydrogen atoms were placed at the calculated positions and refined using a riding model. On the other hand, hydrogen atoms of water molecules could not be located in the difference electron density maps. High thermal factors of the guest and solvent molecules may be due to large thermal vibration arising from weak non-covalent interactions between the trapped molecules and the interior surface. All the crystal structures reported in this paper are not of high quality, and have many Alert B and Cs mainly about thermal parameters using the CheckCIF program. However, there are no serious problems because we do not discuss molecular structures of guests and solvents in detail in terms of their bond distances and angles. The occupancies of guest molecules were refined based on electron densities using free variables in the SHELXL-2013 program, and the resulting moderate occupancies indicate that guest molecules are not entirely bound in each pocket and some pockets should be empty. X-ray structures were displayed using a Mercury program. The electron density maps were displayed using ShelXle.[5] The X-ray crystallographic coordinates for structures reported in this paper have been deposited at the Cambridge Crystallographic Data Centre under deposition numbers CCDC 1468503 (MMF including *p*-toluenesulfonamide), 1468109 (MMF including 4-chlorobenzenesulfonic acid) and 1468110 (*p*-TsOH@MMF).

In this research, we defined "unit-space" as a half of the unit cell of each crystal structure as below. The unit-space therefore corresponds to one unit of a nano-channel in MMF.



Syntheses and identification of new compounds

Synthesis of [5-(4-hydroxymethylphenyl)-10,15,20-triphenylporphyrinato]palladium(II) (5)



To a stirred suspension of $LiAlH_4$ (18.8 mg, 0.495 mmol, 3.60 eq.) in dry THF (5 mL) was added dropwise a solution of 5-(4-carboxymethylphenyl)-10,15,20-triphenylporphyrin (92.6 mg, 0.138 mmol) in dry THF (14 mL) at room temperature under an N_2 atmosphere. After stirring for 15 min at room temperature, water (100 mL) was carefully added to the reaction mixture. The separated aqueous layer was extracted with CH_2Cl_2 twice. The combined organic layer was dried over Na_2SO_4, filtered and concentrated. The residue was used for the next step without further purification.

To a stirred solution of the residue in dry $CHCl_3$ (10 mL) was added $Pd(OAc)_2$ (61.1 mg, 0.272 mmol, 1.97 eq.) at room temperature under an N_2 atmosphere. After stirring for 68 h at reflux temperature, water (40 ml) was added to the reaction mixture. The separated aqueous layer was extracted with $CHCl_3$ twice. The combined organic layer was dried over Na_2SO_4, filtered and concentrated to give a crude product (139 mg) as a red solid. The crude product was purified by silica gel column chromatography (SiO_2: 18 g, CH_2Cl_2) to afford product **5** as a red solid (60.1 mg, 58.6% (2 steps), 80.2 μmol).

^{1}H NMR (500 MHz; $CDCl_3$, 300 K): δ = 8.81-8.79 (m, 8H), 8.17-8.14 (m, 8H), 7.77-7.70 (m, 11H), 5.04 (d, J = 5.8 Hz, 2H), 1.95 (t, J = 5.9 Hz, 1H).

^{13}C NMR (126 MHz; $CDCl_3$, 300 K): δ = 141.92, 141.75, 141.73, 141.70, 141.32, 140.45, 134.44, 134.25, 131.18, 131.06, 127.92, 126.87, 125.49, 121.95, 121.92, 121.52, 65.56.

* 7 peaks are overlapped in ^{13}C NMR.

IR (ATR): υ = 3050.8, 2918.7, 2852.2, 1597.7, 1540.9, 1440.6, 1352.8, 1236.2, 1086.7, 1013.4.

HRMS (EST-TOF): *m/z* calcd for $[C_{45}H_{30}N_4OPd]^{\bullet+}$ 748.1471; found: 748.1489.

Mp.: > 300 °C.

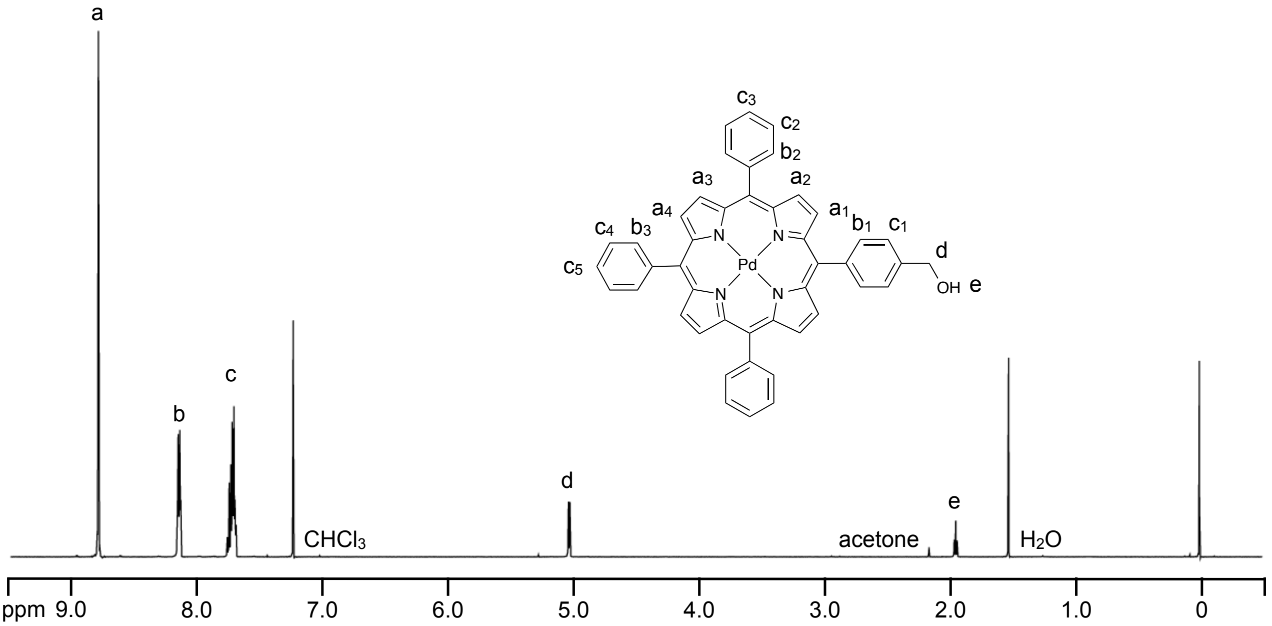


Fig. S1 ^{1}H NMR spectrum of **5** (500 MHz, $CDCl_3$, 300 K).

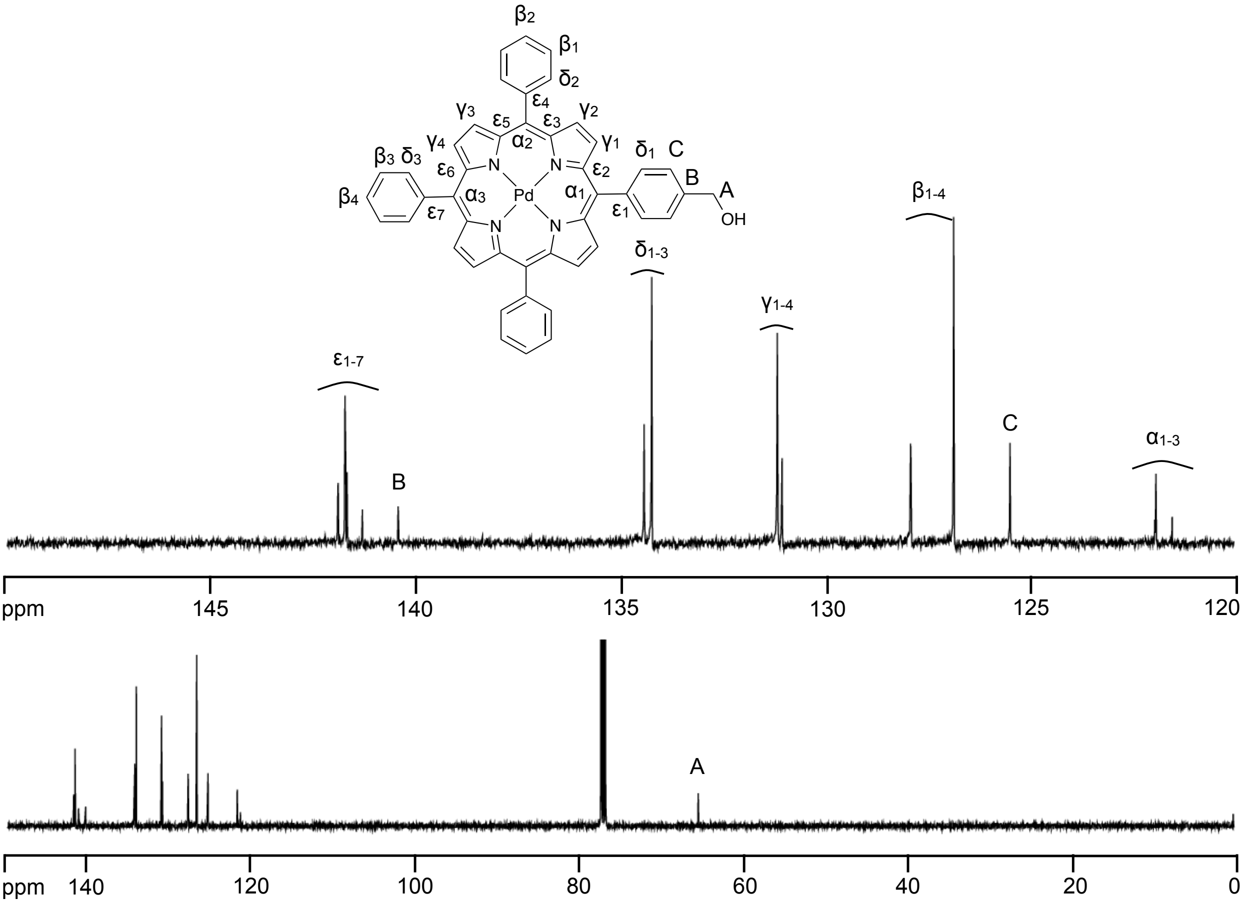


Fig. S2 ^{13}C NMR spectra of **5** (126 MHz, $CDCl_3$, 300 K).

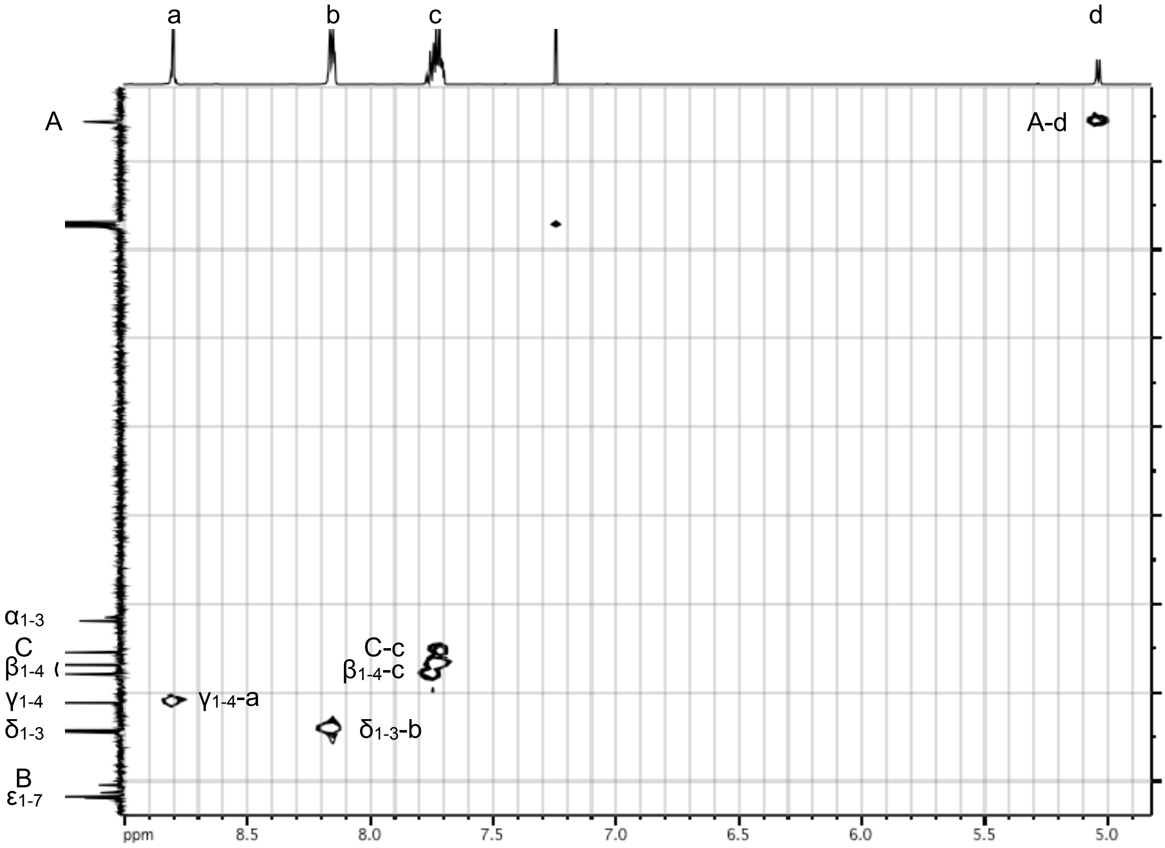


Fig. S3 HSQC NMR spectrum of **5** (all region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, $CDCl_3$, 300 K).

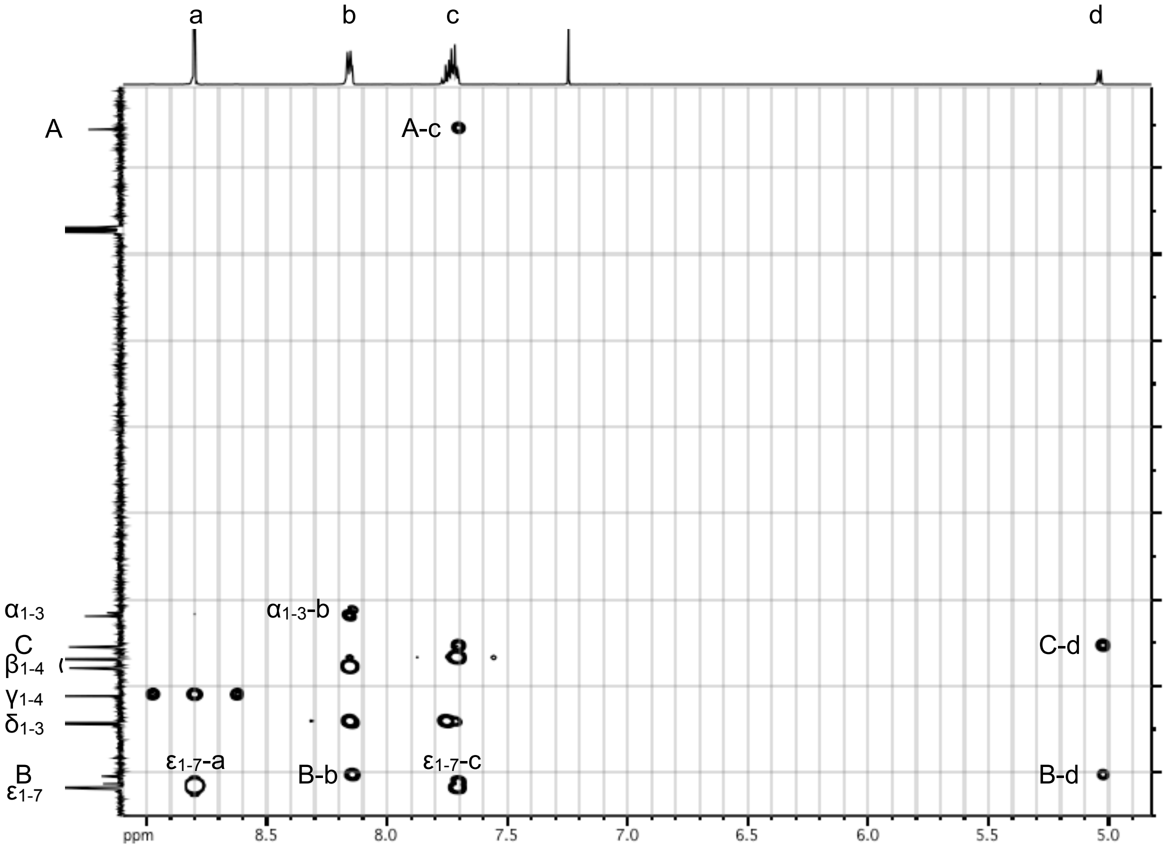
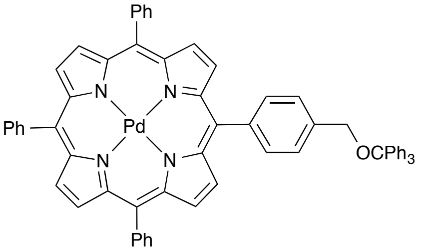


Fig. S4 HMBC NMR spectrum of **5** (all region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, $CDCl_3$, 300 K).

Synthesis of [5-(4-triphenylmethoxymethylphenyl)-10,15,20-triphenylporphyrinato] palladium(II) (4)



To a stirred solution of [5-(4-hydroxymethylphenyl)-10,15,20-triphenylporphyrinato]palladium(II) (**5**) (60.1 mg, 80.2 µmol) in dry CH_2Cl_2 (6.0 mL) were added trityl chloride (23.4 mg, 83.9 µmol, 1.05 eq.) and triethylamine (35 µL, 0.25 mmol, 3.1 eq.) at room temperature under an N_2 atmosphere. After stirring for 20 h at reflux temperature, trityl chloride (20.0 mg, 71.7 µmol, 0.895 eq.) and triethylamine (35 µL, 0.25 mmol, 3.1 eq.) were again added to the mixture at room temperature. After stirring for another 8 h at reflux temperature, saturated aqueous ammonium chloride was added to the reaction mixture. The separated aqueous layer was extracted with CH_2Cl_2 twice. The combined organic layer was dried over Na_2SO_4, filtered and concentrated to give a crude product (124 mg) as a red-purple solid. The crude product was purified by silica gel column chromatography (SiO_2: 20 g, CH_2Cl_2) and reprecipitation (CH_2Cl_2-CH_3OH) to afford product **4** as a red-purple solid (32.7 mg, 41.1%, 33.0 µmol).

^{1}H NMR (500 MHz; $CDCl_3$, 300 K): δ = 8.84 (d, J = 4.9 Hz, 2H), 8.81 (d, J = 5.0 Hz, 2H), 8.80 (s, 4H), 8.17 (dt, J = 7.8, 1.4 Hz, 6H), 8.12 (d, J = 8.0 Hz, 2H), 7.76-7.71 (m, 11H), 7.68 (dt, J = 8.4, 1.6 Hz, 6H) 7.41 (t, J = 7.7 Hz, 6H), 7.32 (tt, J = 7.3, 1.4 Hz, 3H), 4.56 (s, 2H).

^{13}C NMR (126 MHz; $CDCl_3$, 300 K): δ = 144.36, 141.96, 141.82, 141.74, 141.72, 140.63, 138.88, 134.27, 134.18, 131.25, 131.13, 131.12, 129.03, 128.15, 127.90, 127.32, 126.86, 125.35, 121.88, 121.86, 87.47, 65.99.

* 7 peaks are overlapped in ^{13}C NMR.

