Efficient Solar Membrane Distillation and Crystallization using WS_2-PVDF Nanocomposite Membranes

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Abstract

The ever-increasing global demand for clean water underscores the urgency of developing innovative and sustainable desalination technologies. Among these solutions, solar membrane desalination utilizing WS_2-PVDF nanocomposites emerges as a highly promising approach for efficient and environmentally friendly water purification.
In this context, we've conducted an extensive study to explore the potential of WS_2 nanofillers in enhancing solar photothermal membrane distillation. Additionally, we've examined their role in facilitating efficient membrane crystallization for valuable mineral recovery from brines [1]. Through the integration of WS_2 nanofillers into polymeric membranes, we've achieved a significant enhancement in photothermal effects, resulting in an impressive 364% increase in water evaporation when exposed to solar radiation. This breakthrough technology not only overcomes temperature polarization but also leverages WS_2 nanofillers as nanoscale thermal hotspots. This advancement opens the doors to large-scale and efficient desalination, making substantial strides towards sustainable water desalination and effectively addressing global water challenges.

Results and Discussion

Figure 1

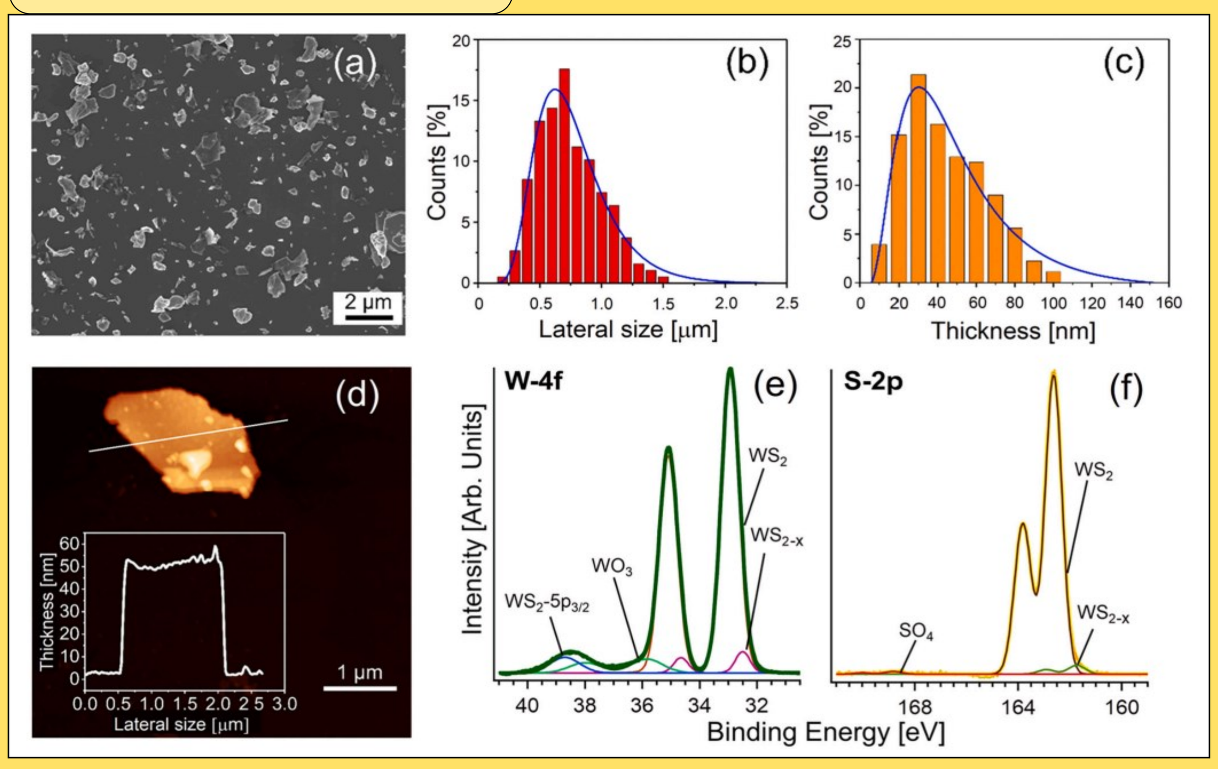


Figure 2

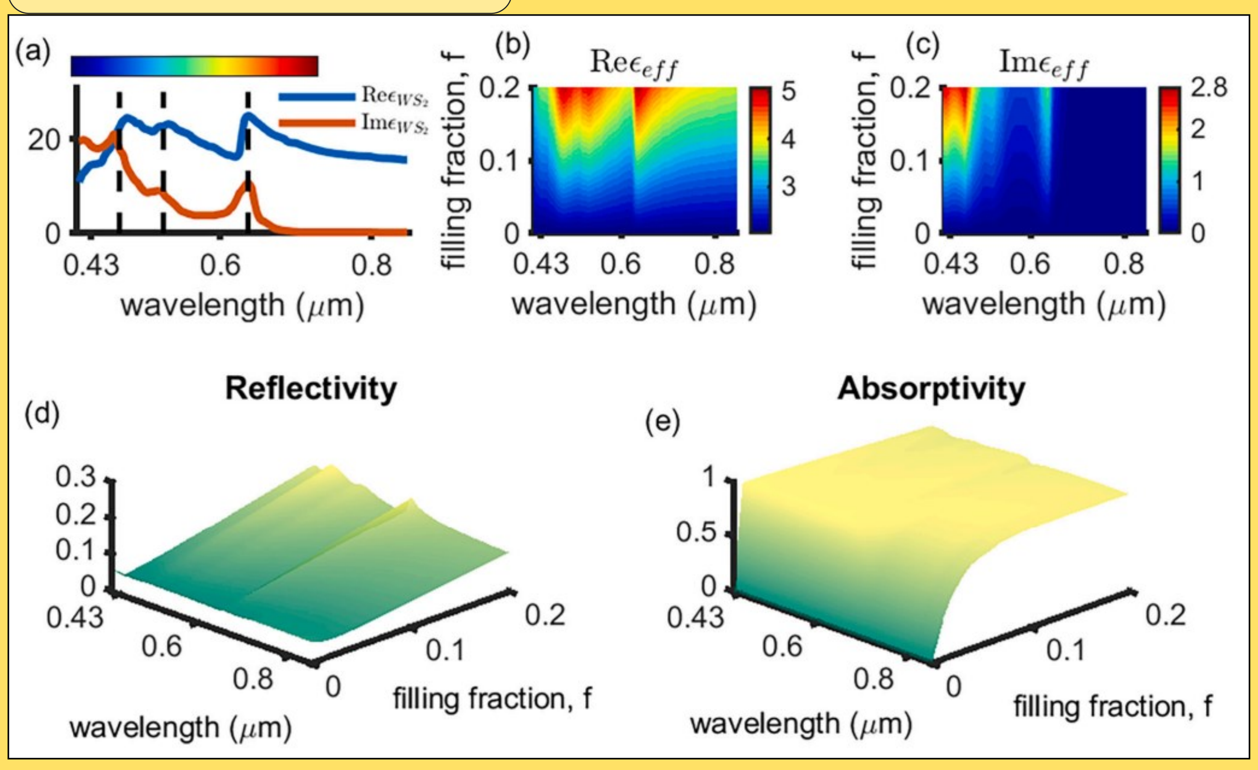
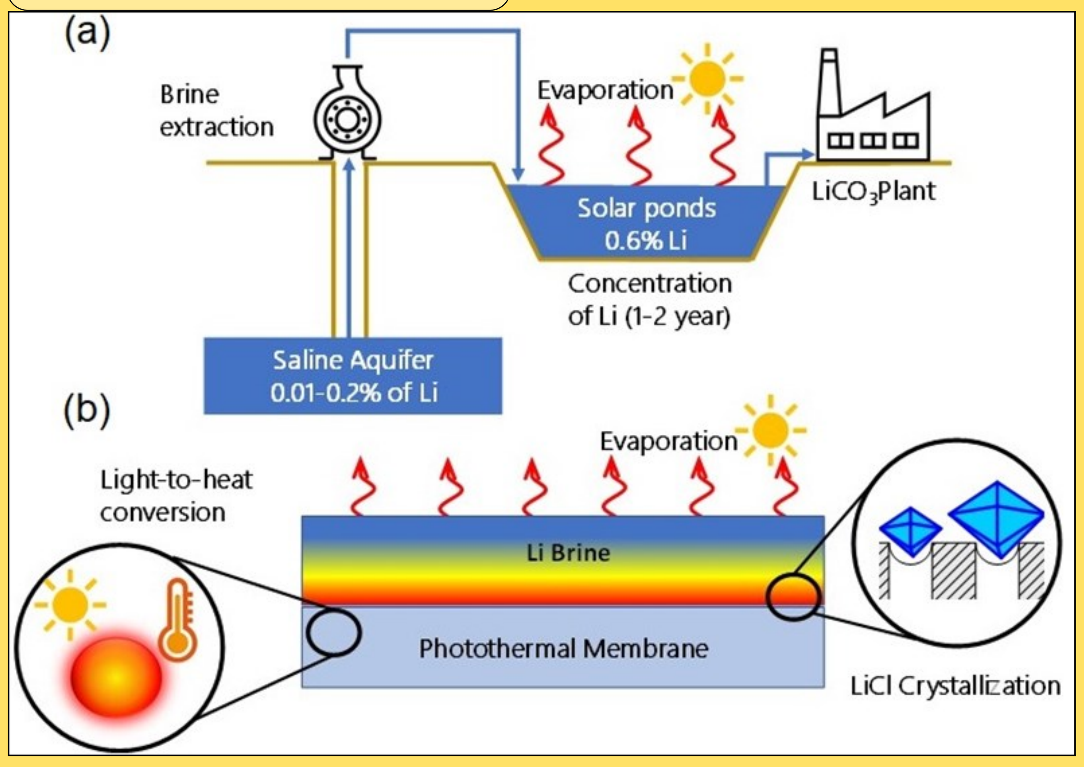


