RUI: Wet Printing of Carbon Nanotube-Enhanced Osmosis Membranes for Water Desalination; NSF Grant # CBET-1510207

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Background and Motivation

This research proposes to develop facile screen-printing systems for massive production of vertically aligned carbon nanotube based osmosis membranes from liquid crystalline solutions. It entails rational design of novel nanotube orientation templates and pursues the manufacturing of vertically aligned nanotube composites from liquid crystalline solutions as a step towards the realization of ideal mixed matrix membranes for water desalination.

Confined inside the nanotubes, water molecules transport through a nano-channel substantially differently from those observed in the bulk. Typically, movement of water inside nanotubes exhibit a ballistic motion of 1D ordered chain-like structures due to strong intermolecular H-bonding. Water molecules move through nanotube pores orders of magnitude faster than through other pores of comparable size.

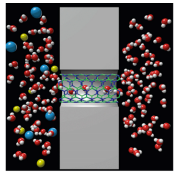

Figure 1. Transport of water molecules through a single walled carbon nanotube

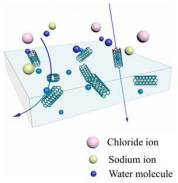

Figure 2. Transport of water molecules through the nanotube based mixed matrix membrane

One of most common approaches of exploiting nanotubes in water treatment is to incorporate nanotubes into the polymer matrix, resulting in a mixed matrix membrane (MMM). Nanotubes act to produce preferential permeation pathways for enhanced selectivity and permeability, whereas the polymer possesses the high processability for cost-effective MMM fabrication. Water can move into the hollow interiors of tubes with an ultrafast flow rate, while the large size ions are rejected.

The ideal nanotube-based MMMs for water treatment possess well-ordered microstructures in which vertically aligned nanotubes are dispersed in the polymer matrix. The development of effective strategies to control vertical alignment of nanotubes in the polymer matrix is crucial for maximizing selectivity and permeability. In this project, we use a liquid crystalline printing technique to fabricate large-area vertically aligned nanotube-based MMMs for water desalination.

Liquid Crystal-Nanotube Composites

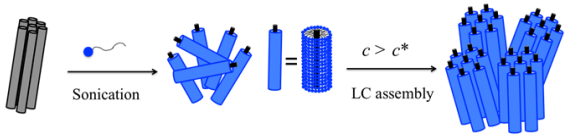

Figure 3. Dispersion and exfoliation of single walled carbon-nanotubes in hexagonal liquid crystalline surfactants

The carbon nanotube dispersion and exfoliation in polymerizable liquid crystalline surfactants have been systematically investigated. In water, the surfactants form cylindrical micelles with hydrophobic cores (Figure 3). The physical absorption of nonpolar tails of surfactants on the surface of nanotubes produces de-bundled tubes, which are incorporated inside cylindrical micelles. When concentrated above a critical value, the surfactants form hexagonal liquid crystalline phases in which nanotubes are hosted. We have found that addition of nanotubes does not alter liquid crystalline phases of the host surfactants (Figure 5) but enhances the order-disorder transition temperature (Figure 6). After photo-polymerization, the liquid crystalline microstructures are retained in the solid films (Figure 5).

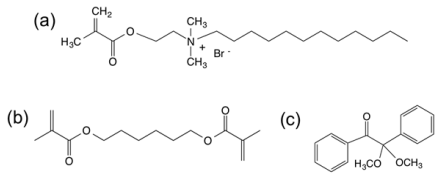

Figure 4. Chemical structures of (a) polymerizable surfactant, (b) cross-linker, and (c) photo-initiator

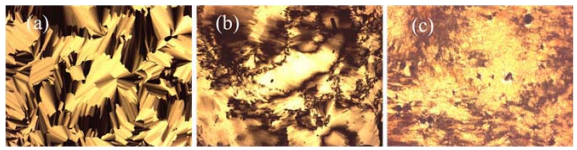

Figure 5. Optical images under crossed polarizers. (a) Hexagonal phase of surfactant solution, (b) same solution as (a) with addition of nanotubes, and (c) polymerized film of the solution (b)

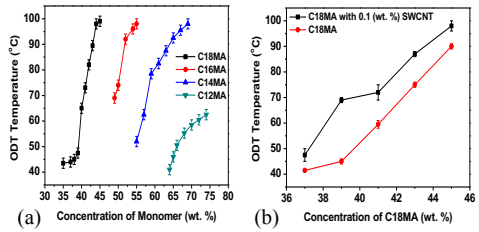

Figure 6. Liquid crystalline phase diagrams. (a) Effect of carbon chain length of surfactants and (b) effect of carbon nanotubes

Liquid Crystalline Printing

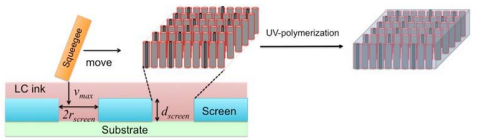

Figure 7. Screen printing of vertically aligned nanotube MMM

The future work will focus on screen-printing nanotube dispersions in hexagonal liquid crystalline surfactants followed by photo-polymerization.

Conclusions

- A series of polymerizable liquid crystalline surfactants are synthesized
- Addition of nanotubes does not alter hexagonal phases but enhances order-disorder transition temperature of surfactants
- After photo-polymerization, the ordered microstructures are retained in the solid thin films

References

1. Hider, et al. Small, 2009, 5, 2183-2190
2. Kim, et al. ACS App. Mater.& Int., 2014, 6, 2819-2829