

CLAIMS

1. A macromolecule membrane structure (2) comprising a membrane (3) comprising water-channeling integral membrane proteins (1) and coated, on a first surface of the membrane (3), with a silica layer (4).
- 5 2. The macromolecule membrane structure according to claim 1, wherein the membrane (3) is a bilayer membrane (3) comprising amphiphilic molecules.
3. The macromolecule membrane structure according to claim 2, wherein the membrane (3) is a lipid bilayer membrane (3), amphiphilic lipids of the lipid bilayer (3) are preferably selected from the group consisting of phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, phosphatidylglycerol, phosphatidylinositol, cardiolipin, cholesterol, sphingomyelin, asolectin, diphytanoylphosphatidylcholine (DPhPC), 1,2-dipalmitoyl-*sn*-glycero-3-phosphocholine (DPPC), 1,2-diheptanoyl-*sn*-glycero-3-phosphocholine (DHPC), 1,2-dihexanoyl-*sn*-glycero-3-phosphoethanolamine (DHPE), 1,2-dimyristoyl-*sn*-glycero-3-phosphocholine (DMPC), dimyristoyl phosphatidylserine (DMPS), dimyristoyl phosphatidylglycerol, dilauroyl phosphatidylcholine (DLPC), 1,2-dimyristoyl-*sn*-glycero-3-phosphoethanolamine (DMPE), 1,2-dimyristoyl-*sn*-glycero-3-[phospho-*rac*-(1-glycerol)] (DMPG), lyso PC, such as 1-myristoyl-2-hydroxy-*sn*-glycero-3-phosphocholine (14:0 lyso PC) or 1-palmitoyl-2-hydroxy-*sn*-glycero-3-phosphocholine (16:0 lyso PC), lyso PE, such as 1-palmitoyl-2-hydroxy-*sn*-glycero-3-phosphoethanolamine (16:0 lyso PE) or 1-oleoyl-2-hydroxy-*sn*-glycero-3-phosphoethanolamine (18:1 lyso PE), 1,2-didecanoyl-*sn*-glycero-3-phosphocholine (DDPC), 1,2-dierucoyl-*sn*-glycero-3-phosphate (DEPA), 1,2-erucoyl-*sn*-glycero-3-phosphocholine (DEPC), 1,2-dierucoyl-*sn*-glycero-3-phosphoethanolamine (DEPE), 1,2-linoleoyl-*sn*-glycero-3-phosphocholine (DLOPC), 1,2-dilauroyl-*sn*-glycero-3-phosphate (DLPA), 1,2-dilauroyl-*sn*-glycero-3-phosphoethanolamine (DLPE), 1,2-dilauroyl-*sn*-glycero-3-phosphoserine (DLPS), 1,2-dimyristoyl-*sn*-glycero-3-phosphate (DMPA), 1,2-dimyristoyl-*sn*-glycero-3-phosphoserine (DMPS), 1,2-dioleoyl-*sn*-glycero-3-phosphate (DOPA), 1,2-oleoyl-*sn*-glycero-3-phosphocholine (DOPC), 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine (DOPE), 1,2-dioleoyl-*sn*-glycero-3-phosphoserine (DOPS), 1,2-dipalmitoyl-*sn*-glycero-3-phosphate (DPPA), 1,2-dipalmitoyl-*sn*-glycero-3-phosphoethanolamine (DPPE), 1,2-dipalmitoyl-*sn*-glycero-3-phosphoserine (DPPS), 1,2-distearoyl-*sn*-glycero-3-phosphate (DSPA), 1,2-distearoyl-*sn*-glycero-3-phosphocholine (DSPC), 1,2-diostearoyl-*sn*-glycero-3-phosphoethanolamine (DSPE), 1-myristoyl-2-stearoyl-*sn*-glycero-3-phosphocholine (MSPC), 1-palmitoyl-2-myristoyl-*sn*-glycero-3-phosphocholine (PMPC), 1-palmitoyl-2-oleoyl-*sn*-glycero-3-phosphocholine (POPC), 1-palmitoyl-2-oleoyl-*sn*-glycero-3-phosphoethanolamine (POPE), 1-palmitoyl-2-stearoyl-*sn*-glycero-3-