IR (ATR): υ = 3054.7, 3024.8, 2922.6, 2851.2, 1953.5, 1809.9, 1597.7, 1490.7, 1447.3, 1352.8, 1311.4, 1074.2, 1013.4.

HRMS (ESI-TOF): *m/z* calcd for $[C_{64}H_{44}N_4OPd]^{\bullet+}$ 990.2571; found: 990.2612.

Mp.: 250 °C (decomp.).

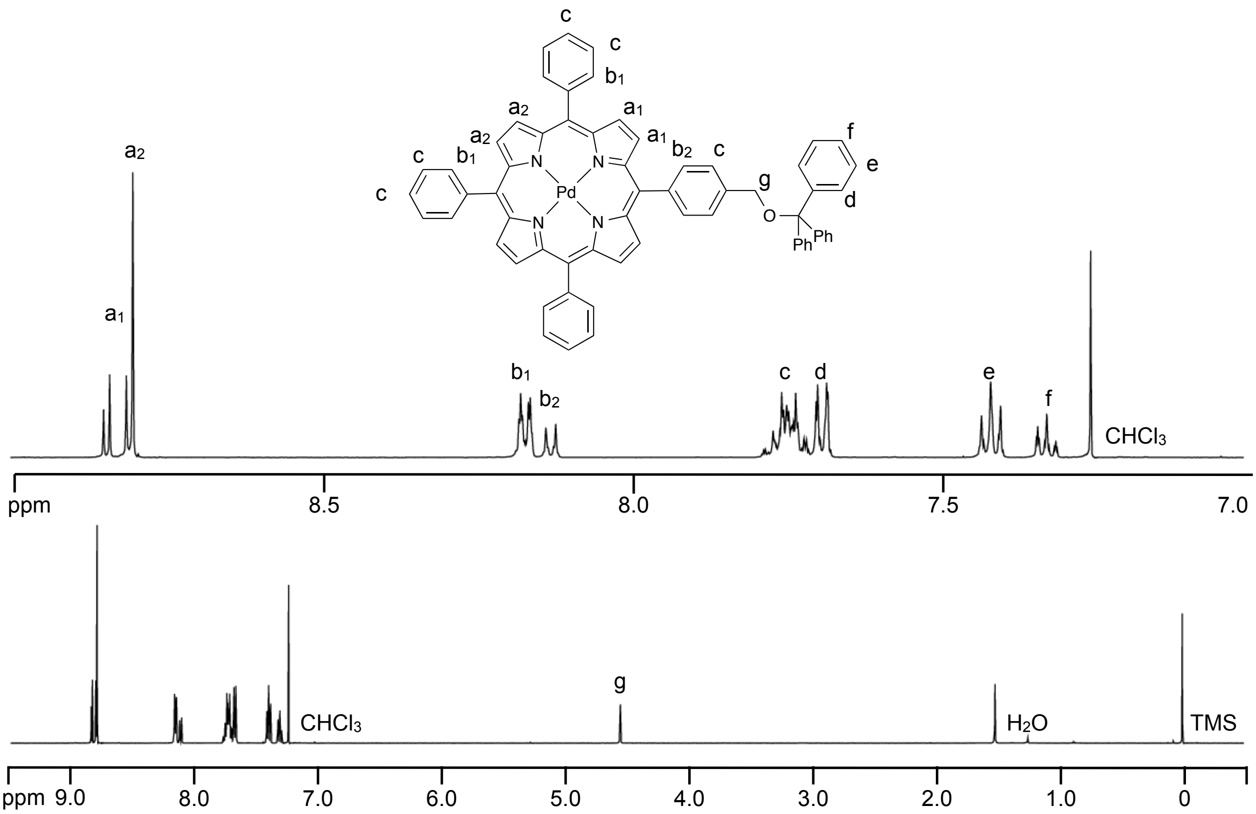


Fig. S5 ^{1}H NMR spectra of **4** (500 MHz, $CDCl_3$, 300 K).

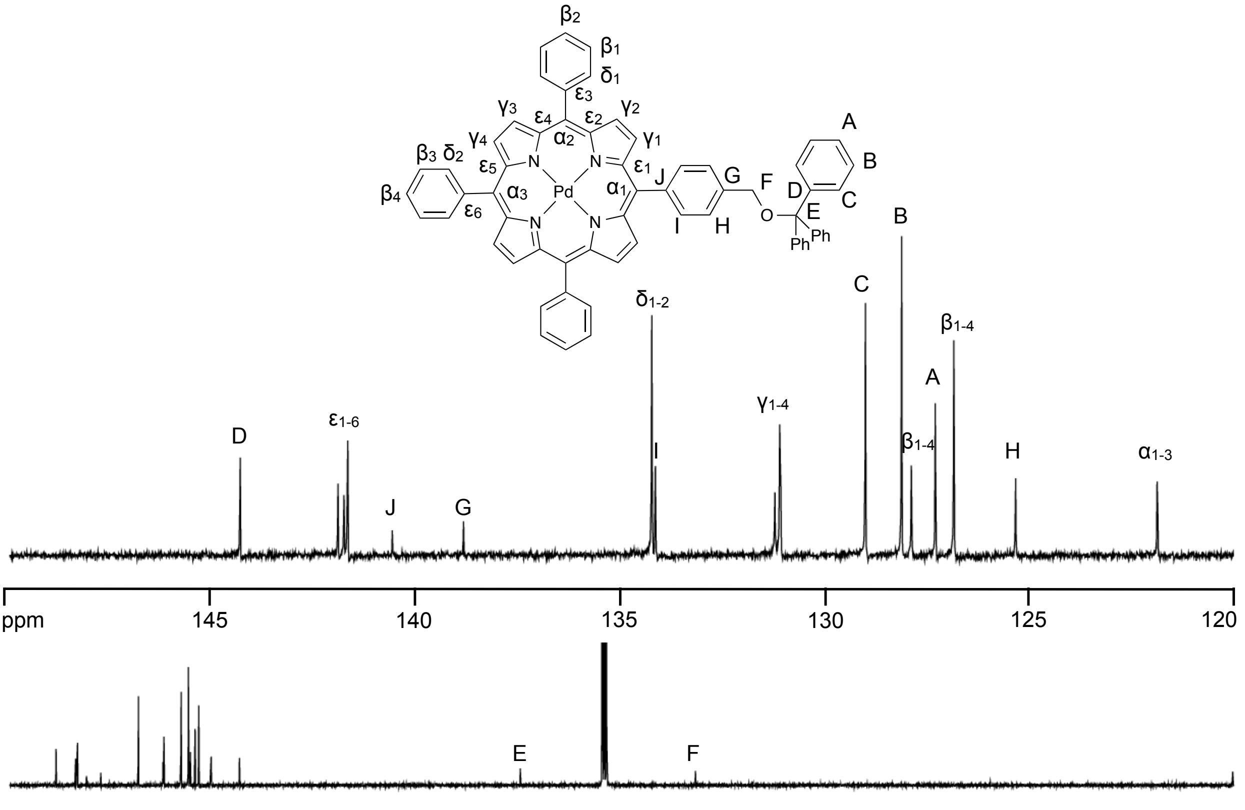


Fig. S6 ^{13}C NMR spectra of **4** (126 MHz, $CDCl_3$, 300 K).

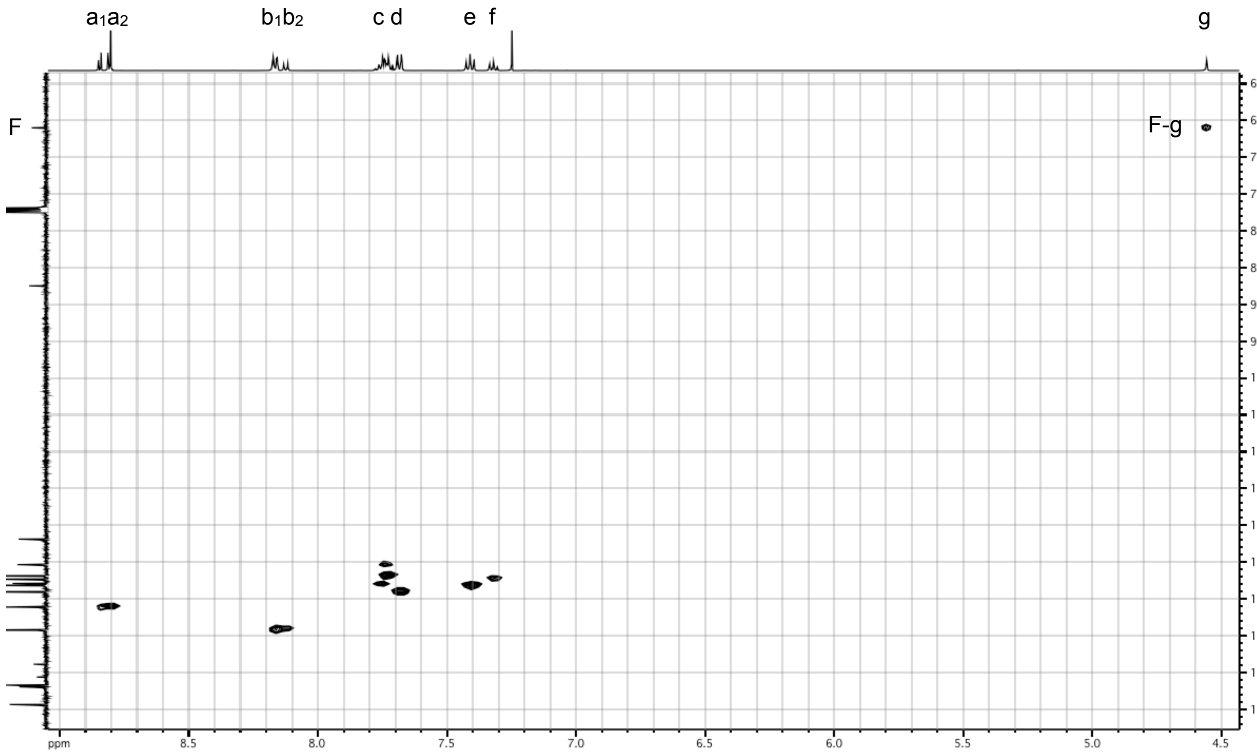


Fig. S7 HSQC NMR spectrum of **4** (all region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, $CDCl_3$, 300 K).

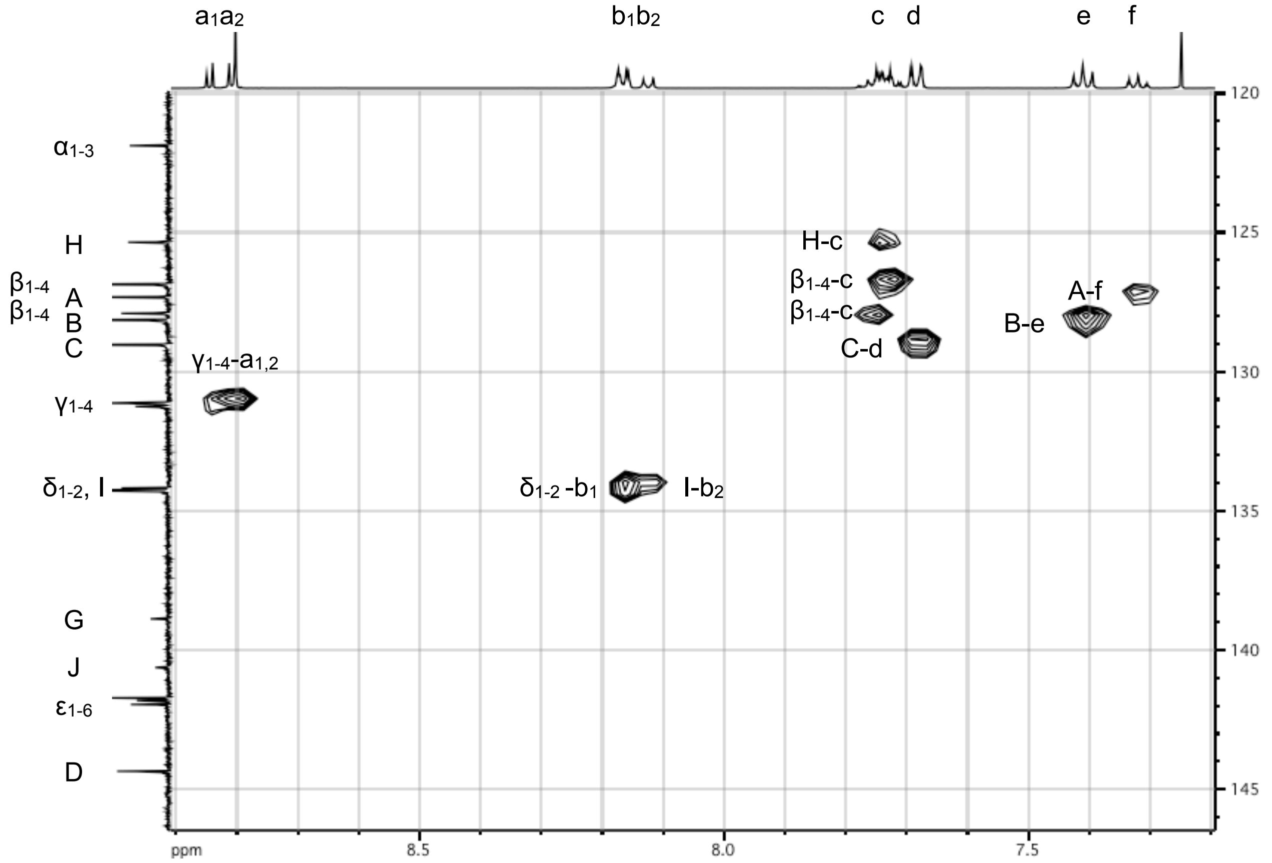


Fig. S8 HSQC NMR spectrum of **4** (aromatic region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, $CDCl_3$, 300 K).

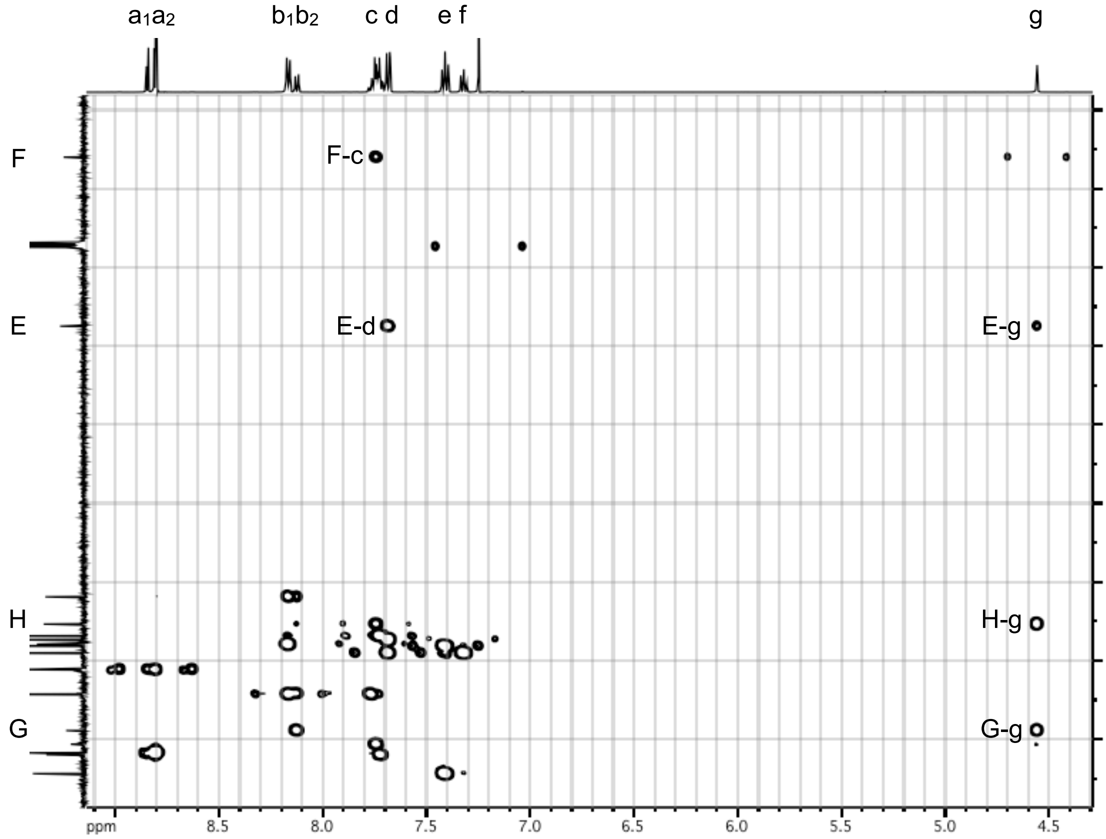


Fig. S9 HMBC NMR spectrum of **4** (all region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, CDCl$_3$, 300 K).

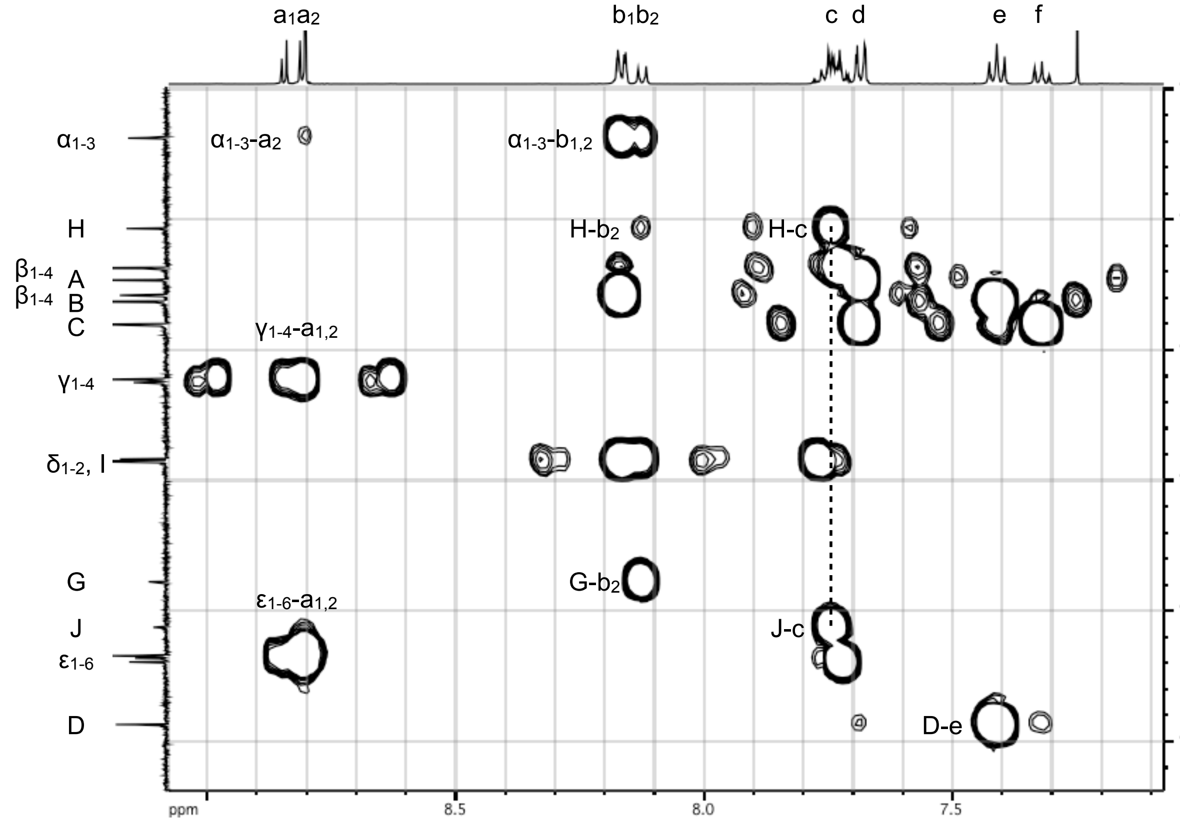


Fig. S10 HMBC NMR spectrum of **4** (aromatic region) (^{1}H: 500 MHz, ^{13}C: 126 MHz, CDCl$_3$, 300 K).

