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NANOFLUIDICS

Silicon for the perfect membrane

Albert van den Berg and Matthias Wessling

Newly developed ultrathin silicon membranes can filter and separate molecules much more effectively than conventional polymer membranes. Many applications, of economic and medical significance, stand to benefit.

On page 749 of this issue, Striemer *et al.*[1] describe a method for preparing ultrathin nanoporous membranes made from silicon. Nanoporous membranes are already widely used in medicine, for instance for the filtration and separation of blood proteins in an artificial kidney (haemodialysis) — a rapidly growing world market currently worth more than US$1 billion annually. They can also function as a mechanical support for desalination membranes used to purify sea water for irrigation and human consumption. Given that the membrane technology is seemingly so mature, why should we bother searching for new methods and different starting materials?

At present, all technologically relevant nanoporous membranes are prepared by initiating the precipitation of a polymer from solution. This is achieved through the addition of a non-solvent (often water), or by rapid cooling. The solution precipitates into micrometre- and nanometre-sized domains rich in polymer that form a filter structure. Between these polymer domains, polymer-free areas form the pore system. A diverse spectrum of morphologies and geometries can thus be produced from a variety of starting materials[2].

These nanoporous membranes have a thin skin, typically less than 500 nanometres thick, made up of small bumps, or nodules, with a radius of a few to 50 nm. The voids between the nodules determine the pore size; the pores are 1–50 nm across, and thus the porosity of the membrane as a whole is low. A much thicker layer, with a larger pore size and porosity, provides mechanical support for the nodular skin. Although the pore size of the membrane skin can be adjusted by the choice of starting material and processing route, other morphological parameters, such as its thickness, porosity and pore-size distribution, are surprisingly insensitive to such choices[3].

Nanoporous membranes prepared according to these methods suffer from a typical trade-off: the flux through them can be enhanced by increasing the pore diameter, but at the cost of less effective molecular discrimination. Optimizing flux and selectivity simultaneously requires a fundamentally new approach, which Striemer and colleagues[1] offer.

Not only do the authors' porous nanocrystalline silicon (pncSi) membranes combine small membrane thickness and pore sizes (Fig. 1), but they are also robust, their pore size can be controlled, and they are simple to produce. Earlier attempts to make ultrathin nanoporous membranes used either sophisticated nanolithography or were based on colloidal templates[4,5]. The first method is expensive; and although the second makes elegant use of self-organization principles, very small, controlled pore sizes are difficult to achieve.

Striemer and colleagues' nanopores self-form from a deposited layer of amorphous silicon through rapid thermal annealing[6]. The pore sizes can be controlled between 5 and 25 nm (the range of interest for protein separation) by the choice of annealing temperature. Although the pore-size distribution is not extremely narrow, it has no tail to larger pore sizes. The absence of such a tail is a prerequisite for molecular specificity — and still a challenge for state-of-the-art polymer-based membranes.

The authors find that two important proteins, immunoglobulin-γ and bovine serum albumin (BSA), with hydrodynamic diameters of 14 and 6.8 nm, and molecular weights that similarly differ by a factor of a little more than two, can be separated using their pncSi membrane. For efficient separation using conventional ultrafiltration membranes, a molecular-weight ratio of more than ten is needed. The flux through the pncSi membranes is more than ten times faster than that through conventional membranes with similar selectivity properties. Moreover, Striemer *et al.*[1] find that by changing the surface charge of their membrane through chemical modification, they can separate proteins that are similar in size, but bear a different charge[7].

Perhaps the most promising advantage of the method presented by Striemer *et al.* is that it can be easily integrated into 'labs-on-a-chip' — microfluidics systems that are currently enjoying rapidly growing attention owing to their potential for medical diagnostics, drug discovery and chemical synthesis[8–10]. It is that promise of integration with other nanofluidic separation and analysis techniques for biochemical and biomedical applications that, together with the inherent advantages of the silicon-based system, make this such an important step forward. We look forward to further improvements and proposals for additional uses for the technique. ■

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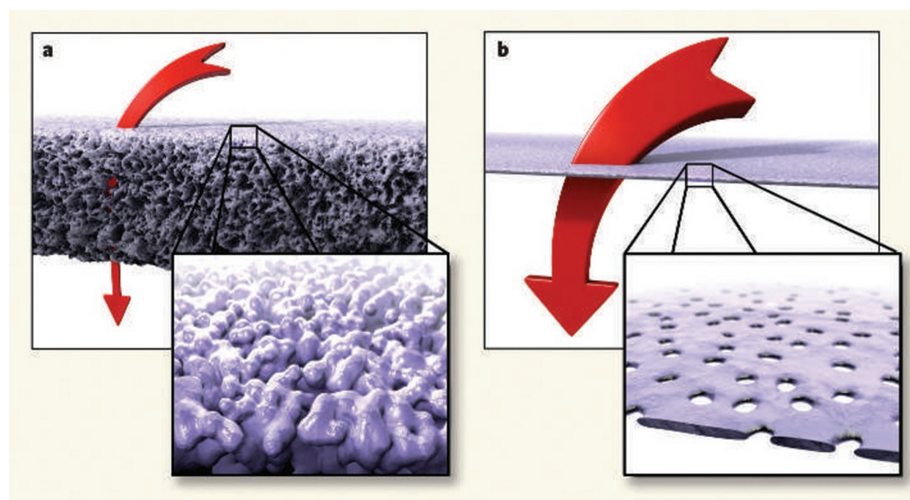

Figure 1 | Barrier to progress. a, The nanoscale nodules that make up the conventional ultrafiltration membrane form a significant restriction to flow. **b,** The ultrathin porous nanocrystalline silicon (pncSi) membranes developed by Striemer *et al.*[1] allow efficient protein separation without restricting the flow as much.

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