

# Structure-Engineered Two-Dimensional Membranes for Transport Regulation and Flexible Devices

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## Abstract

Functional membranes widely operate as continuous thin films in systems for separation, sensing, and signal regulation, where their structural state directly influences stability and performance. However, most membranes are fabricated as planar films, which limits their adaptability to device geometries and operating conditions. Meanwhile, performance optimization has largely relied on compositional modification, while structure-driven strategies at the continuous membrane scale remain less explored.

Here we present a systematic study on structure-engineered two-dimensional membranes linking structural modulation with transport regulation and device integration. By coordinating chemical characteristics such as surface charge distribution with controllable surface morphologies, structurally asymmetric membranes are constructed, revealing how structural factors govern membrane response. Micro-crumpled architectures are further introduced to reconstruct molecular transport pathways, alleviating permeability limitations of conventional layered membranes while maintaining separation selectivity. In addition, a controllable transformation from planar films to curved membranes enables integration into acoustic diaphragm devices.

Beyond membrane systems, the structure-engineered films are applied in pressure sensors and stretchable antennas, where structural design suppresses response saturation at high pressure and maintains stable electromagnetic performance under strains of up to ~60%.

Overall, this work highlights structural engineering as an effective strategy for regulating transport and device performance in functional membranes and provides a pathway toward their broader application in separation technologies and flexible electronics.

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