Single-crystal XRD analyses of MMF including sulfonic acids

MMF including *p*-toluenesulfonamide

[Soaking of MMF crystals in a guest solution]

MMF crystals were soaked in a CH_3CN solution of *p*-toluenesulfonamide (0.50 M) at 20 °C for 10 d. A crystal was then picked up and mixed with fluorolube®, then rapidly cooled to –177 °C under cold N_2 flow on a goniometer to subject to a single-crystal X-ray diffraction measurement. The inclusion of *p*-toluenesulfonamide in MMF crystals was also confirmed by IR analysis of the crystals (Fig. S15) and ^1H NMR analysis of a DMSO-d_6 solution dissolving the crystals (Fig. S14).

Crystal data for $(Pd_3\mathbf{L}Cl_6)_2\cdot$(*p*-toluenesulfonamide)$_{0.41}\cdot(CH_3CN)_{3.88}\cdot(H_2O)_3$: $C_{94.65}H_{105.36}Cl_{12}N_{16.29}O_{3.82}Pd_6S_{0.41}$, F_w = 2609.30, crystal dimensions 0.46 × 0.43 × 0.09 mm^3, monoclinic, space group $P2_1/c$, a = 19.5493(9), b = 51.784(3), c = 14.2759(7) Å, β = 90.7569(14)°, V = 14450.8(12) Å^3, Z = 4, $\rho_{\rm calcd}$ = 1.199 g cm^{-3}, μ = 9.998 cm^{-1}, T = 96 K, λ (MoKα) = 0.71075 Å , $2\theta_{\rm max}$ = 55.0°, 119637/32140 reflections collected/unique ($R_{\rm int}$ = 0.1299), R_1 = 0.1170 ($I > 2\sigma(I)$), wR_2 = 0.3675 (for all data), GOF = 1.082, largest diff. peak and hole 1.32/–1.31 eÅ^{-3}. CCDC deposit number 1468503. Several restraints were applied to [$Pd_3\mathbf{L}Cl_6$] and CH_3CN and guest molecules as described below to avoid collapse of the structures during least-square refinement. The contribution of the electron density (708 electrons/unit cell) caused by severely disordered molecules in the void (4254 Å^3/unit cell) was removed by the SQUEESE function.

See below for the details of applied restraints.

Geometrical restraints

DFIX (d = 1.3900, s = 0.0500) C57 C58 C58 C59 C59 C60 C60 C61 C61 C62 C62 C57

DFIX (d = 2.4080, s = 0.0500) C57 C59 C58 C60 C59 C61 C60 C62 C61 C57 C62 C58

DFIX (d = 1.1000, s = 0.0200) N1S C1S N2S C2S N3S C3S N6S C6S

DFIX (d = 1.5000, s = 0.0200) C1S C1T C2S C2T C3S C3T C6S C6T

DFIX (d = 2.6000, s = 0.0200) N1S C1T N2S C2T N3S C3T N6S C6T

DFIX (d = 1.3900, s = 0.0200) C85 C86 C86 C87 C87 C88 C88 C89 C89 C90 C90 C85

DFIX (d = 2.4080, s = 0.0200) C85 C87 C86 C88 C87 C89 C88 C90 C89 C85 C90 C86

DFIX (d = 1.1000, s = 0.0200) N7S C7S

DFIX (d = 1.5000, s = 0.0200) C7S C7T

DFIX (d = 2.6000, s = 0.0200) N7S C7T

DFIX (d = 1.8000, s = 0.0500) S1 O1 S1 O2 S1 N13

SADI (s = 0.0200) N7 C43 N8 C48 N9 C57 N10 C62 N11 C71 N12 C76

SADI (s = 0.0200) N7 C84 N8 C49 N9 C56 N10 C63 N11 C70 N12 C77

SADI (s = 0.0200) C49 C50 C53 C56 C63 C64 C67 C70 C77 C78 C81 C84

SADI (s = 0.0200) C86 S1 C90 S1

SADI (*s* = 0.0200) C87 C91 C89 C91

SADI (*s* = 0.0200) S1 O1 S1 O2 S1 N13

SADI (*s* = 0.0200) N13 O1 N13 O2 O1 O2

SADI (*s* = 0.0200) C85 O1 C85 O2 C85 N13

FLAT (*s* = 0.1000) C57 C59 C61 C58 C60 C62

FLAT (*s* = 0.1000) C85 C87 C89 C86 C88 C90 S1 C91

Restraints on anisotropic displacement parameters

DELU (*s* = 0.0100, *st* = 0.0100) C57 C58 C59 C60 C61 C62

SIMU (*s* = 0.0100, *st* = 0.0200) C85 C86 C87 C88 C89 C90 C91 S1 O1 O2 N13

SIMU (*s* = 0.0100, *st* = 0.0200) C57 C58 C59 C60 C61 C62

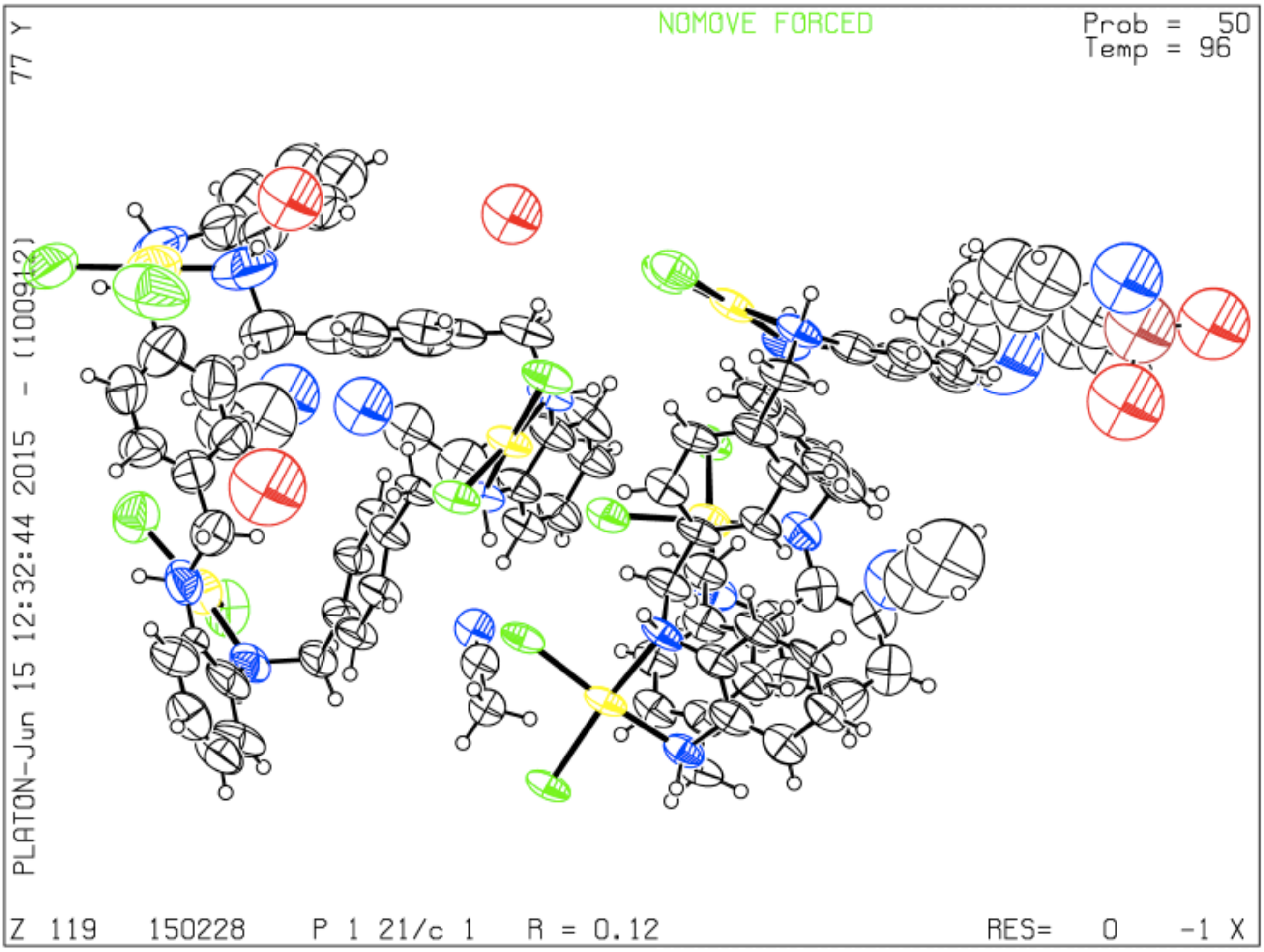


Fig. S11 ORTEP drawing of MMF including *p*-toluenesulfonamide at 50% probability level. C: black, N: blue, Cl: green, Pd: yellow, O: red, S: brown.

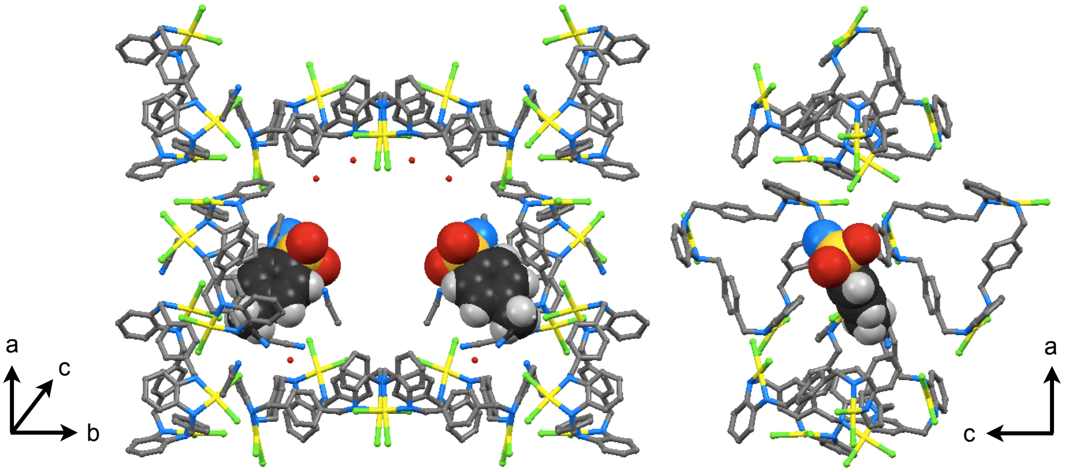


Fig. S12 Binding structure of *p*-toluenesulfonamide at bottom corners in the crystal structure of MMF including *p*-toluenesulfonamide. MMF and solvents: stick model, guest: space-filling model. C: black, N: blue, Cl: green, Pd: yellow, O: red, S: pale-brown.

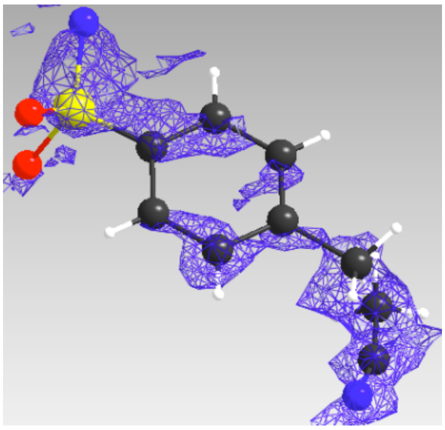


Fig. S13 Electron density map (F_o) of *p*-toluenesulfonamide included at a bottom corner (contour level: 0.80 eÅ^{-3}). A disordered acetonitrile molecule is also shown.

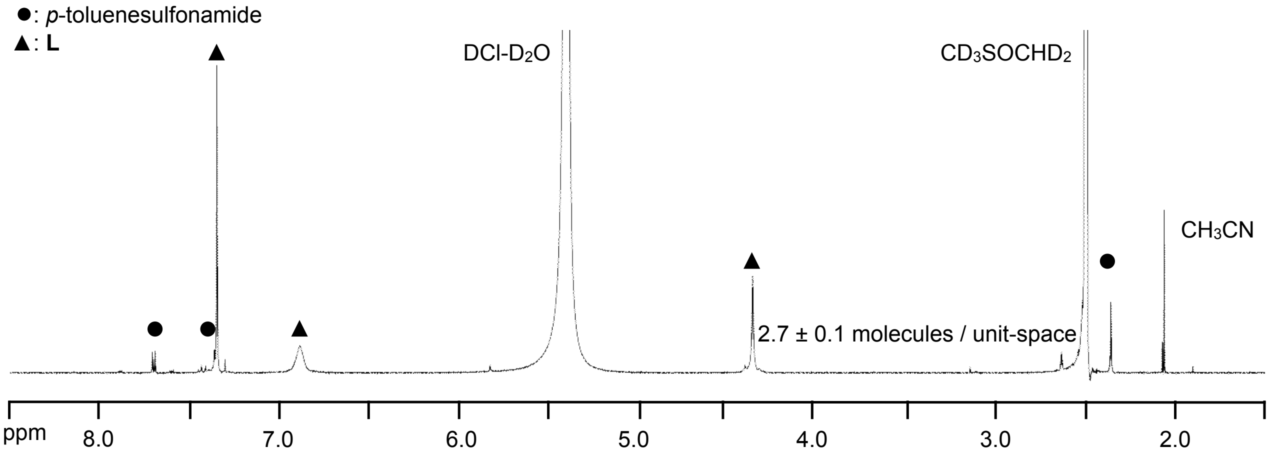


Fig. S14 ^{1}H NMR spectrum (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated number of *p*-toluenesulfonamide molecules included in the unit-space of MMF is denoted on the right side of the spectrum.

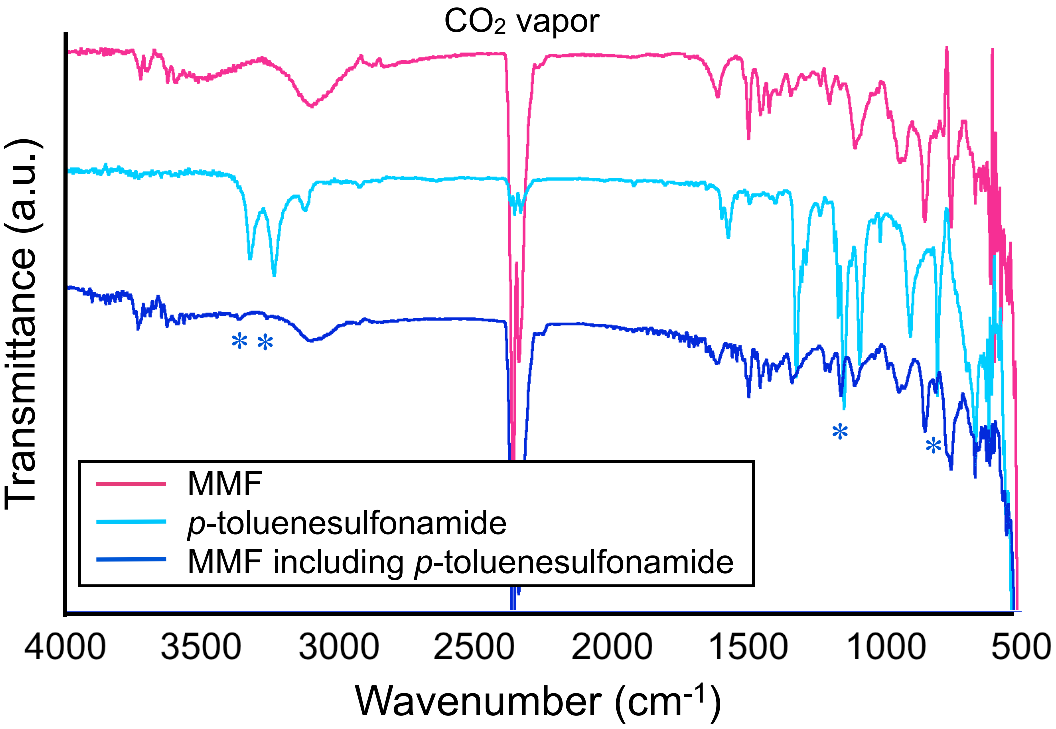


Fig. S15 IR spectra of MMF, *p*-toluenesulfonamide and MMF including *p*-toluenesulfonamide (ATR, neat, 20 °C). Peaks denoted as * appear to be the evidence of the presence of *p*-toluenesulfonamide.

MMF including 4-chlorobenzenesulfonic acid

[Soaking of MMF crystals in a guest solution]

MMF crystals were soaked in a CH_3CN solution of 4-chlorobenzenesulfonic acid hydrate (0.50 M) at 20 °C for 3 d. A crystal was then picked up and mixed with fluorolube®, then rapidly cooled to –180 °C under cold N_2 flow on a goniometer to subject to a single-crystal X-ray diffraction measurement. The inclusion of 4-chlorobenzenesulfonic acid in MMF crystals was also confirmed by IR analysis of the crystals (Fig. S20) and ^{1}H NMR analysis of a DMSO-d_6 solution dissolving the crystals (Fig. S19).

Crystal data for $(Pd_3\mathbf{L}Cl_6)_2\cdot$(4-chlorobenzenesulfonic acid)$_{0.48}\cdot(CH_3CN)_{2.43}\cdot(H_2O)_3$: $C_{91.75}H_{99.7}Cl_{12.48}N_{14.43}O_{4.45}Pd_6S_{0.48}$, F_w = 2572.05, crystal dimensions 0.63 × 0.20 × 0.15 mm^3, monoclinic, space group $P2_1/c$, a = 19.6264(6), b = 52.3974(15), c = 14.3627(4) Å, β = 90.6803(11)°, V = 14769.2(7) Å^3, Z = 4, ρ_{calcd} = 1.157 g cm^{-3}, μ = 9.87 cm^{-1}, T = 93 K, λ (MoKα) = 0.71075 Å , $2\theta_{\mathrm{max}}$ = 55.0°, 125162/32946 reflections collected/unique (R_{int} = 0.0834), R_1 = 0.1043 ($I > 2\sigma(I)$), wR_2 = 0.3529 (for all data), GOF = 1.172, largest diff. peak and hole 2.90/–2.29 eÅ^{-3}. CCDC deposit number 1468109. Several restraints were applied to $[Pd_3\mathbf{L}Cl_6]$ and CH_3CN and guest molecules as described below to avoid collapse of the structures during least-square refinement. A part of the *anti*-form of [Pd$_3$**L**Cl$_6$] was modeled as a disordered structure based on the electron densities of each atom. The contribution of the electron density (612 electrons/unit cell) caused by severely disordered molecules in the void (4801 Å^3/unit cell) was removed by the SQUEESE function.

See below for the details of applied restraints, and the responses to alert A pointed out in the IUCR's checkCIF routine.