Figure 3



- **Characteristics of WS_2 flakes exfoliated via LPE** (Figure 1): (a) Representative SEM image of WS_2 flakes exfoliated using Liquid Phase Exfoliation (LPE). (b) Analysis of lateral size distribution of WS_2 flakes determined from SEM images. (c) Analysis of thickness distribution determined from AFM measurements. (d) Representative AFM image of WS_2 flakes. The height profile along the solid white line is shown in the inset. (e) W-4f core levels and (f) S-2p core levels of WS_2 flakes.
- **Optical Characteristics of WS_2 and WS_2-Based Composite** (Figure 2): (a) The relative dielectric function of WS_2 as a function of wavelength (λ) in the optical range, with the top axis indicating the corresponding zone of the electromagnetic spectrum in the visible. The real and imaginary components of the dielectric function are shown in blue and red, respectively. (b-c) The effective dielectric function of the WS_2-based composite (PVDF loaded with WS_2 nanosheets) as a function of λ and the WS_2 volume fraction (f). (d) Reflectivity and (e) absorptivity of a nanocomposite slab (with a finite thickness, set at 55 µm) as a function of λ and f.
- **Comparison of Lithium (Li) Extraction Processes** (Figure 3): (a) Conventional Li extraction process, which typically involves time-consuming methods from ores or brines. (b) Solar-driven Photothermal Membrane Crystallization (PhMCr), an innovative and sustainable approach to accelerate Li extraction from brines using solar energy.