phosphocholine (PSPC), 1-stearoyl-2-myristoyl-*sn*-glycero-3-phosphocholine (SMPC), 1-stearoyl-2-oleoyl-*sn*-glycero-3-phosphocholine (SOPC), 1-stearoyl-2-palmitoyl-*sn*-glycero-3-phosphocholine (SPPC), a lipid from a cell membrane, a lipid from an organelle, a cross-linkable lipid, and a mixture thereof, preferably POPC.

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4. The macromolecule membrane structure according to claim 2, wherein the amphiphilic molecules are selected from amphiphilic AB, ABA and ABC copolymers, and mixtures thereof, such as poly(methyloxazoline)-poly(dimethylsiloxane)-poly(methyloxazoline) (PMOXA-PDMS-PMOXA), poly(2-ethyl-2-oxazoline)-*b*-poly(dimethylsiloxane)-*b*-poly(2-ethyl-2-oxazoline) (PEtOz-PDMS-PEtOz), and a
10 mixture thereof.

5. The macromolecule membrane structure according to any of the claims 1 to 4, wherein the membrane (3) is a proteoliposome or a proteopolymersome and the outer surface of the proteoliposome or proteopolymersome is coated with the silica layer (4).

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6. The macromolecule membrane structure according to any of the claims 1 to 5, wherein the water-channel integral membrane proteins (1) are aquaporins, preferably selected from the group consisting of a human aquaporin (hAQP), such as hAQP0, hAQP1, hAQP2, hAQP3, hAQP4, hAQP5, hAQP6, hAQP7, hAQP8, hAQP9, hAQP10, hAQP11, hAQP12, preferably hAQP0, hAQP1, hAQP2,
20 hAQP4, hAQP5, hAQP6, or hAQP8, and more preferably hAQP4; a bovine aquaporin, such as bAQP1; a fish aquaporin, such as cpAQP1aa; a yeast aquaporin, such as Aqp1; a plant aquaporin, such as SoPIP2; 1, AtTIP2; 1 or AtPIP2; 4; a bacterial aquaporin, such as AqpZ; and a mixture thereof.

7. The macromolecule membrane structure according to any of the claims 1 to 6, wherein the silica
25 layer (4) has an average thickness selected within a range of from 0.1 nm to 1000 nm, preferably from 1 to 100 nm, and more preferably from 1 to 10 nm.

8. The macromolecule membrane structure according to any of the claims 1 to 7, wherein the water-channeling integral membrane proteins (1) being capable of channeling water through the
30 membrane (3) in the presence of the silica layer (4).

9. The macromolecule membrane structure according to any of the claims 1 to 8, wherein the silica layer (4) is a functionalized silica layer (4), preferably comprising a silane, such as fluoroalkylsilane (FAS), an alkoxysilane, such as hexamethyldisilazane (HMDZ), or a combination thereof.

10. A filtration device (5) comprising:
a porous support (6) comprising a plurality of pores (7); and
macromolecule membrane structures (2) according to any of the claims 1 to 9.

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11. The filtration device according to claim 10, wherein the macromolecule membrane structures (2) are provided on a surface of the porous support (6) and/or are provided in the pores (7) of the porous support (6).