Geometrical restraints

DFIX (*d* = 1.3900, *s* = 0.0200) C85 C86 C86 C87 C87 C88 C88 C89 C89 C90 C90 C85

DFIX (*d* = 2.4080, *s* = 0.0200) C85 C87 C86 C88 C87 C89 C88 C90 C89 C85 C90 C86

DFIX (*d* = 1.5000, *s* = 0.1000) S1 O1 S1 O2 S1 O3

DFIX (*d* = 1.1000, *s* = 0.0200) N1S C1S N2S C2S N3S C3S

DFIX (*d* = 1.5000, *s* = 0.0200) C1S C1T C2S C2T C3S C3T

DFIX (*d* = 2.6000, *s* = 0.0200) N1S C1T N2S C2T N3S C3T

DFIX (*d* = 1.1000, *s* = 0.0200) N6S C6S

DFIX (*d* = 1.5000, *s* = 0.0200) C6S C6T

DFIX (*d* = 2.6000, *s* = 0.0200) N6S C6T

DFIX (*d* = 1.3900, *s* = 0.0300) C57A C58A C58A C59A C59A C60A C60A C61A C61A C62A C62A C57A

DFIX (*d* = 2.4080, *s* = 0.0300) C57A C59A C58A C60A C59A C61A C60A C62A C61A C57A C62A C58A

DFIX (*d* = 1.3900, *s* = 0.0300) C57B C58B C58B C59B C59B C60B C60B C61B C61B C62B C62B C57B

DFIX (*d* = 2.4080, *s* = 0.0300) C57B C59B C58B C60B C59B C61B C60B C62B C61B C57B C62B C58B

DFIX (*d* = 1.3900, *s* = 0.0500) C64A C65A C65A C66A C66A C67A C67A C68A C68A C69A C69A C64A

DFIX (*d* = 2.4080, *s* = 0.0500) C64A C66A C65A C67A C66A C68A C67A C69A C68A C64A C69A C65A

DFIX (*d* = 1.3900, *s* = 0.0500) C64B C65B C65B C66B C66B C67B C67B C68B C68B C69B C69B C64B

DFIX (*d* = 2.4080, *s* = 0.0500) C64B C66B C65B C67B C66B C68B C67B C69B C68B C64B C69B C65B

DFIX (*d* = 1.4600, *s* = 0.0500) C57A N9A C57B N9B C62A N10A C62B N10B

DFIX (*d* = 1.4600, *s* = 0.0200) C62B N10B

DFIX (*d* = 2.9, *s* = 0.04) N9A N10A N9B N10B

SADI (*s* = 0.0200) N7 C43 N8 C48 N9A C57A N10A C62A N11 C71 N12 C76

SADI (*s* = 0.0200) N7 C84 N8 C49 N9A C56A N9B C56B N10A C63A N10B C63B N11 C70A N11 C70B N12 C77

SADI (*s* = 0.0200) C49 C50 C53 C56A C53 C56B C63A C64A C63B C64B C67A C70A C67B C70B

SADI (*s* = 0.0200) Pd4 Cl7 Pd4 Cl8 Pd5A Cl9A Pd5A Cl1A Pd5B Cl9B Pd5B Cl1B Pd6 CL11 PD6 CL12

SADI (*s* = 0.0200) Pd4 N7 Pd4 N8 Pd5A N9A Pd5A N10A Pd5B N9B Pd5B N10B Pd6 N11 PD6 N12

SADI (*s* = 0.0200) Pd4 C43 Pd4 C48 Pd5A C57A Pd5A C62A Pd5B C57B Pd5B C62B Pd6 C71 PD6 C76

SADI (*s* = 0.0200) O1 O2 O2 O3 O3 O1

SADI (*s* = 0.0200) C63A C65A C63A C69A

SADI (*s* = 0.0200) C63B C65B C63B C69B

SADI (*s* = 0.0200) N9A N10A N9B N10B

FLAT (*s* = 0.1000) C57A C59A C61A C58A C60A C62A

FLAT (*s* = 0.1000) C57B C59B C61B C58B C60B C62B

FLAT (*s* = 0.1000) C64A C66A C68A C65A C67A C69A

FLAT (*s* = 0.1000) C64B C66B C68B C65B C67B C69B

FLAT (*s* = 0.1000) C85 C87 C89 C86 C88 C90 Cl13 S1

Restraints on anisotropic displacement parameters

DELU (*s* = 0.0100, *st* = 0.0100) N9 N10

DELU (*s* = 0.0100, *st* = 0.0100) C50 C51 C52 C53 C54 C55

DELU (*s* = 0.0100, *st* = 0.0100) C71 C72 C73 C74 C75 C76

SIMU (*s* = 0.0100, *st* = 0.0200) C2T C2S N2S

SIMU (*s* = 0.0100, *st* = 0.0200) N6S C6S C6T

SIMU (*s* = 0.0100, *st* = 0.0200) Cl13 C85 C86 C87 C88 C89 C90 S1 O1 O2 O3

SIMU (*s* = 0.0100, *st* = 0.0200) N9 N10

SIMU (*s* = 0.0100, *st* = 0.0200) C57A C58A C59A C60A C61A C62A

SIMU (*s* = 0.0100, *st* = 0.0200) C57B C58B C59B C60B C61B C62B

SIMU (*s* = 0.0100, *st* = 0.0200) C50 C51 C52 C53 C54 C55

SIMU (*s* = 0.0100, *st* = 0.0200) C63A C64A C65A C66A C67A C68A C69A C70A

SIMU (*s* = 0.0020, *st* = 0.0200) N9A N10A N9B N10B

SIMU (*s* = 0.0100, *st* = 0.0200) PD5A > H70B

SIMU (*s* = 0.0100, *st* = 0.0200) PD5B > H70D

SIMU (*s* = 0.0100, *st* = 0.0200) C71 C72 C73 C74 C75 C76

PLAT201_ALERT_2_A Isotropic non-H atoms in main residue(s) 21

A part of *anti*-isomers of [Pd_3**L**Cl_6] was refined isotropically because of disordering.

PLAT482_ALERT_4_A Small D-H..A angle rep for N9A..N9B, N10A..N10B

Response: N9A, N10A and N9B, N10B are atoms of disordered structures. Therefore angles shown in this Alert have no chemical significance.

PLAT973_ALERT_2_A Check calcd positive residual density on Pd2 3.16 eA^{-3}

Response: The atom type is correct and there is no evidence of twinning. The large residual density near Pd atoms may be due to an anomalous dispersion effect and has no chemical significance.

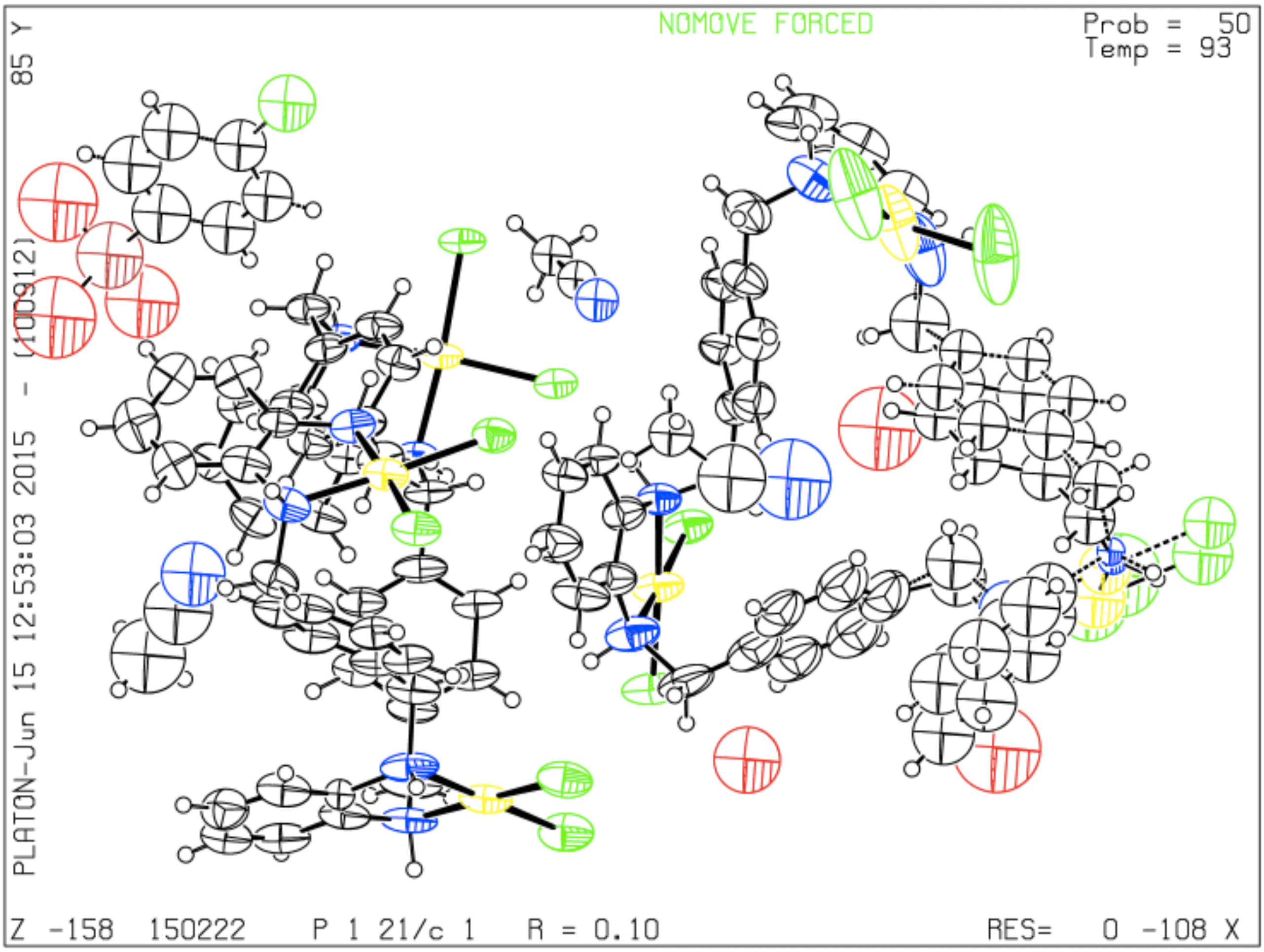


Fig. S16 ORTEP drawing of MMF including 4-chlorobenzenesulfonic acid at 50% probability level. C: black, N: blue, Cl: green, Pd: yellow, O: red, S: brown.

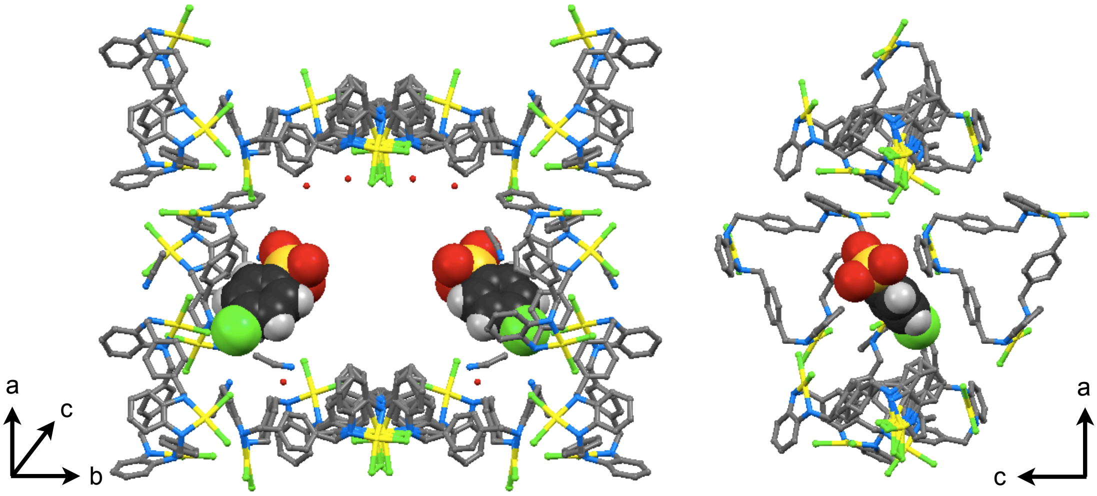


Fig. S17 Binding structure of 4-chlorobenzenesulfonic acid at the bottom corners in the crystal structure of MMF including 4-chlorobenzenesulfonic acid. MMF and solvents: stick model, guest: space-filling model. C: black, N: blue, Cl: green, Pd: yellow, O: red, S: pale-brown.

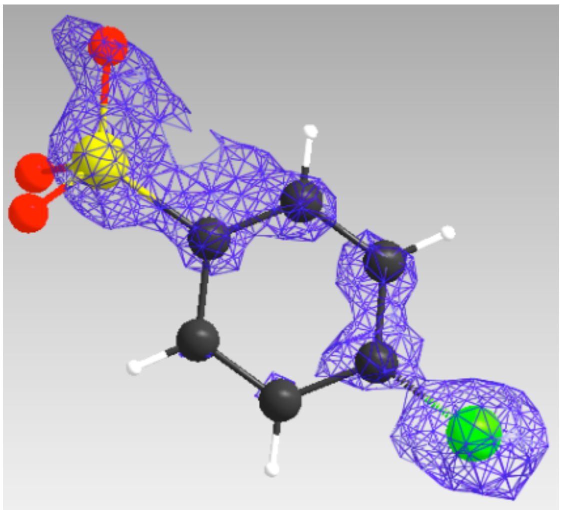


Fig. S18 Electron density map (F_o) of 4-chlorobenzenesulfonic acid included at the bottom corners (contour level: 1.00 eÅ^{-3}).

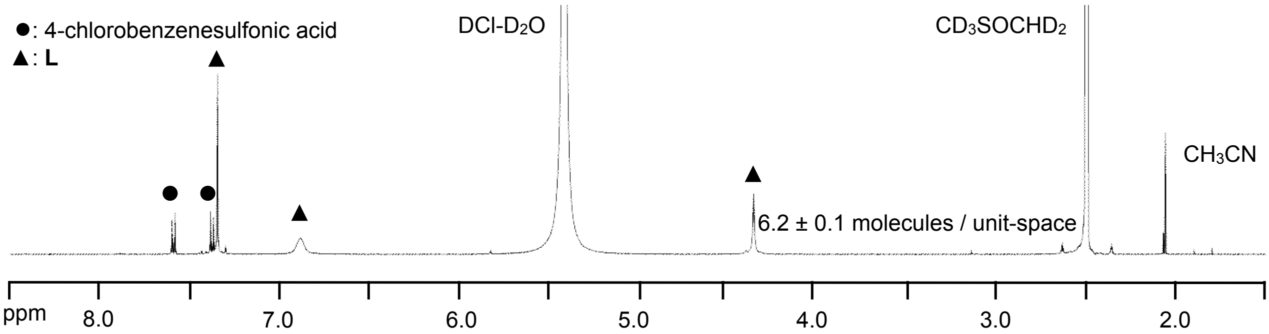


Fig. S19 ^{1}H NMR spectrum (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated number of 4-chlorobenzenesulfonic acid molecules included in the unit-space of MMF is denoted on the right side of the spectrum.

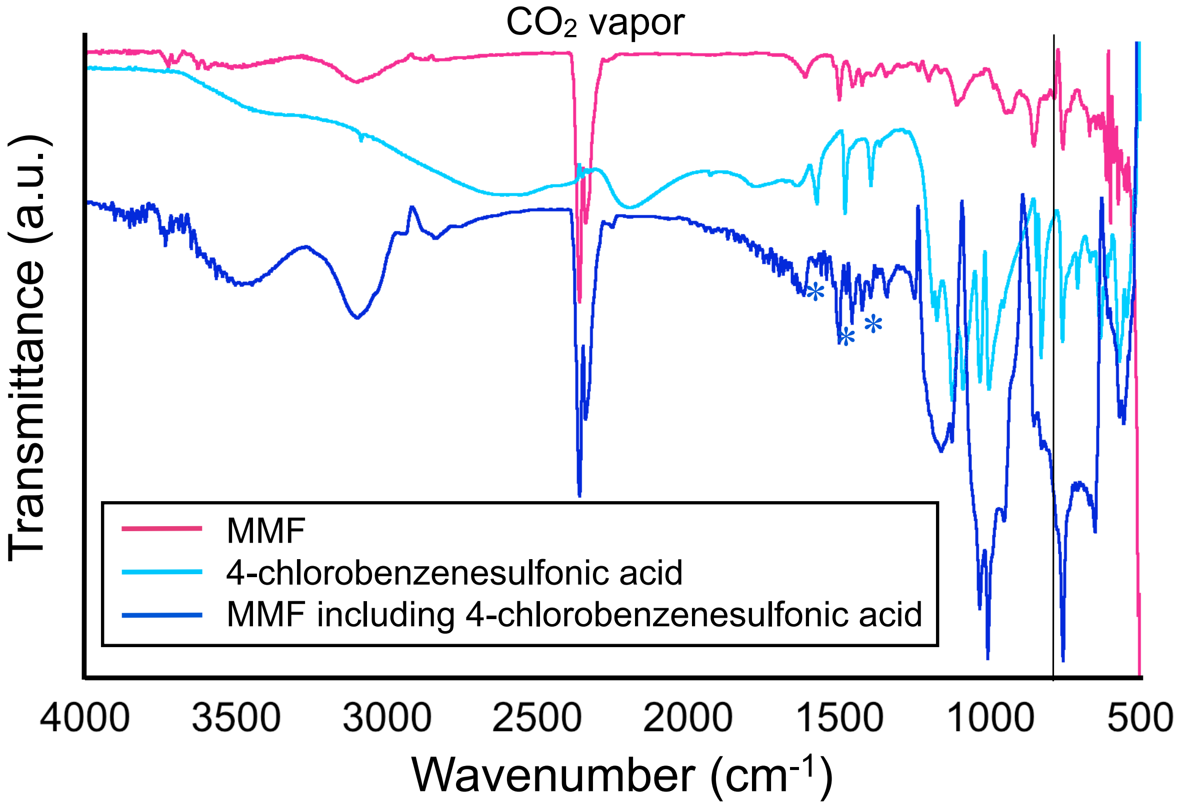


Fig. S20 IR spectra of MMF, 4-chlorobenzenesulfonic acid and MMF including 4-chlorobenzenesulfonic acid (ATR, neat, 20 °C). Peaks denoted as * appear to be the evidence of the presence of 4-chlorobenzenesulfonic acid.

Preparation and characterisation of *p*-TsOH@MMF

General remark

A washing solvent $CHCl_3$ was washed in advance with water in a separating funnel to remove ethanol, and then dried over Na_2SO_4 just prior to be used for washing MMF crystals.

Time-course ^{1}H NMR digestion analysis

[General procedure for incorporation of *p*-TsOH·H_2O into MMF]

MMF crystals were soaked in a CH_3CN solution of *p*-TsOH·H_2O (0.80 M) at room temperature for a constant time (Figs. S21, S22). The soaked MMF crystals were collected by filtration, washed with a small amount of CH_3CN (ca. 200 μL) and air-dried for 10 sec on a filter paper. The resulting crystals were dissolved in DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) and subjected to ^{1}H NMR measurement. The number of *p*-TsOH molecules included in the unit-space of MMF was estimated by the comparison of the signal intensities of *p*-TsOH and protonated **L**. In each time, three NMR samples were independently prepared from the same batch to average the numbers of *p*-TsOH molecules included in the unit-space of MMF.

