Claims

1. A semi-permeable membrane comprising:
   - at least two two-dimensional (2D) heterostructure layers; and
   - a polyelectrolyte layer between each 2D heterostructure layer of the at least two 2D heterostructure layers,

wherein each 2D heterostructure layer of the at least two 2D heterostructure layers and the polyelectrolyte layer are bonded to one another via electrostatic interactions, hydrogen bonds, van der Waals interaction, hydrophobic interactions, or a combination thereof.

2. The membrane according to claim 1, wherein the membrane is formed by self-assembly of the at least two 2D heterostructure layers and the polyelectrolyte layer.

3. The membrane according to any preceding claim, wherein the membrane comprises the at least two 2D heterostructure layers in a layer-by-layer assembly.

4. The membrane according to any preceding claim, wherein the 2D heterostructure layer comprises: graphene, graphene-oxide, hexagonal boron nitride (hBN), transition metal dichalcogenides, 2D transition metal carbides, 2D transition metal nitrides, 2D metal oxides, or a combination thereof.

5. The membrane according to any preceding claim, wherein the polyelectrolyte layer comprises: proteins, polybases, polyacids, polynucleotides, polysaccharides, or a combination thereof.

6. The membrane according to any preceding claim, wherein average interlayer distance between each 2D heterostructure layer of the at least two 2D heterostructure layers is 1-3 nm.

7. The membrane according to any preceding claim, wherein the membrane has an average thickness of 50 nm - 100 μm.

8. The membrane according to any preceding claim, wherein the membrane is a free-standing membrane and has an average thickness of ≥ 1000 nm.

9. The membrane according to any preceding claim, wherein water flux through the membrane is controlled by changes in internal osmotic pressure within the membrane.

10. A method of preparing a membrane of any preceding claim, the method comprising:

- mixing a 2D heterostructure solution and a polyelectrolyte solution to form a mixture; and
- vacuum filtering the mixture onto a substrate to form the membrane.

11. The method according to claim 10, wherein the 2D heterostructure solution comprises graphene, graphene-oxide, hexagonal boron nitride (hBN), silicon, doped graphene, hydrogenated graphene, fluorinated graphene, amorphous carbon, amorphous graphene, transition metal dichalcogenides, 2D transition metal carbides, 2D transition metal nitrides, 2D metal oxides, or a combination thereof.

12. The method according to claim 10 or 11, wherein the polyelectrolyte solution comprises: proteins, polybases, polyacids, polynucleotides, polysaccharides, or a combination thereof.

13. The method according to any of claims 10 to 12, wherein the mixture may be a colloidal mixture.

14. The method according to claim 13, wherein the method further comprises centrifuging the colloidal mixture to separate particles from the colloidal mixture.

15. The method according to any of claims 10 to 14, wherein the method further comprises drying the membrane following the vacuum filtering.