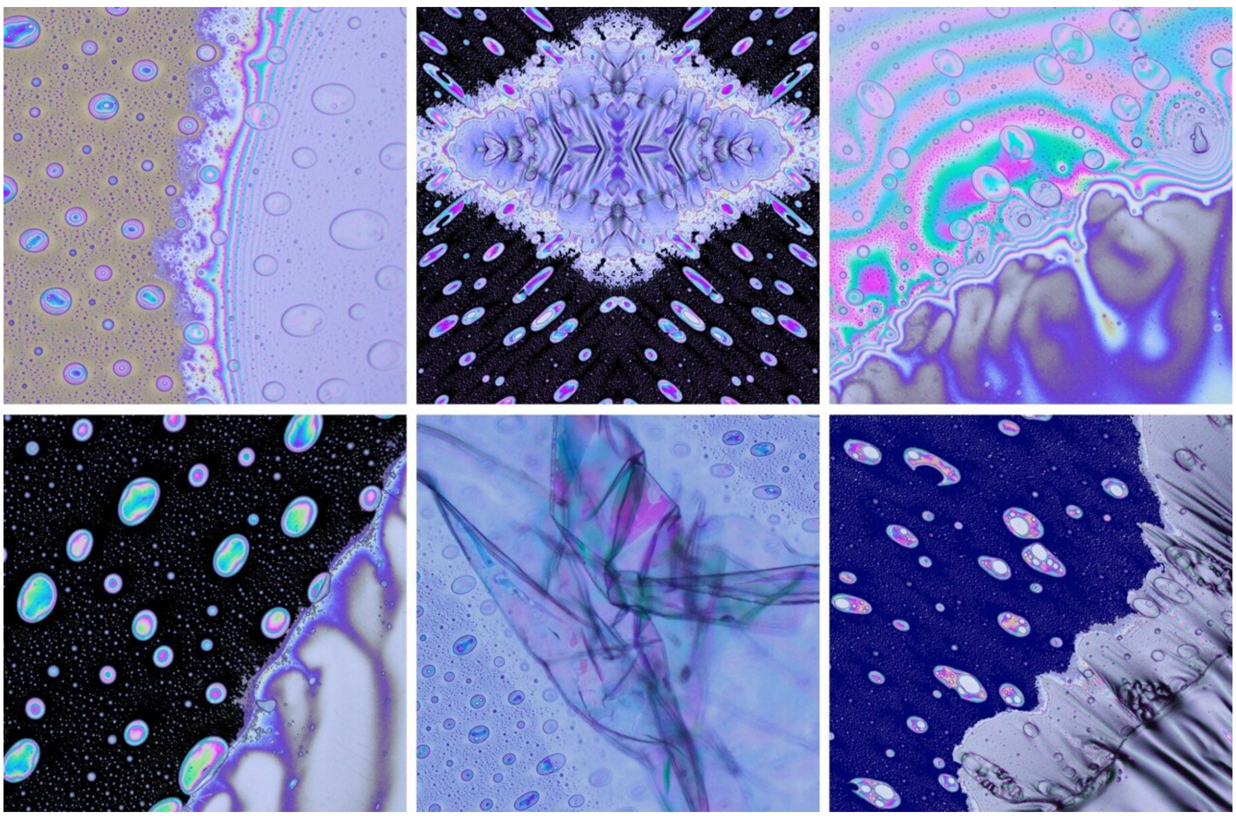
Energy-efficient and customizable inorganic membranes for a cleaner future

March 30 2023



Free at last—This collection of microscope photos depicts the wonderful moments of dynamic particles moving towards various freestanding membranes at the air-liquid interface. Credit: National University of Singapore

A breakthrough in synthesis strategy enables the facile formulation of inorganic membranes that are not just energy-efficient but also highly customizable, potentially revolutionizing the way many industries operate for greater sustainability.

Inorganic membranes can be thought of as kitchen sieves. Similar to how sieves separate smaller particles from larger ones, inorganic membranes, typically made of ceramics or metals, selectively separate molecules based on their size and properties.

In a ground-breaking achievement, a team of researchers from the College of Design and Engineering (CDE) at the National University of Singapore, led by Professor Ho Ghim Wei from the Department of Electrical and Computer Engineering, has developed a revolutionary technique for producing ultrathin inorganic membranes. These freestanding membranes can function without any supporting substrate—a significant advancement in membrane technology. The team's findings were published in the scientific journal *Nature* on March 29, 2023.

Highly customizable and simple to produce, the inorganic membranes—underpinned by a universal, facile synthesis strategy—have the potential to benefit applications beyond filtration and separation. From energy conversion to catalysis and sensing, the membranes' versatility could transform various sectors and industries that depend on membrane technology. By promoting efficiency and sustainability in industrial processes, the NUS scientists' pioneering research has unveiled new possibilities for overcoming energy challenges in the face of climate change.

Membranes reimagined

Conventional membrane technologies used in purification and separation processes are known to be energy-intensive and therefore expensive, often entailing a combination of pressure, heat, and sometimes chemicals to function effectively. Moreover, the membranes must be regenerated, while the filtered components usually require further treatment after separation, leading to additional energy demands and costs.

Such limitations of traditional membrane technologies served as the impetus for postdoctoral research fellow Dr. Zhang Chen in Prof Ho's team to develop a new synthesis strategy for highly efficient inorganic membranes. Dr. Zhang's method involves taming chaotic, free-floating, inorganic building-blocks in a liquid environment, coaxing them to self-assemble into the desired membrane. This tunable process provides an effective means to tailor the membrane's thickness and pore characteristics for specific applications, achieving maximum energy efficiency.

"Our study has also allowed us to take a fresh approach to rethink how inorganic membranes are traditionally developed," added Dr. Zhang.

The NUS scientists have presented a synthesis template that other researchers can utilize for their work, which could spur the discovery of more novel membranes with a wider compositional range in a scalable and cost-effective manner.

From a structural perspective, the membranes they produced have more geometric diversity than conventional ones, providing more flexibility and options when designing membrane structures.

Additionally, the study also explores membrane functionality, where highly selective 2D barriers are used to control energy flow across the membrane. This feature could influence how the membrane functions—allowing ions to be filtered based on their charge, different forms of energy such as thermal, electrical, or light to be harnessed, or specific molecules to be selectively concentrated. Such flexibility is highly desirable in various energy-related applications, including fuel cells and solar energy conversion.

"Our new technique has the potential to transform industries that heavily rely on membranes for their operation, particularly those related to energy or the environment," said Prof Ho. "The ability to create freestanding inorganic membranes that are highly selective opens up numerous exciting possibilities for applications in advanced spatial dynamic separation, catalysis, sensors, memories, and ionic conductors, all of which represent unprecedented developments."

Formulating a greener future

With an emphasis on efficiency and customization, the researchers' innovation plays a key role in NUS' sustainability initiatives, greatly reducing the energy consumption of membrane-related processes worldwide and cutting the carbon footprint of various industries as a result.

Driven by the potential of the breakthrough, Prof Ho plans to lead an interdisciplinary team of scientists in a multi-faceted research program to advance membrane technology to the next level. "By exploring the vast range of membrane compositions and coupling them with various forms of energy, we hope to unlock new applications and make further strides towards a more sustainable future," shared Prof Ho.

The team is also looking to develop automated manufacturing tools to streamline the production process of inorganic membranes, ultimately making their technology more accessible on a larger scale.

More information: Chen Zhang et al, Mechanistic formulation of inorganic membranes at the air–liquid interface, *Nature* (2023). DOI: 10.1038/s41586-023-05809-y

Provided by National University of Singapore