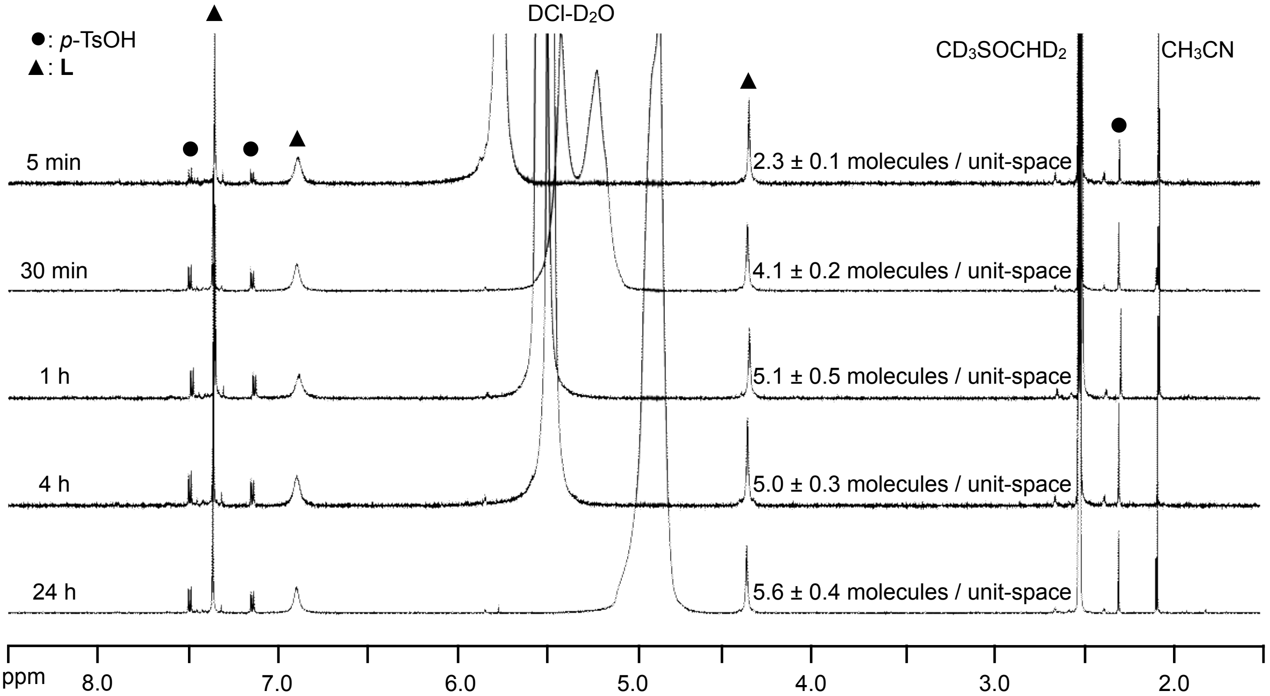


Fig. S21 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The "time" on the left side of each spectrum indicates the total soaking time. The estimated numbers of *p*-TsOH molecules included in the unit-space of MMF are denoted on the right side of each spectrum.

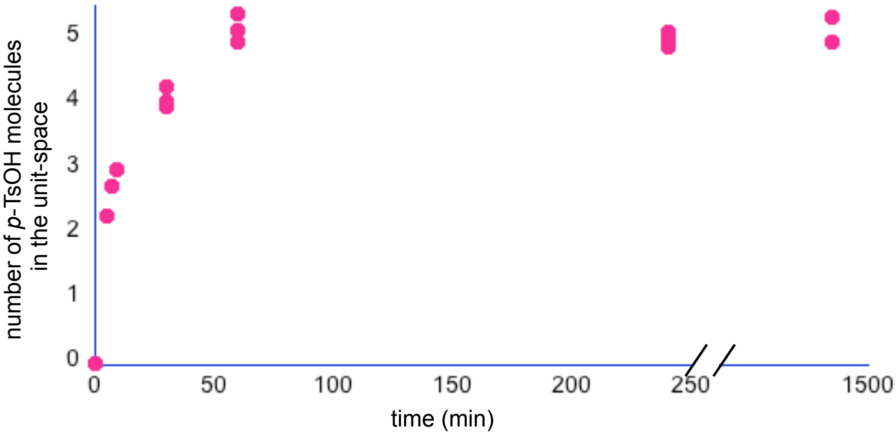


Fig. S22 Time-course of the number of *p*-TsOH included in the unit-space of MMF crystals. This graph was generated based on the data shown in Fig. S21.

Screening of washing solvents

[General procedure for washing]

MMF crystals were soaked in a CH_3CN solution of *p*-TsOH·H_2O (0.75 M) at 20 °C for 20 h. The MMF crystals were collected by filtration, washed with a small amount of CH_3CN (ca. 200 μL) and air-dried for 10 sec on a filter paper. To wash out the excess amount of *p*-TsOH·H_2O, the crystals were soaked in each solvent (CH_3CN, CH_2Cl_2 or *n*-hexane) at 20 °C for 12 h, and then were collected by filtration, washed with a small amount of the solvent (ca. 200 μL) and air-dried for 10 sec on a filter paper. This washing operation was repeated three times in total.

After each step, the amount of *p*-TsOH·H_2O remained in the unit-space was estimated by ^1H NMR analyses of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) solution dissolving a small part of the crystals. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of *p*-TsOH molecules included in each step.

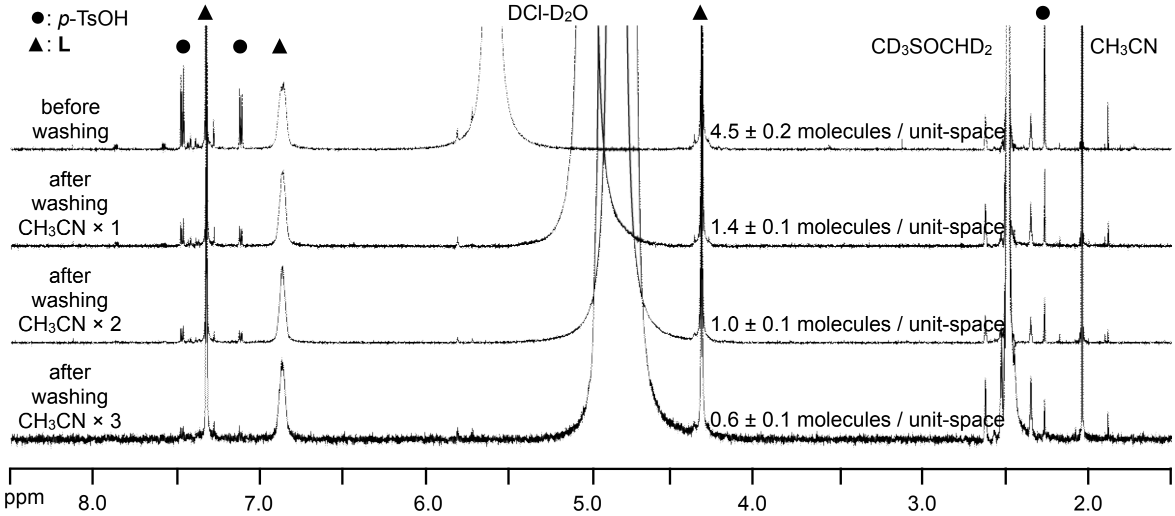


Fig. S23 ^1H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH remained in the unit-space of MMF are denoted on the right side of each spectrum.

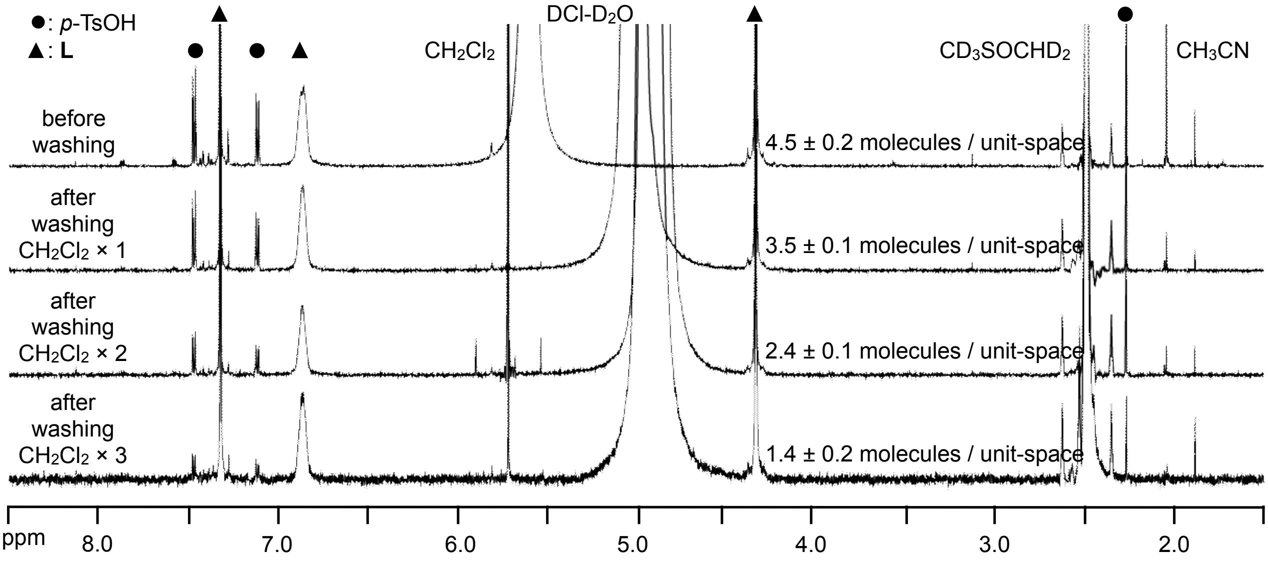


Fig. S24 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

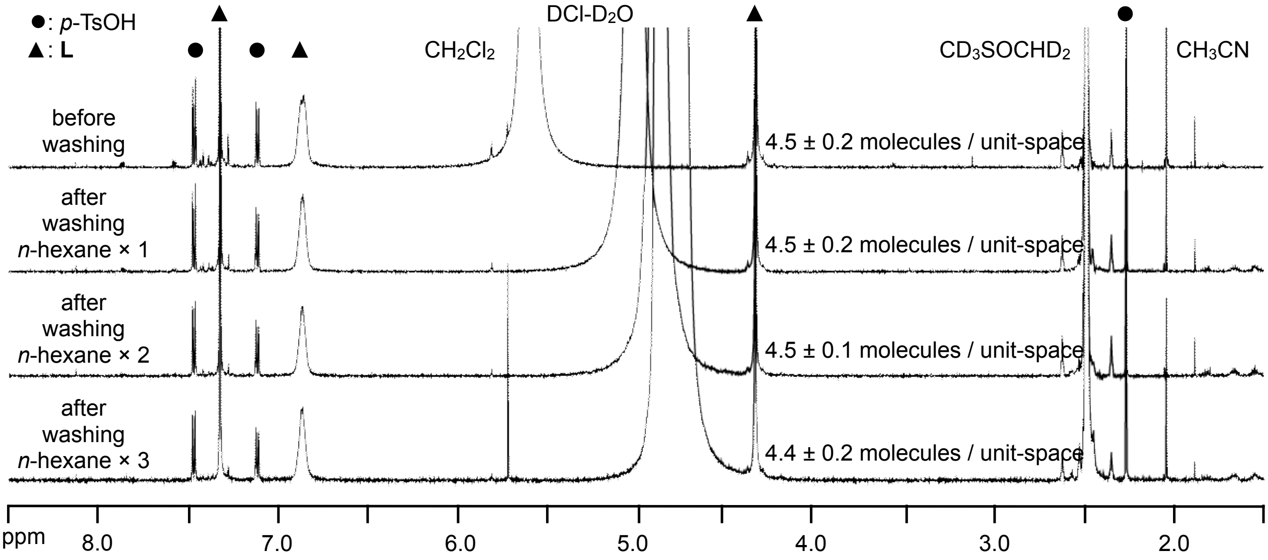


Fig. S25 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

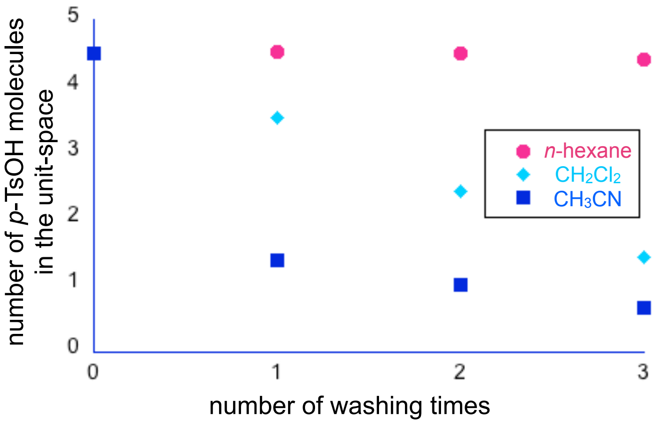


Fig. S26 The numbers of p-TsOH molecules remained in the unit-space of MMF crystals after each washing with several solvents (CH_3CN, CH_2Cl_2, n-hexane). This graph was generated based on the data shown in Figs. S23–S25.

Optimization of washing procedure with CH_2Cl_2

[Procedure for washing]

MMF crystals were soaked in a CH_3CN solution of p-TsOH·H_2O (0.75 M, MMF/CH_3CN = 10 mg/mL) at 20 °C for 20 h. Soaked MMF crystals were collected by filtration, washed with a small amount of CH_3CN (ca. 200 μL) and air-dried for 10 sec on a filter paper. To wash out the excess amount of p-TsOH·H_2O, the crystals were soaked in CH_2Cl_2 (MMF/CH_2Cl_2 = 1 mg/mL) at 20 °C for 24 h, and then were collected by filtration, washed with a small amount of CH_2Cl_2 (ca. 200 μL) and air-dried for 10 sec on a filter paper. This washing operation was repeated four times in total.

After each step, the amount of p-TsOH·H_2O remained in the unit-space was estimated by ^{1}H NMR analyses of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) solution dissolving a small part of the crystals. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of p-TsOH molecules included in each step.

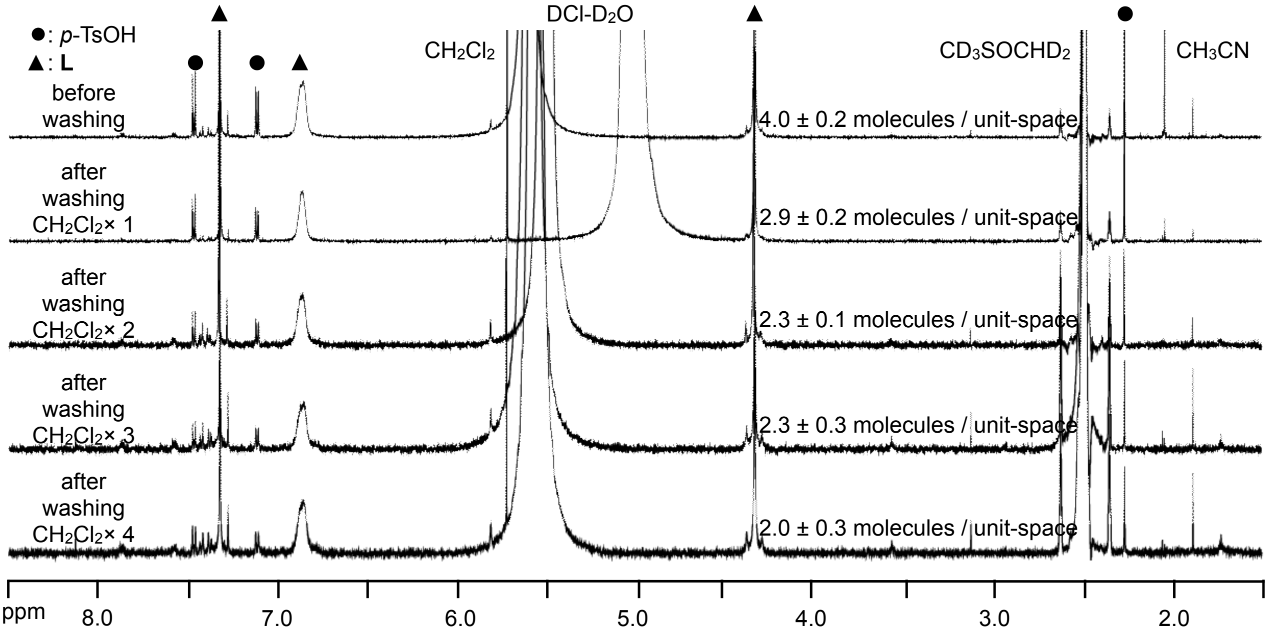


Fig. S27 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

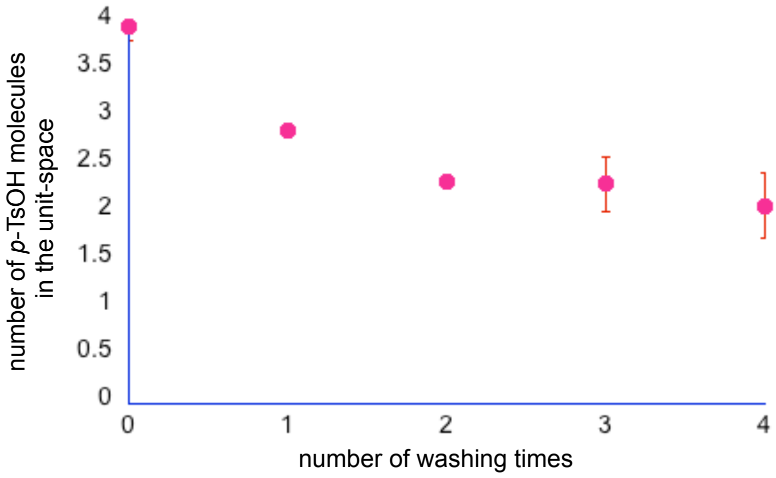


Fig. S28 The numbers of *p*-TsOH molecules remained in the unit-space of MMF crystals after each washing with CH_2Cl_2. This graph was generated based on the data shown in Fig. S27.

Preparation of *p*-TsOH@MMF

[Procedure for preparation]

MMF crystals were soaked in a CH_3CN solution of *p*-TsOH·H_2O (0.75 M) at 20 °C for 20 h. The MMF crystals were collected by filtration, washed with a small amount of CH_3CN (ca. 200 μL) and air-dried for 10 sec on a filter paper. To wash out the excess amount of *p*-TsOH·H_2O, the crystals were soaked in CH_2Cl_2 (MMF/CH_2Cl_2 = 1 mg/mL) at 20 °C for 24 h, separated by decantation and washed with CH_2Cl_2 (ca. 5 mL) twice. This washing operation was repeated three times in total. The resulting crystals were soaked in $CHCl_3$ (MMF/$CHCl_3$ = 1 mg/mL) at 20 °C for 24 h, collected by filtration, washed with a small amount of $CHCl_3$ and air-dried for 10 sec on a filter paper to afford *p*-TsOH@MMF. After the preparation, this catalyst was immediately used for catalytic reactions.

After each step, the amount of *p*-TsOH·H_2O remained in the unit-space was estimated by ^{1}H NMR analyses of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) solution dissolving a small part of the crystals. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of *p*-TsOH molecules included in each step.

