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Pristine Graphene Membranes for Highly Selective Gas Separation

Pristine graphene, a single-atom-thick carbon material, holds immense promise for revolutionizing gas separation technologies due to its unique properties, including atomic thinness, exceptional mechanical strength, and inherent impermeability to gases. This paper details the advancements in fabricating nanoporous pristine graphene membranes designed for highly selective gas separation, particularly for critical industrial applications such as carbon dioxide (CO2) capture and hydrogen (H2) purification. We explore both top-down (electron beam drilling, ion bombardment) and bottom-up (Chemical Vapor Deposition with intrinsic pore control) methodologies for creating precisely sized sub-nanometer pores. The fundamental principles of gas transport, driven by size-selective molecular sieving and pore-edge interactions, are discussed, supported by theoretical predictions from molecular dynamics simulations. Experimental characterization techniques, including Raman spectroscopy, TEM, and AFM, are highlighted for their role in validating pore structure and membrane integrity. Performance metrics, including permeability and selectivity, are presented, demonstrating how these membranes can potentially surpass the conventional Robeson upper bound. While challenges in scalability, cost-effectiveness, and defect management persist, ongoing research into sustainable production methods and advanced pore engineering continues to push the boundaries of this transformative technology, positioning pristine graphene membranes as a cornerstone for future sustainable industrial processes.

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