Figure 4

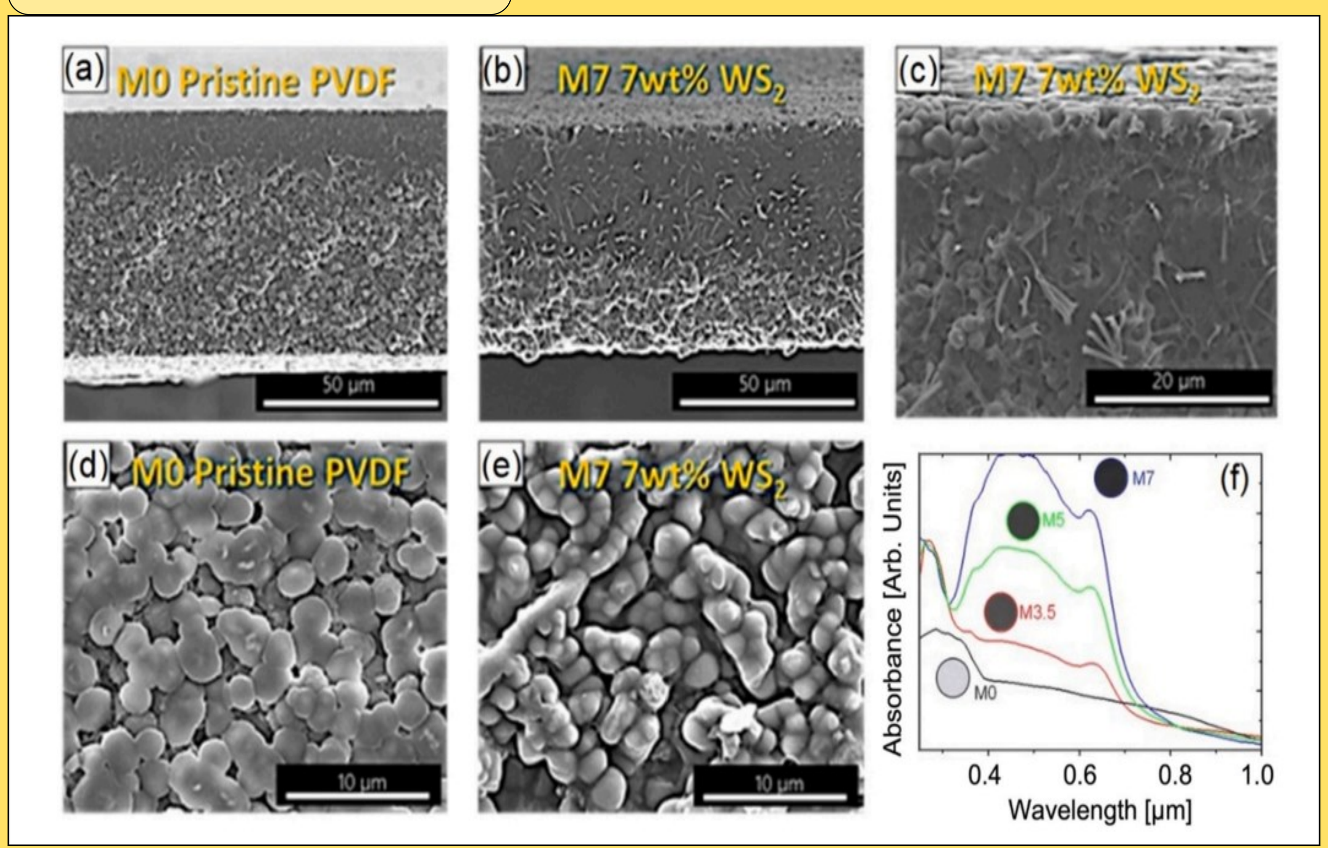


Figure 5