- 10 12. The filtration device according to claim 10 or 11, wherein the porous support (6) is made of a material selected from the group consisting of a polymer, such as polysulfone, polyethersulfone, polyphenylsulfone, polyetherethersulfone, polyetherketone, polyetheretherketone, polyphenylene ether, polydiphenylphenylene ether, cellulose, polyvinylene cellulose acetate, cellulose diacetate, cellulose triacetate, cellulose nitrate, polyphenylene sulfide, nitrocellulose, acetylated methylcellulose,
15 polyacrylonitrile, polyvinylalcohol, polycarbonate, organic siloxane carbonate, polyester carbonate, organic polysiloxane, polyethylene oxide, polyamide, polyimide, polyamidoimide, polybenzimidazole, polyolefin, polyacrylonitrile, nylon and a mixture thereof; a metal, or an oxide of the metal, such as aluminum, titanium, zirconium, iron, or an oxide thereof; silicon dioxide; glass fiber; and a mixture thereof.

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13. The filtration device according to any of the claims 10 to 12, wherein
the filtration device (5) comprises macromolecule membrane structures (2) according to claim 9;
and
functionalized groups of the functionalized silica layer (4) link the macromolecule membrane
25 structures (2) to the porous support (6).

14. A method of preparing a water filtrate, the method comprising filtering an aqueous solution through a macromolecule membrane structure (2) according to any of the claims 1 to 9 or a filtration device (5) according to any of the claims 10 to 13 to obtain the water filtrate.

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15. A method for concentrating a compound dissolved or dispersed in an aqueous solution, the method comprising filtering the aqueous solution through a macromolecule membrane structure (2) according to any of the claims 1 to 9 or a filtration device (5) according to any of the claims 10 to 13 to

obtain a water filtrate lacking the compound and a retentate comprising the compound at a higher concentration than the aqueous solution.

16. A process for preparation of a macromolecule membrane structure (2), the process comprising
5 contacting a membrane (3) comprising water-channeling integral membrane proteins (1) with a silica precursor to form a silica layer (4) coated on a first surface of the membrane (3).

17. A process for preparation of a filtration device (5), the process comprising:
depositing a membrane (3) comprising water-channeling integral membrane proteins (1) onto
10 and/or into a porous support (6); and
contacting the membrane (3) comprising water-channeling integral membrane proteins (1)
deposited onto and/or into the porous support (6) with a silica precursor to form a silica layer (5) coated
on a first surface of the membrane (3).

15 18. The process according to claim 16 or 17, wherein the silica precursor is selected from the group consisting of a silicon alkoxide, such as tetramethyl orthosilicate (TMOS), tetraethyl orthosilicate (TEOS), tetrapropyl orthosilicate, tetrabutylorthosilicate, methyltriethoxysiloxane (MTES), dimethyldiethoxysiloxane (DMDES), tetrakis(glycerol)orthosilicate (TGS) or tetrakis-(2-hydroxyethyl)-orthosilicate (THEOS); a silane, such as allyltrimethoxysilane, (3-
20 aminopropyl)triethoxysilane, butyltrichlorosilane, chloropentamethyldisilane, 1,2-dichlorotetramethyldisilane, diethoxydiphenylsilane, [3-(diethylamino)propyl]trimethoxysilane, dimethoxydimethylsilane, dimethoxy(methyl)octylsilane, (3-glycidyloxypropyl)trimethoxysilane, hexamethyldisilane, isobutyl(trimethoxy)silane, methyltrichlorosilane, pentamethyldisilane, n-propyltriethoxysilane, tetraethylsilane, 1,1,2,2-tetramethyldisilane, tetramethylsilane,
25 triethoxymethylsilane, triethoxyoctylsilane, trimethoxyphenylsilane, triethoxyphenylsilane, triethoxyvinylsilane, trimethoxymethylsilane, γ -aminopropyltriethoxysilane, silicon tetrachloride (tetrachlorosilane), silicon tetrabromide (tetrabromidesilane) or γ -aminopropylsilanetriol (APSTOL); a silicate, such as sodium silicate; a silanol, such as tris(*tert*-pentoxy)silanol or tris(*tert*-butoxy)silanol; a silazane, *N*-sec-butyl(trimethylsilyl)amine, and a combination thereof, preferably TEOS.