The chemical composition of *p*-TsOH@MMF except for water was estimated to be $(Pd_3\mathbf{L}Cl_6)_4\cdot(p\text{-TsOH})_{1.5}\cdot(CHCl_3)_8\cdot(H_2O)_n$ based on the integral ratios in the ^{1}H NMR spectrum. The presence of water in *p*-TsOH@MMF was suggested by FT-IR measurement (Fig. S33). The number of water molecules included in *p*-TsOH@MMF was temporarily assumed to be n = 20 (Mw = 6224.8). Because the number of water molecules included in as-synthesized MMF crystals was estimated to be 36 by previous elemental analysis ($(Pd_3\mathbf{L}Cl_6)_4\cdot(CH_3CN)_2\cdot(H_2O)_{36}$),[1] the number n and the molecular weight Mw of *p*-TsOH@MMF should fall within $0 \leqq n \leqq 36$ and $5864.5 \leqq Mw \leqq 6513.0$, respectively. Therefore the error of catalyst quantity used here (n = 20, Mw = 6224.8) falls within 10% regardless of water contents.

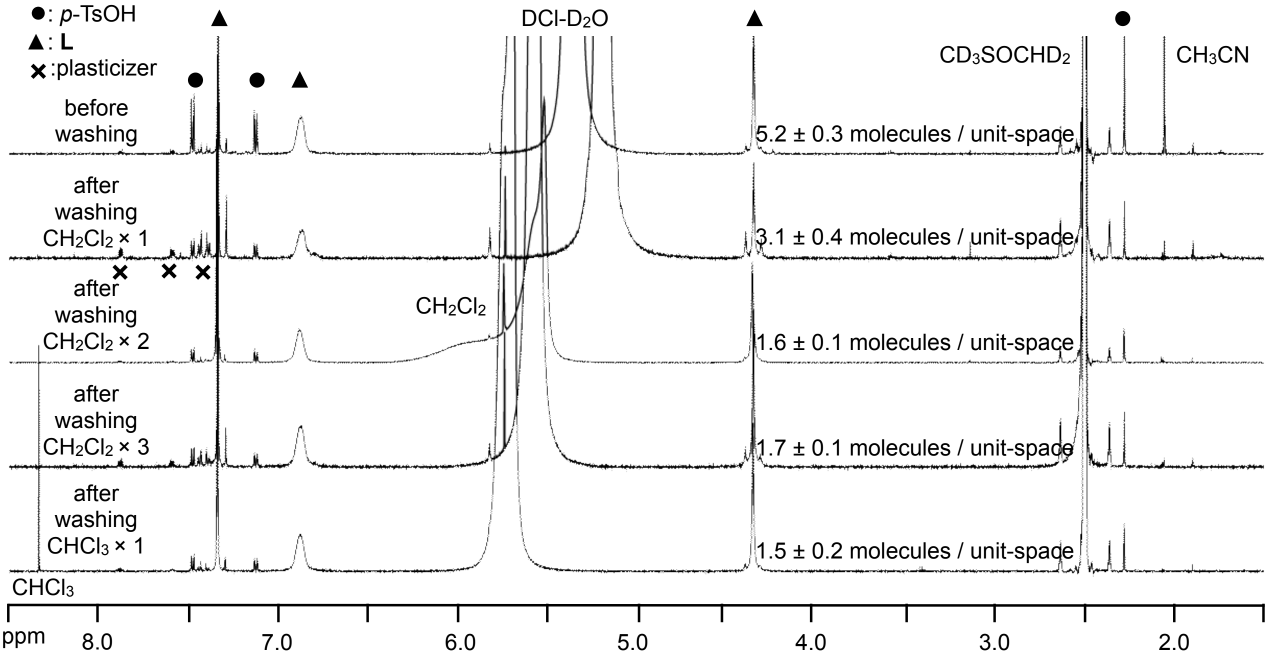


Fig. S29 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

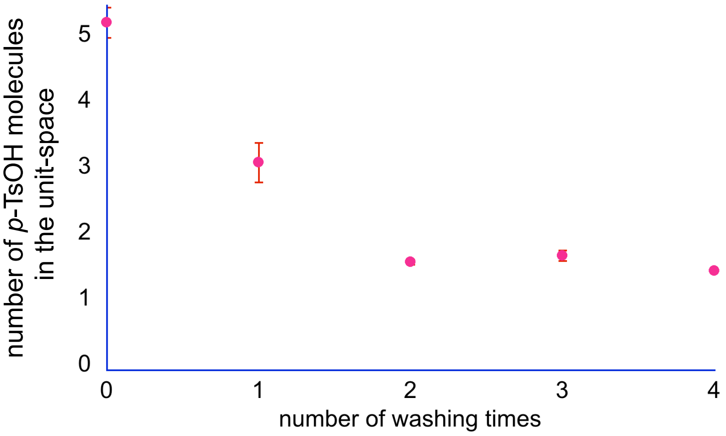


Fig. S30 The numbers of *p*-TsOH molecules remained in the unit-space of MMF crystals after each washing with CH_2Cl_2. This graph was generated based on the data shown in Fig. S29.

Acid leaching tests of *p*-TsOH⊂MMF and *p*-TsOH@MMF

[Preparation of *p*-TsOH⊂MMF]

MMF crystals were soaked in a CH_3CN solution of *p*-TsOH·H_2O (0.75 M) at 20 °C for 20 h, collected by filtration, washed with a small amount of CH_3CN (ca. 200 μL) and air-dried for 10 sec on a filter paper to afford *p*-TsOH⊂MMF, which contained excess amount of *p*-TsOH in the channel due to the omission of repetitive washing with CH_2Cl_2.

[Leaching test]

Crystals of *p*-TsOH⊂MMF or *p*-TsOH@MMF were soaked in $CDCl_3$ respectively (crystals/$CDCl_3$ = 1.6 mg/mL). After 30 min at room temperature, the suspensions were analyzed by ^{1}H NMR measurements to check the leaching of *p*-TsOH. In order to forcibly release *p*-TsOH from the crystals, $CDCl_3$ solutions of Et_3N (0.1 M, 50 μL) were then added to the suspensions, which were stood for 1 day to subject to ^{1}H NMR measurement.

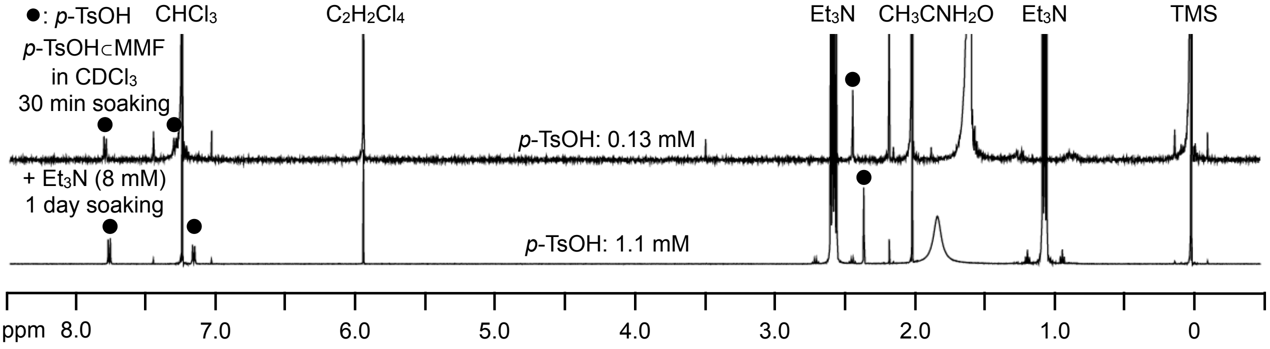


Fig. S31 ^{1}H NMR spectra (500 MHz, $CDCl_3$, 300 K) of the supernatant of *p*-TsOH⊂MMF. The estimated concentrations of *p*-TsOH in the supernatants are denoted on the middle of each spectrum. 1,1,2,2-Tetrachloroethane was added as an internal standard to estimate concentration of *p*-TsOH.

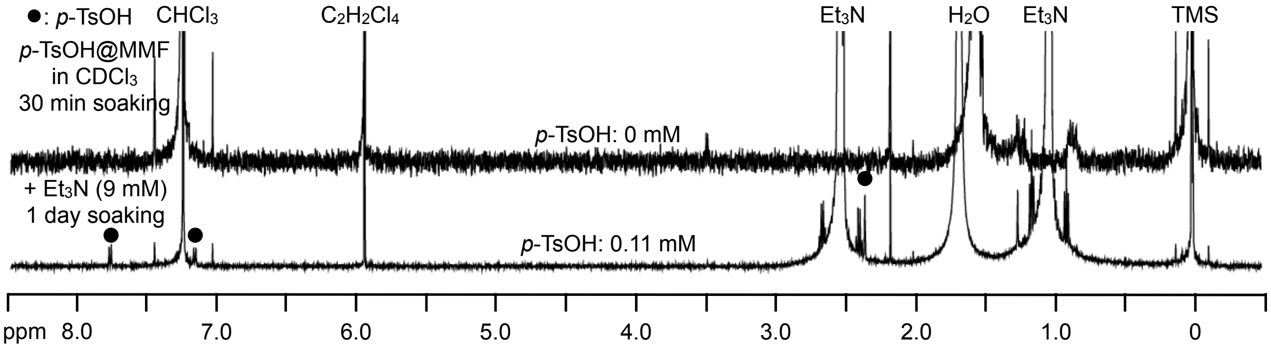


Fig. S32 ^{1}H NMR spectra (500 MHz, $CDCl_3$, 300 K) of the supernatant of *p*-TsOH@MMF. The estimated concentrations of *p*-TsOH in the supernatants are denoted on the middle of each spectrum. 1,1,2,2-Tetrachloroethane was added as an internal standard to estimate concentration of *p*-TsOH.

IR spectra of *p*-TsOH@MMF

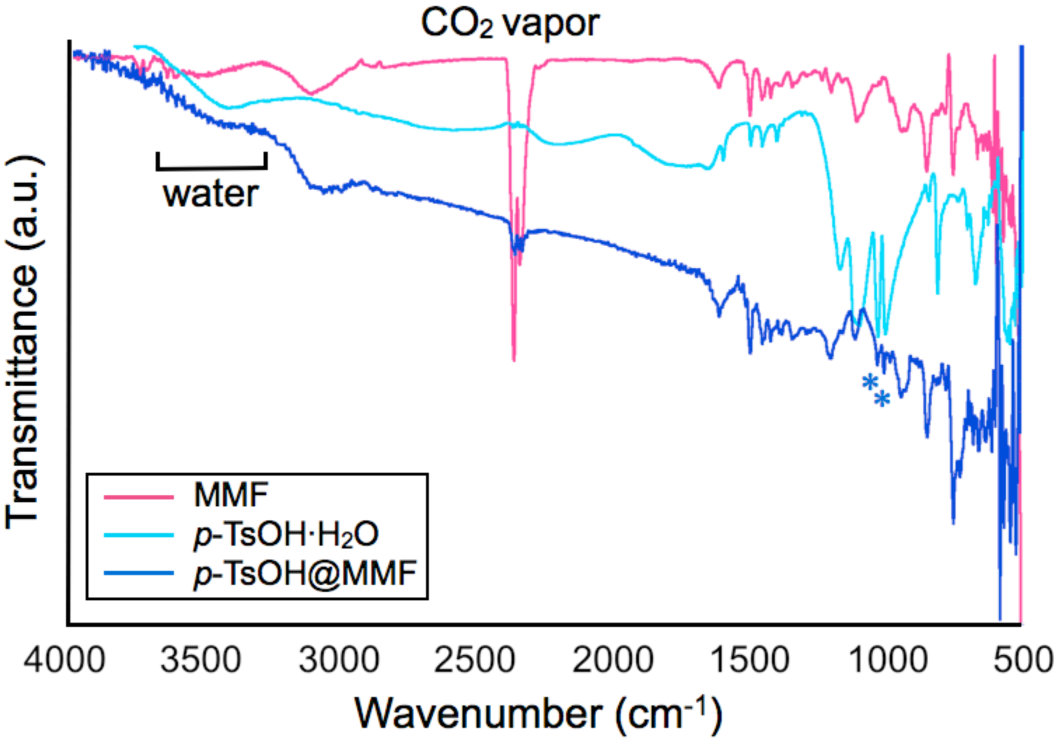


Fig. S33 IR spectra of *p*-TsOH@MMF, MMF and *p*-TsOH·H_2O (ATR, neat, 20 °C). Peaks denoted as * and a broad peak around 3400 cm^{-1} appear to be the evidence of the presence of *p*-TsOH and water molecules in crystals of *p*-TsOH@MMF, respectively.

Single-crystal XRD analysis of *p*-TsOH@MMF

[Preparation of *p*-TsOH@MMF crystals suitable for XRD analysis]

MMF crystals were soaked in a CH_3CN solution of *p*-TsOH·H_2O (0.75 M) at 20 °C for 20 h, collected by filtration, washed with a small amount of CH_3CN (ca. 200 µL) and air-dried for 10 sec on a filter paper. To wash out the excess amount of *p*-TsOH·H_2O, the crystals were soaked in CH_2Cl_2 (MMF/CH_2Cl_2 = 1 mg/mL) at 20 °C for 9 h. After soaking, the solvent was removed by decantation and replaced with pure CH_2Cl_2. After soaking at 20 °C for 13 h, the solvent was removed by decantation and replaced with pure CH_2Cl_2. After soaking for 17 days, a crystal was picked up and mixed with fluorolube®, then rapidly cooled to –180 °C under cold N_2 flow on a goniometer to subject to a single-crystal X-ray diffraction measurement.

Crystal data for $(Pd_3\mathbf{L}Cl_6)_2\cdot(CH_2Cl_2)_2\cdot(H_2O)_8$: $C_{86}H_{104}Cl_{116}N_{12}O_8Pd_6$, F_w = 2639.49, crystal dimensions 0.29 × 0.23 × 0.07 mm^3, monoclinic, space group $P2_1/c$, a = 19.5796(13), b = 52.142(3), c = 14.2469(10) Å, β = 91.162(2)°, V = 14542.0(16) Å^3, Z = 4, ρ_{calcd} = 1.206 g cm^{-3}, μ = 10.607 cm^{-1}, T = 93 K, λ (MoKα) = 0.71075 Å , $2\theta_{max}$ = 34.0°, 35169/7998 reflections collected/unique (R_{int} = 0.1001), R_1 = 0.1612 ($I > 2\sigma(I)$), wR_2 = 0.4455 (for all data), GOF = 1.124, largest diff. peak and hole 1.20/–0.78 eÅ^{-3}. CCDC deposit number 1468110. Several restraints were applied to $[Pd_3\mathbf{L}Cl_6]$ and CH_2Cl_2 molecules as described below to avoid collapse of the structures during least-square refinement. CH_2Cl_2 and water molecules were refined isotropically. Hydrogen atoms of water molecules could not be located in the difference electron density maps. Refinement was performed using the reflection data of 1.2 Å resolution, since the values of R_{merge} and mean $F^2/\sigma(F^2)$ in the resolution shell between 1.32 and 1.15 Å were 37.7% and 1.58, respectively.

See below for the details of applied restraints, and the responses to alert A pointed out in the IUCR's checkCIF routine.

Geometrical restraints

SADI (s = 0.0200): N7 C43 N8 C48 N9 C57 N10 C62 N11 C71 N12 C76

SADI (s = 0.0200): N7 C84 N8 C49 N9 C56 N10 C63 N11 C70 N12 C77

SADI (s = 0.0200): C49 C50 C53 C56 C63 C64 C67 C70 C77 C78 C81 C84

DFIX (d = 1.3900, s = 0.0400): C57 C58 C58 C59 C59 C60 C60 C61 C61 C62 C62 C57

DFIX (d = 2.4080, s = 0.0400): C57 C59 C58 C60 C59 C61 C60 C62 C61 C57 C62 C58

FLAT (s = 0.1000): C57 C59 C61 C58 C60 C62

DFIX (d = 1.3900, s = 0.0400): C71 C72 C72 C73 C73 C74 C74 C75 C75 C76 C76 C71

DFIX (d = 2.4080, s = 0.0400): C71 C73 C72 C74 C73 C75 C74 C76 C75 C71 C76 C72

FLAT (s = 0.1000): C71 C73 C75 C72 C74 C76

DFIX (d = 1.3900, s = 0.0400): C64 C65 C65 C66 C66 C67 C67 C68 C68 C69 C69 C64

DFIX (d = 2.4080, s = 0.0400): C64 C66 C65 C67 C66 C68 C67 C69 C68 C64 C69 C65

FLAT (s = 0.1000): C64 C66 C68 C65 C67 C69

DFIX (d = 1.3900, s = 0.0400): C22 C23 C23 C24 C24 C25 C25 C26 C26 C27 C27 C22

DFIX (d = 2.4080, s = 0.0400): C22 C24 C23 C25 C24 C26 C25 C27 C26 C22 C27 C23

DFIX (d = 1.3900, s = 0.0400): C29 C30 C30 C31 C31 C32 C32 C33 C33 C34 C34 C29

DFIX (d = 2.4080, s = 0.0400): C29 C31 C30 C32 C31 C33 C32 C34 C33 C29 C34 C30

FLAT (s = 0.1000): C22 C24 C26 C23 C25 C27

FLAT (s = 0.1000): C29 C31 C33 C30 C32 C34

DFIX (d = 1.3900, s = 0.0400): C53 C54 C54 C55 C55 C50 C50 C51 C51 C52 C52 C53

DFIX (d = 2.4080, s = 0.0400): C53 C55 C54 C50 C55 C51 C50 C52 C51 C53 C52 C54

FLAT (s = 0.1000): C53 C55 C51 C54 C50 C52

SADI (s = 0.0200): C1S Cl1S C1S Cl1T

Restraints on anisotropic displacement parameters

SIMU (s = 0.0100, st = 0.0100): Pd1 > C42

SIMU (s = 0.0100, st = 0.0100): Pd4 > C84

THETM01_ALERT_3_A The value of sinq$_{max}$/wavelength is less than 0.550

Response: Low-resolution reflection data was used.

PLAT602_ALERT_2_A Very large solvent accessible void(s) in structure

Response: Some solvents in the pore could not be located due to severe disordering.

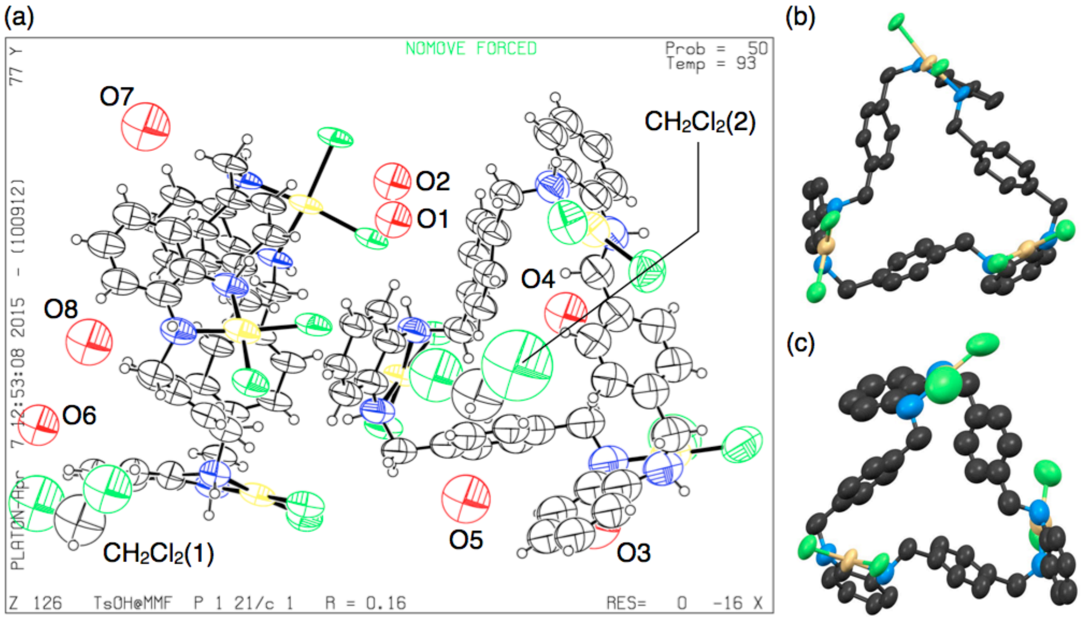


Fig. S34 (a) ORTEP drawing of the asymmetric unit of *p*-TsOH@MMF (50% probability level). Ellipsoid model (50% probability level) of (b) (*P*)-*syn*- and (c) (*M*)-*anti*-[Pd$_3$**L**Cl$_6$]. Hydrogen atoms are omitted for clarity. C: black, N: blue, Pd: yellow, Cl: green and O: red.