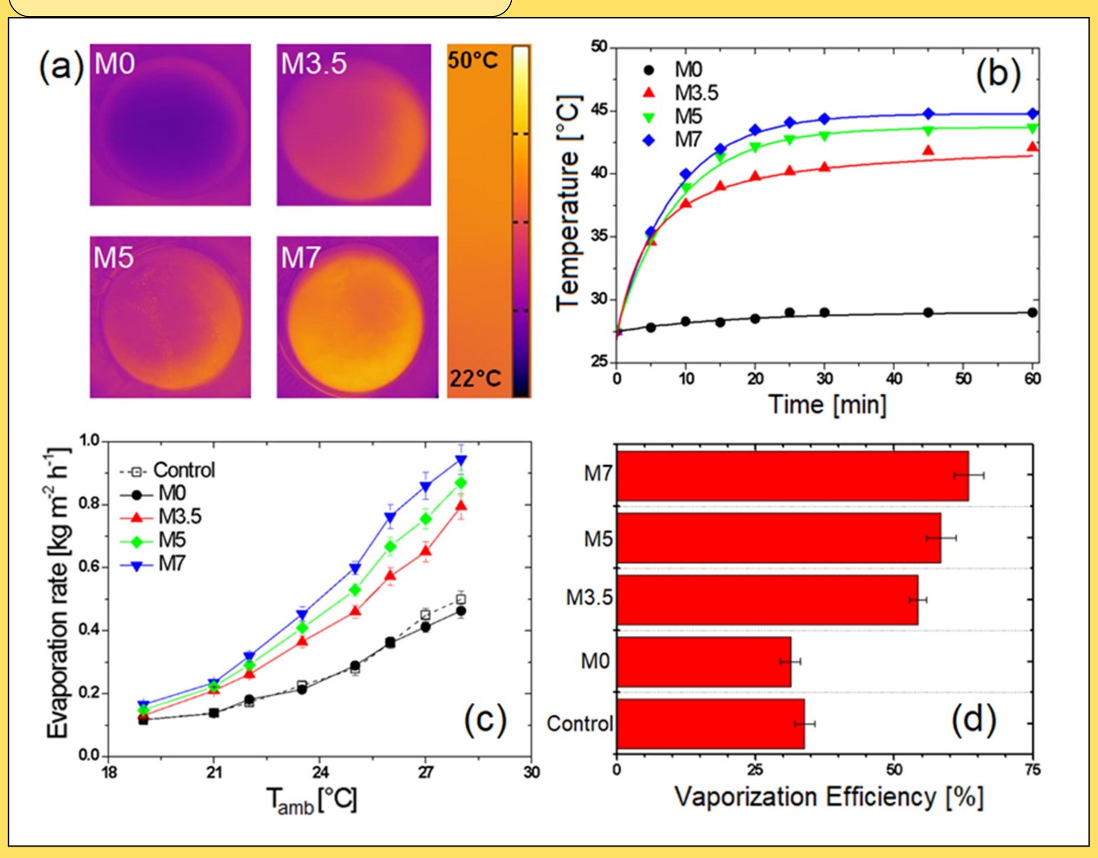
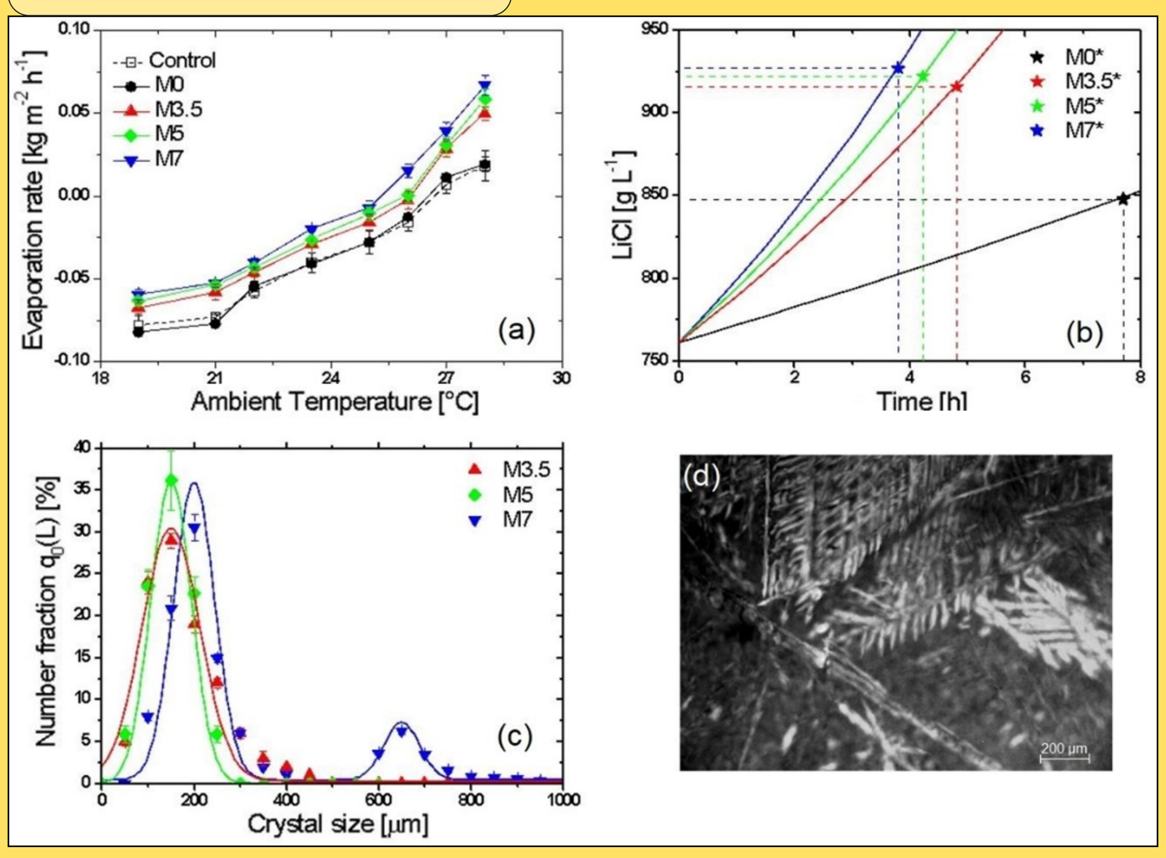


Figure 6



- **Microstructural Analysis of PVDF Membranes with Varying WS_2 Loading** (Figure 4): (a-b) SEM images of cross-sections of the pristine PVDF membrane (M0) and PVDF loaded with 7 wt% WS_2 (M7) at 2500× magnification. (c) Detailed microstructure of PVDF-7 wt% WS_2 (M7) at 6000× magnification. (d-e) High-resolution SEM images of the top surface of pristine PVDF membrane (M0) and PVDF-7 wt% WS2 (M7) at 10,000× magnification. (f) UV-Vis spectra and visual appearance of the membranes with varying WS_2 loading.
- **Photothermal Effects and Water Vaporization Performance** (Figure 5): (a) Infrared thermography captured using a thermal camera for membranes M0, M3.5, M5, and M7 exposed to 60 minutes of sunlight irradiation. (b) Recorded temperature changes in the same membranes over time during solar irradiation. (c) Evaporation rates of distilled water from the PhMCr system under varying ambient temperatures with solar radiation. (d) Vaporization efficiency of distilled water under solar radiation at a constant temperature of 28°C.
- **Solar-Driven Photothermal Membrane Crystallization (PhMCr) for Lithium Chloride (LiCl) Recovery** (Figure 6): (a) Evaporation rate from LiCl brine (18 M) in PhMCr under the solar radiation at different temperatures; (b) Evolution of LiCl concentration in PhMCr experiments (T = 28 ◦C) and theoretical supersaturation point (stars); (c) LiCl crystal size distribution; (d) Microscopic image of LiCl crystal achieved on the M7 surface after the experiments of PhMCr.

Conclusion

Overall, this innovative and sustainable nanotechnology-enabled platform based on photothermal effects originating from excitons in nanosheets of van der Waals semiconductors demonstrates the possibility to combine renewable energy sources (such as sunlight) with membrane technologies to intensify the extraction of Li from salars, with the possibility to extend the use of PhMCr also for the recovery of other minerals. Notably, the implementation of PhMCr further expands the breadth of the application fields of van der Waals semiconductors and their nanocomposites to include (i) the crystallization and (ii) the recovery of economically strategic minerals at reduced operating costs, in excellent matching with the principles of circular blue economy.

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Reference

[1] S. Santoro, M. Aquino, C. Rizza, J. Occhiuzzi, D. Mastrippolito, G. D'Olimpio, A. H. Avci, J. De Santis, V. Paolucci, L. Ottaviano, L. Lozzi, A. Ronen, M. Bar-Sadan, D. S. Han, A. Politano and E. Curcio, Lithium recovery through WS_2 nanofillers-promoted solar photothermal membrane crystallization of LiCl, Desalination 546 (2023) 116186.