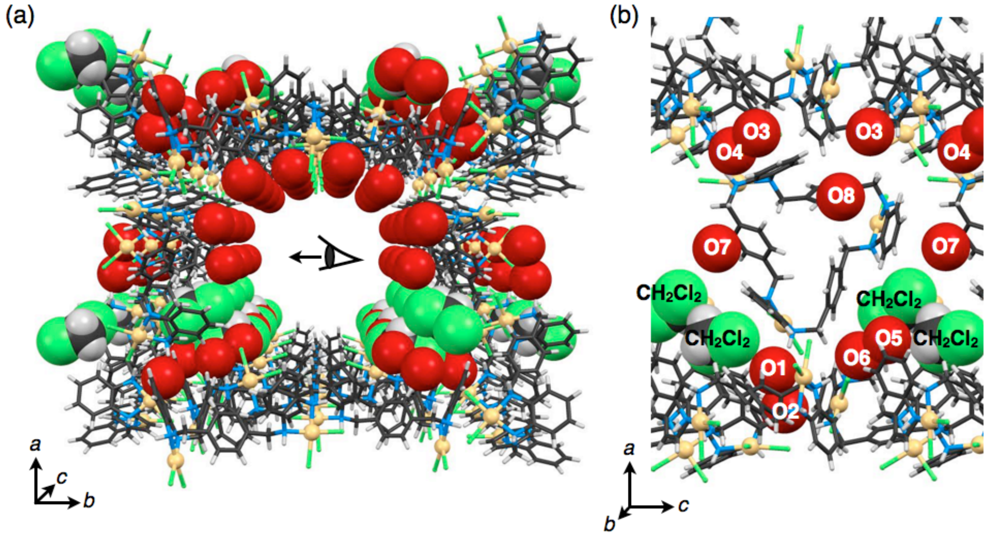


Fig. S35 Crystal structures of TsOH@MMF (MMF: stick model, solvent: space-filling model). (a) Single nano-channel. (b) Side surface of the nano-channel. C: black, N: blue, Pd: yellow, Cl: green and O: red.

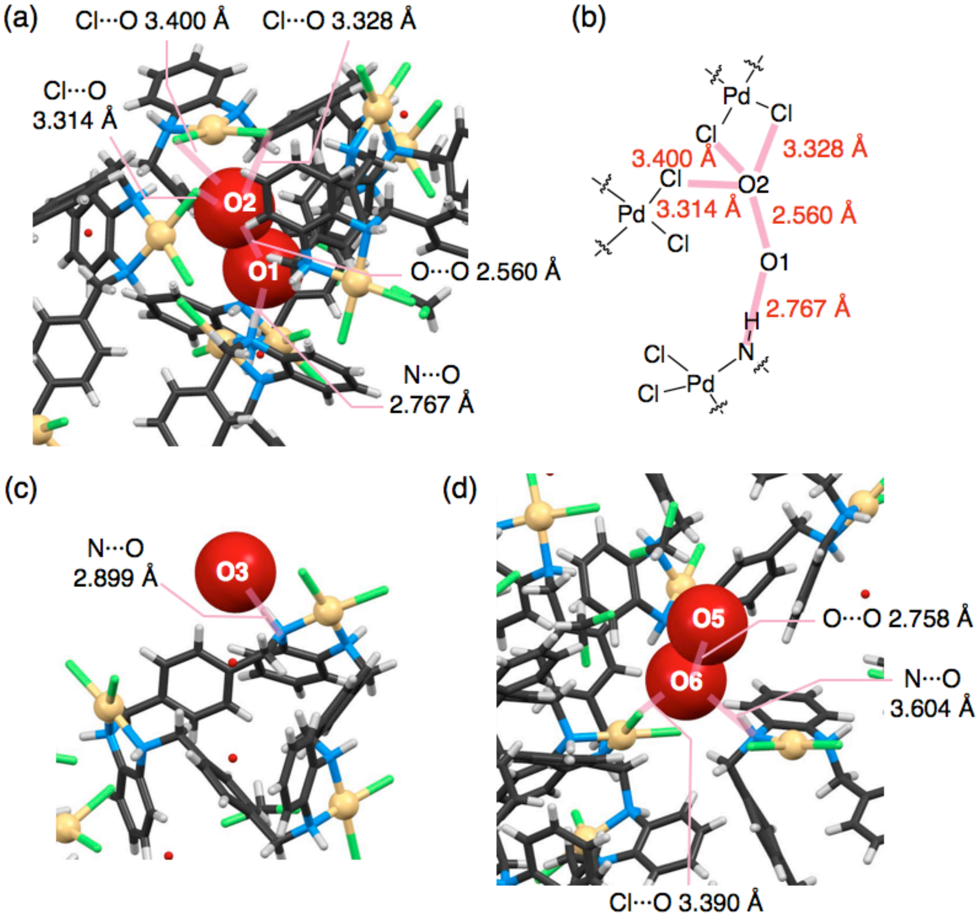


Fig. S36 Partial crystal structures around water molecules forming hydrogen bonding. (a) O1 and O2. (b) Chemical structures around O1 and O2. (c) O3. (d) O5 and O6. C: black, N: blue, Pd: yellow, Cl: green and O: red.

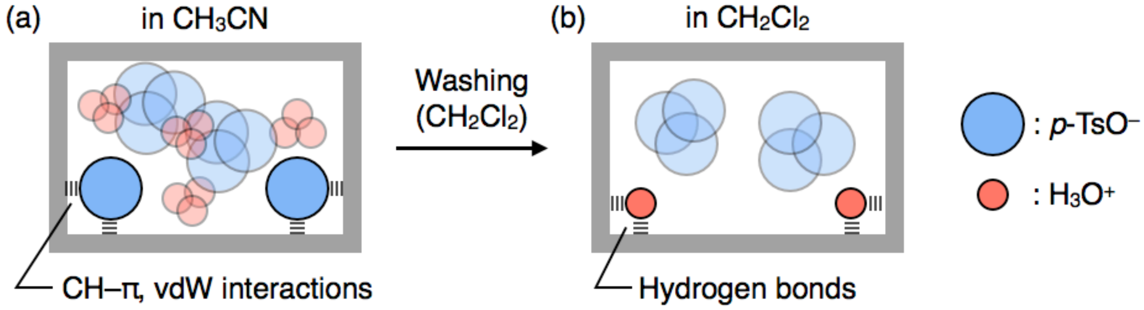
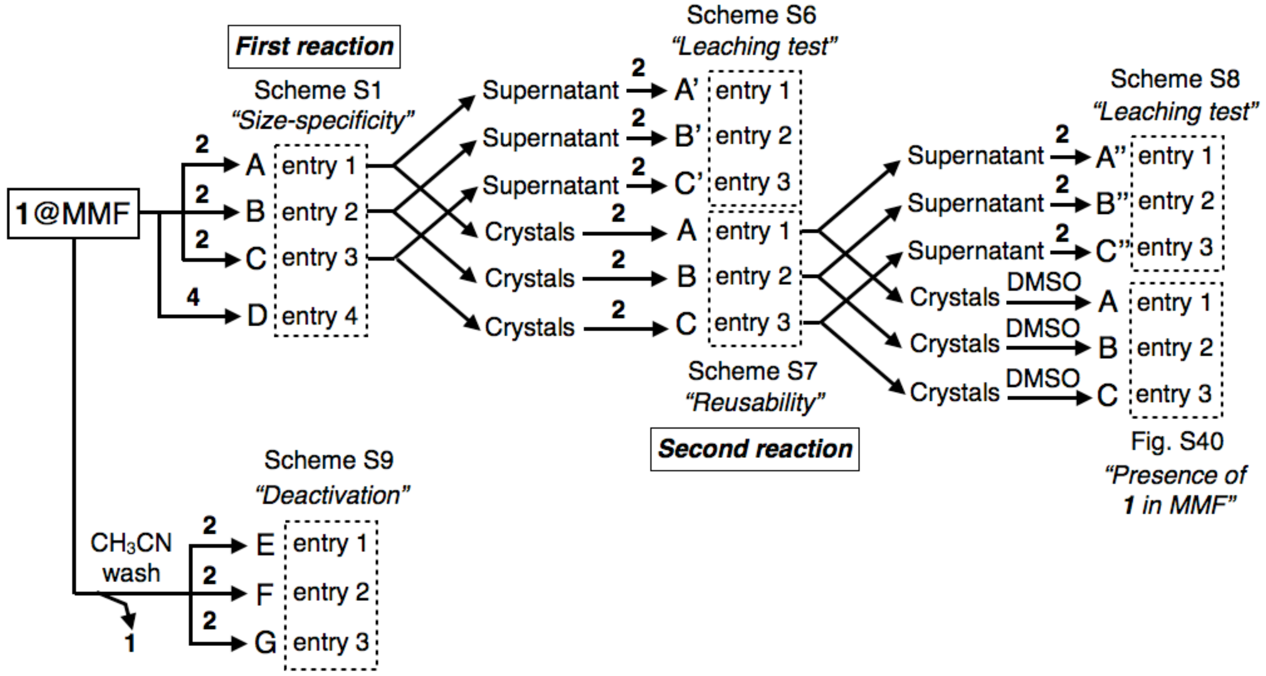


Fig. S37 Plausible binding modes of *p*-TsOH·H_2O in the unit-space of MMF based on the single-crystal XRD analyses. (a) In CH_3CN, some *p*-TsO^- ions are bound at the corner voids of the channel surface.[6] Other *p*-TsO^- ions and solvated H_3O^+ ions should be disordered in the channel. (b) After washing with CH_2Cl_2, H_3O^+ ions are likely to be bound on the channel surface through hydrogen bonding with polar functionalities of MMF such as Cl and NH. In contrast, the counter anions, *p*-TsO^-, should be disordered in the channel.

Deprotection reactions of trityl group with *p*-TsOH@MMF

General remarks

[Outline and general procedures]



Here, we used fresh crystals of *p*-TsOH@MMF collected from the same synthetic batch. Most reactions were conducted in three different batches to confirm the reproducibility. The mole number of the catalyst was calculated based on that of *p*-TsOH included in MMF. $CDCl_3$ was filtered through an oven-dried alumina (activated basic) column to remove trace amount of acid. A small amount of 1,1,2,2-tetrachloroethane was added as an internal standard (2 mM) to estimate the concentrations of substrates, products and water in ^1H NMR analyses. The $CDCl_3$ solution prepared as above was immediately used as reaction solvent. The amount of water in a $CDCl_3$ solution was estimated from the signal intensity of water in ^1H NMR analysis, whose results were comparable to water contents measured by Karl Fischer method. The reaction conversions were estimated by the comparison of the signal intensities of the product and internal standard. Note that the term "0% yield" means that we could not detect the products at all in ^1H NMR analyses.

[Channel dimension of MMF and kinetic diameters of the reaction substrates]

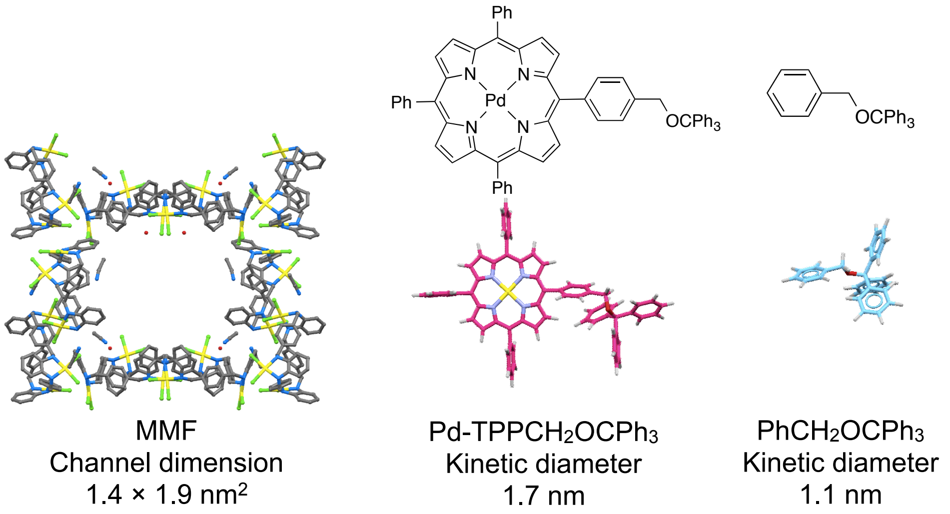


Fig. S38 Channel dimension of MMF and kinetic diameters of Pd-TPPCH$_2$OCPh$_3$ (**4**) and PhCH$_2$OCPh$_3$ (**2**). The kinetic diameters were estimated by the molecular modeling.[7]

Size-specific reaction (deprotection of 2 or 4)

[Reaction with PhCH$_2$OCPh$_3$ (**2**)]

In order to confirm the reproducibility of this reaction, we prepared three similar samples as below. To fresh crystals of *p*-TsOH@MMF (0.39, 0.32 and 0.31 mg, 0.094, 0.077 and 0.075 µmol as *p*-TsOH: entry 1, 2 and 3, respectively) were added CDCl$_3$ solutions of PhCH$_2$OCPh$_3$ (**2**) (2.2 mM, 0.78, 0.64 and 0.62 mL, 1.7, 1.4 and 1.4 µmol: entry 1, 2 and 3, respectively). The mixtures were transferred into NMR tubes and stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. The water contents of entries 1–3 in the initial states were estimated to be 23 mM by ^{1}H NMR analyses.

[Reaction with Pd-TPPCH$_2$OCPh$_3$ (**4**)]

To fresh crystals of *p*-TsOH@MMF (0.39 mg, 0.094 µmol as *p*-TsOH: entry 4) was added a CDCl$_3$ solution of Pd-TPPCH$_2$OCPh$_3$ (**4**) (2.1 mM, 0.78 mL, 1.6 µmol: entry 4). Then, the mixture was transferred into an NMR tube and stood at 20 °C to pursue this reaction by ^{1}H NMR measurements. As a result, no deprotection of **4** proceeded even after 3 weeks. The water content of entry 4 in the initial state was estimated to be 23 mM by ^{1}H NMR analyses.

2: R = H
4: R = Pd-TPP

3: R = H
5: R = Pd-TPP

Entry	R	Results
1	H	71% (3 weeks)
2	H	77% (3 weeks)
3	H	59% (3 weeks)
4	Pd-TPP	0% (3 weeks)

Scheme S1 Trityl deprotection of **2** ([**2**] = 2.2 mM) and **4** ([**4**] = 2.1 mM) with *p*-TsOH@MMF (6 mol%) in $CDCl_3$ at 20 °C. Each entry corresponds to the samples described above.

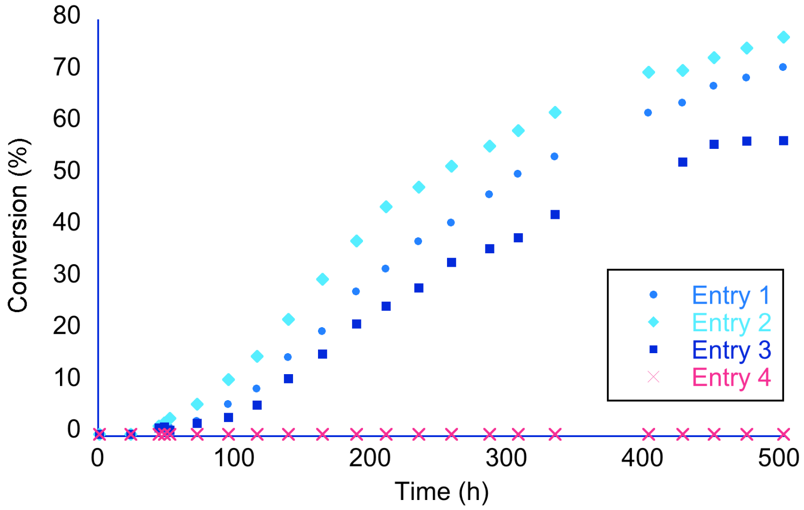
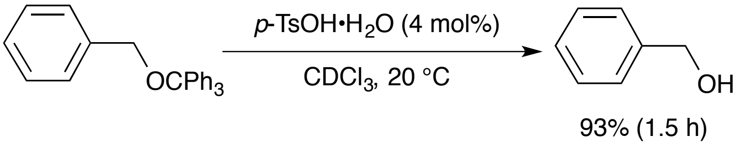


Fig. S39 Time-course of trityl deprotection reactions of **2** and **4** based on the data of Scheme S1. The conversion rates were estimated by the comparison of the signal intensities of the product and internal standard.

Control experiments

[Homogeneous deprotection of **2** with *p*-$TsOH \cdot H_2O$]

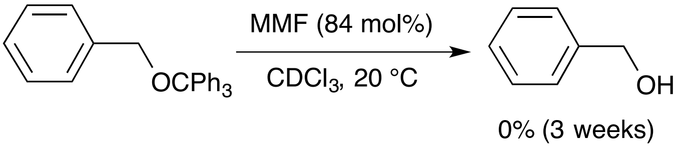
In order to confirm the difference of this deprotection reaction between homogeneous *p*-$TsOH \cdot H_2O$ and heterogeneous *p*-TsOH@MMF, we prepared a reference sample as below. A $CDCl_3$ solution of $PhCH_2OCPh_3$ (**2**) (5.2 mM, 0.19 mL, 0.99 μmol) was evaporated in an NMR tube. To this was added a $CDCl_3$ solution of *p*-$TsOH \cdot H_2O$ (0.08 mM, 0.50 mL, 0.04 μmol). The mixture was stood at 20 °C to pursue the reaction by ^1H NMR measurements. As a result, deprotection reaction of **2** was almost completed within 1.5 h (93% conversion). The water content in the initial state was estimated to be 20 mM by ^1H NMR analyses.



Scheme S2 Trityl deprotection of **2** ([**2**] = 1.8 mM: this concentration was estimated from the integral ratio in ^{1}H NMR) with *p*-TsOH·H_2O (4 mol%) in $CDCl_3$ at 20 °C.

[Control reaction with acid-free MMF crystals]

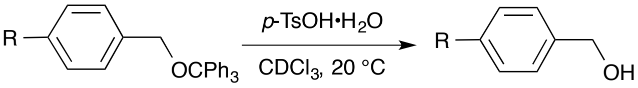
In order to check the catalytic activity of MMF itself, we prepared a control sample as below. To MMF crystals (1.27 mg, 1.09 μmol as [Pd_3**L**Cl_6], 84 mol%) freshly prepared was added a $CDCl_3$ solution of $PhCH_2OCPh_3$ (**2**) (1.9 mM, 0.70 mL, 1.3 μmol). Then, the mixture was transferred into an NMR tube and stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. As a result, no deprotection of **2** proceeded even after 3 weeks. Note that in the cases of the deprotection of **2** with *p*-TsOH@MMF (6 mol% for *p*-TsOH), the catalytic amount of [Pd_3**L**Cl_6] corresponded to 16 mol%. The water content of the initial state was estimated to be 29 mM by ^{1}H NMR analyses.



Scheme S3 Trityl deprotection of **2** ([**2**] = 1.9 mM) with MMF (84 mol% as [Pd_3**L**Cl_6]) in $CDCl_3$ at 20 °C.

[Comparison of acid lability between **2** and **4**]

In order to compare the reactivity of reaction substrates **2** and **4**, we prepared three samples (Scheme S4, entry 1-3) as below. To $CDCl_3$ solutions of $PhCH_2OCPh_3$ (**2**) (1.2 mM, 0.60 mL, 0.72 μmol), Pd-TPPCH$_2$OCPh$_3$ (**4**) (1.6 mM, 0.60 mL, 0.96 μmol) and a mixture of **2** and **4** (0.60 mL, [**2**] = 1.2 mM, 0.72 μmol, [**4**] = 1.2 mM, 0.72 μmol), $CDCl_3$ suspensions of *p*-TsOH·H_2O (50 μL; entry 1: 0.04 μmol, entry 2: 0.06 μmol, entry 3: 0.04 μmol) were added. The mixtures were stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. As a result, both substrates **2** and **4** showed similar reactivity (95–96% conversion after 1.5 h). In addition, any demetalation of **4** was not detected under these conditions. The water contents of entries 1–3 in the initial states were estimated to be 27, 35 and 25 mM, respectively, by ^{1}H NMR analyses.



2: R = H
4: R = Pd-TPP

3: R = H
5: R = Pd-TPP

Entry	**2**	**4**	p-TsOH•H_2O	Results
1	+	–	5 mol%	**3**: 96% (1.5 h)
2	–	+	4 mol%	**5**: 95% (1.5 h)
3	+	+	6 mol%	**3**: 90%, **5**: 90% (1.5 h)

Scheme S4 Trityl deprotection of **2** ([**2**] = 1.2 mM), **4** ([**4**] = 1.6 mM) and a mixture ([**2**] = 1.2 mM, [**4**] = 1.2 mM) with *p*-TsOH·H_2O (4–6 mol%) in $CDCl_3$ at 20 °C. The amounts of *p*-TsOH·H_2O in this scheme (5, 4 and 6 mol%) were estimated from the integral ratios in ^{1}H NMR spectra.

[Guest uptake of **2** into MMF pore]

To check the accessibility of **2** into MMF pores, MMF crystals were soaked in a $CDCl_3$ solution of $PhCH_2OCPh_3$ (**2**) (0.5, 0.1, 0.01 M) at 20 °C for 1 day. The MMF crystals were collected by filtration, washed with a small amount of $CDCl_3$ (ca. 200 μL) and air-dried for 10 sec on a filter paper. The amount of **2** included in the unit-space of MMF was estimated by ^{1}H NMR analyses of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) solution dissolving the crystals. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of **2** included in the pore. In the case of [**2**] = 0.5 M (entry 1), 0.2 molecules of **2** were included in the unit-space of MMF.

$$\text{MMF} \xrightarrow[\text{CDCl}_3\text{, 20 °C, 1 d}]{\mathbf{2}\text{ (Conc.)}} \text{NMR measurement}$$

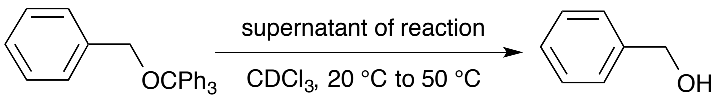
Entry	Conc.	Results
1	0.5 M	0.2 ± 0.03 molecules/unit-space
2	0.1 M	not detected.
3	0.01 M	not detected.

Scheme S5 Digestion experiments for MMF crystals soaked in $CDCl_3$ solutions of **2**.

Confirmation of the heterogeneous character of *p*-TsOH@MMF

[Reactions with supernatants of the first reactions]

After the first reactions, the reaction mixtures were decanted to collect their supernatants. Then the supernatants containing both **2** and **3** were filtered with cotton. To the filtrates were added $CDCl_3$ solutions of $PhCH_2OCPh_3$ (**2**) (6.7 mM, 0.23, 0.19 and 0.19 mL, 1.5, 1.3 and 1.3 μmol: entries 1, 2 and 3, respectively) and these mixtures were messed up to 0.78, 0.64 and 0.62 mL with $CDCl_3$, respectively. The mixtures were stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. Because the ratios of **2** and **3** did not change at all even after 3 weeks, the temperature was raised to 50 °C and stood another 2 weeks to pursue the reactions by ^{1}H NMR measurements. As a result, no further conversion of **2** proceeded even after 2 weeks at 50 °C. The water contents of entries 1–3 in initial states were estimated to be 25 mM by ^{1}H NMR analyses.



Entry	Conditions	Results
1	20 °C, 3 weeks + 50 °C, 2 weeks	<1% conversion <1% conversion
2	20 °C, 3 weeks + 50 °C, 2 weeks	<1% conversion <1% conversion
3	20 °C, 3 weeks + 50 °C, 2 weeks	<1% conversion <1% conversion

Scheme S6 Trityl deprotection of **2** ($CDCl_3$, 20 °C to 50 °C) with supernatants of the first reactions.

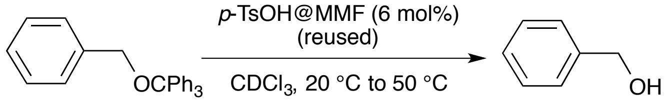
Reusability of *p*-TsOH@MMF

[Preparation of *p*-TsOH@MMF (reused)]

After the first reactions, the reaction mixtures were decanted to remove supernatants. To the remained crystals was added pure $CDCl_3$ (ca. 100 μL) and the supernatants were removed by careful decantation after 5 min. This washing operation was repeated once more. Then the supernatants were removed by careful decantation to afford *p*-TsOH@MMF (reused). After the preparation, these catalysts were immediately used for deprotection reactions of **2**.

[Reactions with *p*-TsOH@MMF (reused)]

To freshly prepared *p*-TsOH@MMF (reused) (if there was no loss of crystals during preparation of *p*-TsOH@MMF (reused); 0.39, 0.32 and 0.31 mg, 0.094, 0.077 and 0.075 μmol as *p*-TsOH: entries 1, 2 and 3, respectively) were added $CDCl_3$ solutions of $PhCH_2OCPh_3$ (**2**) (2.0 mM, 0.78, 0.64 and 0.62 mL, 1.6, 1.3 and 1.2 μmol: entries 1, 2 and 3, respectively). The mixtures were stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. Because the reaction did not proceed at all even after 3 weeks, the temperature was raised to 50 °C and the mixtures were stood another several weeks to pursue the reactions by ^{1}H NMR measurements. As a result, deprotection of **2** proceeded to some extent (24–91%) after 3–6 weeks depending on the reaction batches. The water contents of entries 1–3 in initial states were estimated to be 12 mM by ^{1}H NMR analyses.

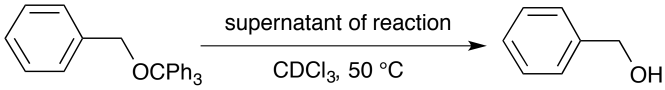


Entry	Conditions	Results
1	20 °C, 3 weeks	0%
	+ 50 °C, 6 weeks	24%
2	20 °C, 3 weeks	0%
	+ 50 °C, 6 weeks	65%
3	20 °C, 3 weeks	0%
	+ 50 °C, 3 weeks	91%

Scheme S7 Trityl deprotection of **2** ([**2**] = 2.0 mM) with *p*-TsOH@MMF (reused) (6 mol%) in $CDCl_3$ at 20 °C or 50 °C.

[Reaction with supernatants of the second reactions]

After the second reactions, the reaction mixtures were decanted to collect their supernatants. Then the supernatants containing both **2** and **3** were filtered with cotton. To the filtrates were added $PhCH_2OCPh_3$ (**2**) (0.51, 0.43 and 0.41 mg, 1.5, 1.2 and 1.2 μmol: entries 1, 2 and 3, respectively) and these mixtures were messed up to 0.78, 0.64 and 0.62 mL with $CDCl_3$, respectively. The mixtures were stood at 50 °C to pursue the reactions by ^{1}H NMR measurements. As a result, no further conversion of **2** proceeded even after 3 weeks. The water contents of entries 1–3 in the initial states were estimated to be 25 mM by ^{1}H NMR analyses.



Entry	Results
1	<1% (3 weeks)
2	<1% (3 weeks)
3	<1% (3 weeks)

Scheme S8 Trityl deprotection of **2** ($CDCl_3$, 50 °C) with supernatants of the second reactions.

[Digestion experiment of *p*-TsOH@MMF after the second reactions]

After the second reactions, the reaction mixtures were decanted to remove supernatants. To the remained crystals was added pure $CDCl_3$ (ca. 100 μL) and the mixtures were stood for 5 min and then decanted to remove supernatants. This washing operation was repeated once more. The resulting crystals were dried up in vacuo and dissolved in solutions of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) to estimate the numbers of *p*-TsOH molecules included in the unit-spaces by ^{1}H NMR analyses. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of *p*-TsOH molecules included. As a result, we revealed that most of *p*-TsOH molecules included in the initial *p*-TsOH@MMF crystals (1.5 molecules/unit-space) were remained in crystals even after the second reactions (1.2–1.5 molecules/unit-space).

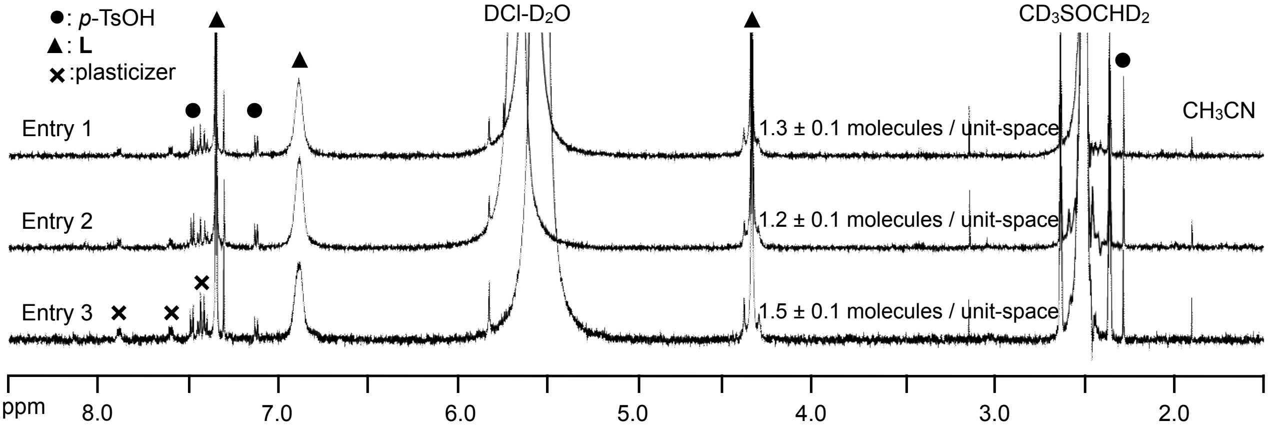


Fig. S40 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D_2O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

Deactivation of *p*-TsOH@MMF by CH_3CN washing

[Preparation of *p*-TsOH@MMF (washed)]

To wash out the *p*-TsOH molecules adsorbed in the *p*-TsOH@MMF crystals, the crystals were soaked in CH_3CN (MMF/CH_3CN = 1 mg/mL) at 20 °C for 24 h, separated by decantation and washed with CH_3CN (ca. 5 mL). This washing operation was further repeated twice. The resulting crystals were soaked in CH_3CN (MMF/CH_3CN = 1 mg/mL) at 20 °C for 24 h, collected by filtration, washed with a small amount of CH_3CN and air-dried for 10 sec on a filter paper to afford *p*-TsOH@MMF (washed). After the preparation, this catalyst was immediately used for deprotection reactions.

After each step, the amount of *p*-TsOH·H_2O remained in the unit-space was estimated by ^{1}H NMR analyses of DMSO-d_6/DCl-D_2O ([DCl] = 0.17 M) solution dissolving a small part of the crystals. In each measurement, the same NMR sample was repeatedly analyzed three times to average the numbers of *p*-TsOH molecules included in each step.

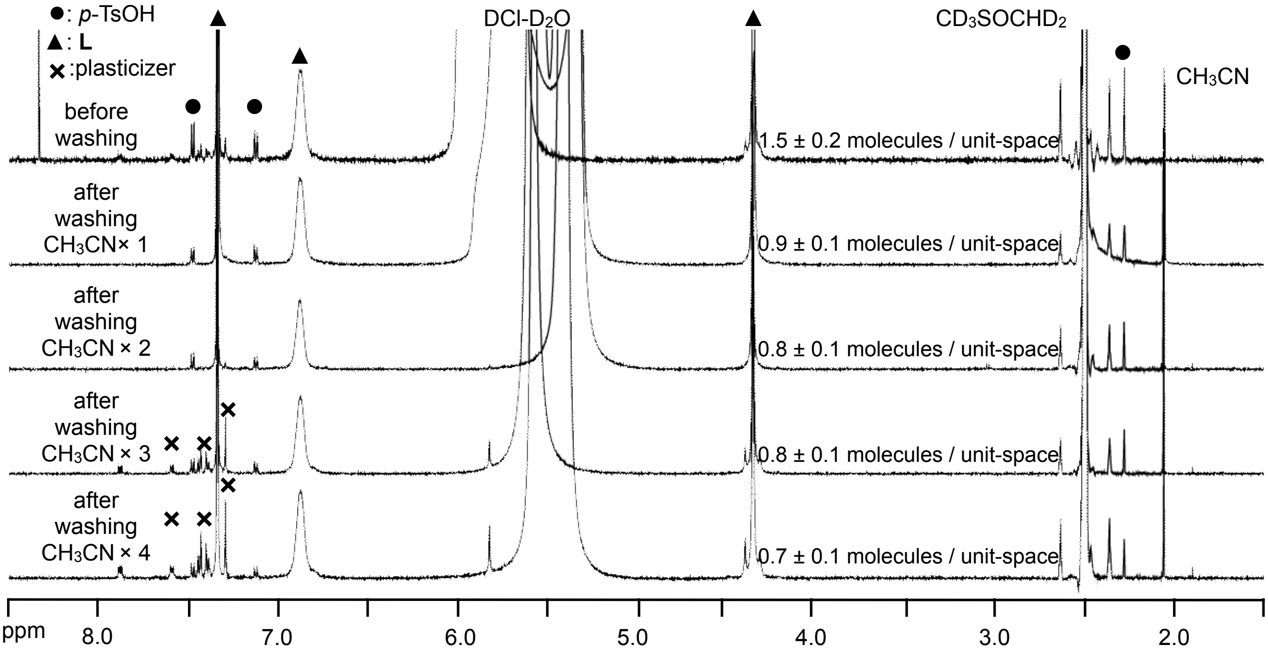


Fig. S41 ^{1}H NMR spectra (500 MHz, DMSO-d_6/DCl-D$_2$O, 300 K). The estimated numbers of *p*-TsOH molecules remained in the unit-space of MMF are denoted on the right side of each spectrum.

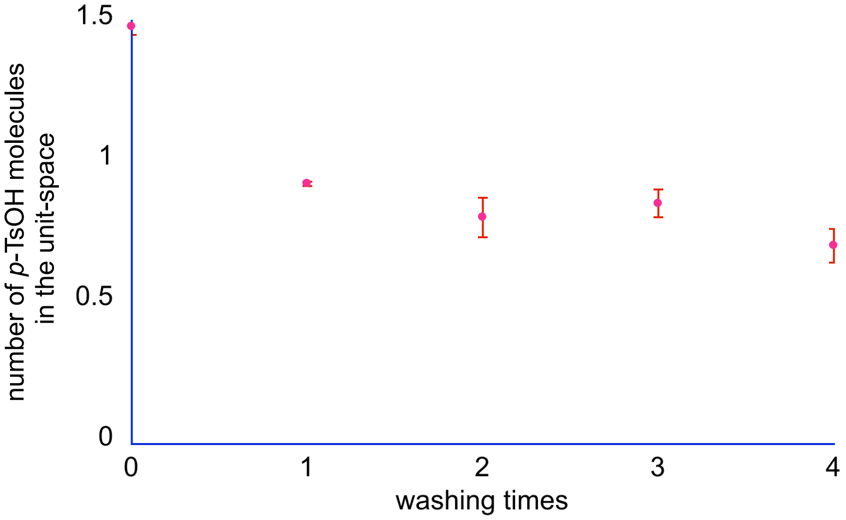
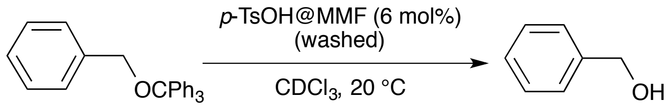


Fig. S42 The numbers of *p*-TsOH molecules remained in the unit-space of MMF crystals after each washing with CH$_3$CN. This graph was generated based on the data shown in Fig. S41.

[Reaction with *p*-TsOH@MMF (washed)]

To freshly prepared *p*-TsOH@MMF (washed) (0.82 mg, 0.72 and 0.70 mg, 0.092, 0.081 and 0.079 µmol as *p*-TsOH: entries 1, 2 and 3, respectively) were added CDCl$_3$ solutions of PhCH$_2$OCPh$_3$ (**2**) (2.0 mM, 0.82, 0.72 and 0.70 mL, 1.6, 1.4 and 1.4 µmol: entries 1, 2 and 3, respectively). The mixture were stood at 20 °C to pursue the reactions by ^{1}H NMR measurements. As a result, no deprotection of **2** proceeded even after 4 weeks. The water contents of entries 1–3 in the initial states were estimated to be 15 mM by ^{1}H NMR analyses.



Entry	Results
1	0% (4 weeks)
2	0% (4 weeks)
3	0% (4 weeks)

Scheme S9 Trityl deprotection of **2** ([**2**] = 2.0 mM) with *p*-TsOH@MMF (washed) (6 mol%) in $CDCl_3$ at 20 °C.

Stability and catalytic activity of *p*-TsOH@MMF

Although MMF crystals are thermally stable up to 220 °C as previously confirmed by thermogravimetric analysis,[1] the crystallinity of MMF is gradually lost by drying or long-time soaking in $CHCl_3$.

For *p*-TsOH@MMF, a decrease in the crystallinity should be a key factor to lower the catalytic activity. For instance, a reused catalyst after the first reaction, which was soaked in $CDCl_3$ for 3 weeks, showed a lower catalytic activity than the as-prepared catalyst as described in the main text. However, the most of *p*-TsOH molecules was maintained in the reused crystals (Fig. S40). Therefore the deactivation should be due to the decrease in crystallinity and/or degradation of pore entrances that may inhibit uptake of substrates in the pore. This idea seems reasonable because diffusion of substrate molecules into the pores drastically affects the reaction rate as shown in the main text (e.g. Fig. 3).

A method for acceleration of the reaction speed is heating. We have already demonstrated that heating a reaction mixture with reused *p*-TsOH@MMF at 50 °C accelerates the deprotection of **2** as mentioned in the footnote 11. In addition, the reaction speed is expected to increase when smaller substrates are used, because the molecular size of **2** (1.1 nm) is close to the limit of the pore size (1.4 × 1.9 nm^2). This study is now underway towards further application of *p*-TsOH@MMF for various acid-catalytic reactions.

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