# Nuclear techniques reveal 'tunability' of membranes for enhanced electrical conductivity in graphene

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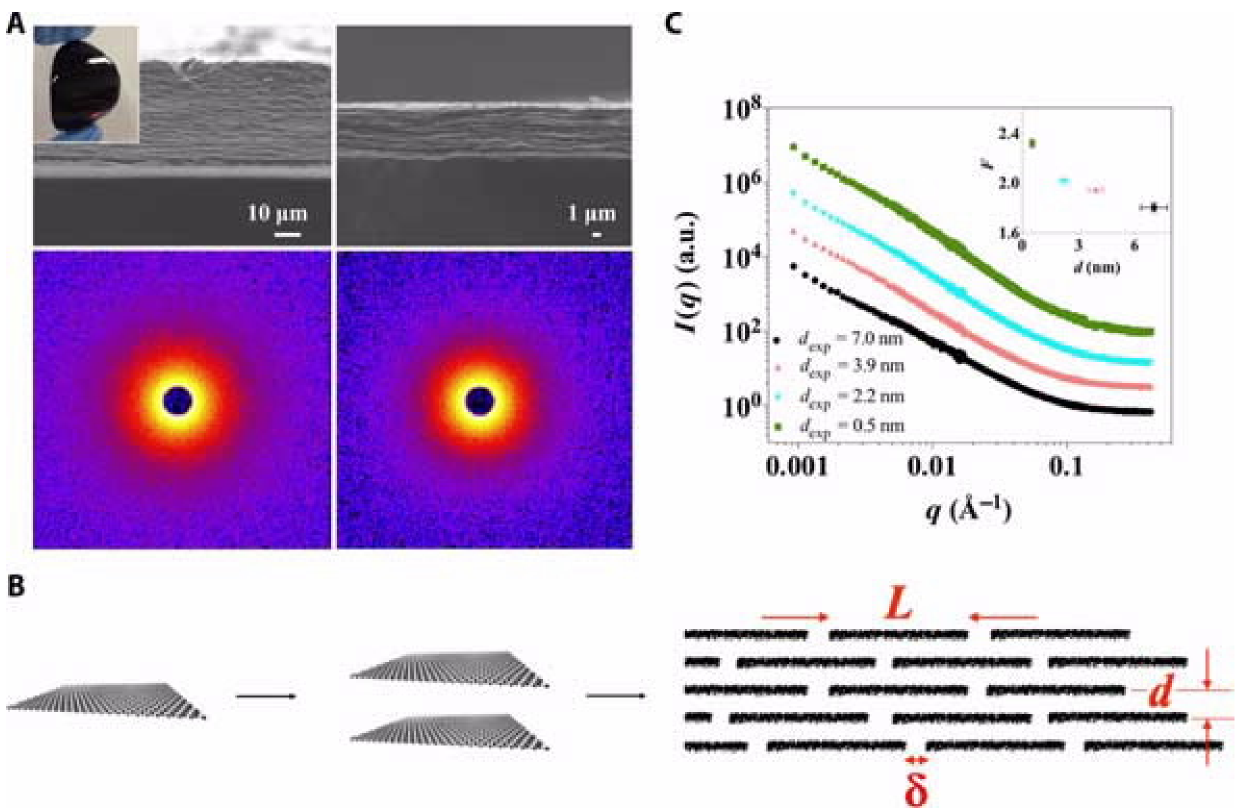


(A) Top: Scanning electron microscopy images of the cross-section of the LGG membranes with dexp compressed to 3.2 nm (left) and 0.5 nm (right), respectively. Bottom: Isotropic SANS patterns of the compressed gel membranes with dexpof 3.9 nm (left) and 0.5 nm (right), respectively. The inset at the upper left corner is a photograph of the LGG membrane. (B) A schematic showing the formation of an array of cascading nanoslits through parallel stacking multiple graphene nanosheets. L, d, and δ are the key geometrical variables of the proposed structural model for describing the porous structure of the LGG membrane. (C) Reduced 1D SANS data offset from the absolute intensity scale. The upper inset on the right shows the slope F from the linear regressions in the q range from 0.001 to 0.01 Å−1as a function of dexp.

ANSTO research has contributed to an understanding of the ion transport mechanism in graphene, a highly electrically conductive material that has been investigated for use in flexible electronics and innovative forms of energy storage and conversion.

Small angle neutron scattering (SANS) using the Quokka instrument has brought insight into how ions are transported at the nano level in stacked membranes of graphene, materials that have many unique properties. The research was aimed to develop graphene into a more versatile material.

Instrument Scientist Chris Garvey, who undertook the SANS measurements on Quokka, and co-authors from Monash University have published their findings in *Science Advances*.

Using the complementary power of neutron scattering experiment and computer simulation they found a robust quantitative relationship between the macroscopic permeation properties of the graphene based membranes and their complex nanoslit structure.

They reported that both the diffusion of ions and electrokinetic effects are different when length scales between the sheets are smaller than 10 nanometres.

Co-author and graphene pioneer Prof Dan Li, also of Monash University, has previously stated that the challenge of making useful things out of graphene has been overcoming its tightly packed structure, only one atom thick, in order for other molecules, such as ions, to interact with it.

Because graphene sheets are prone to restack into graphite when placed close together, Prof Li developed a graphene gel film as a stable platform. Graphene can be used as an electrode when liquid electrolytes are added.

The researchers assembled a bulk layered graphene membrane structure with nanochannels in a process developed by lead author Dr Chi Cheng at the Monash Centre for Atomically Thin Materials for the study. The membrane material houses a series of cascading slits. The ions must move through the minute slits in the membrane.

Structural imperfections, the height of the nanoslits (channel size), the lateral size of individual nanosheets and the gap between the ends of the sheets, affect ion transport.

For the investigations, the researchers modified channel size from 10 nanometres down to less than a nanometre.

Analysis using SANS measurements confirmed that the nanospace between the sheets did not fully collapse when compressed and the cascading nanoslits remain largely continuous.

"We were trying to understand the holes inside the nanosheets, where ionic fluid flows through" said Garvey.

"There is a charge moving through the membrane that generates some form of electric field and that affects how things are transported through it," said Garvey.

"The data that is acquired from Quokka is deceptively simple," explained Garvey. "To get a detailed picture of the material involves narrowing down the structural possibilities, which is quite challenging."

Although the measurement using cold neutrons on Quokka took only a day and a half, the analysis extended to two years.

The analysis of Quokka data can be used to investigate length scales from 1/10th of an angstrom up to a couple of hundred nanometres.

"We can simultaneously 'look' at many objects that extend over that huge range of sizes, that is the power of small angle scattering," said Garvey. "By contrast real space imaging, such as microscopy, is able to look at few objects in the field of view."

Interlayer spacing was found to be the dominant structural index that changed with compression of the nanosheets and affected ion diffusion and electrokinetic effects.

At length scales less than 10 nanometres, the concentration gradient and electric field were driven by channel size.

At length scales below two nanometres, the authors suspected that complex cascading nanofluidic circuitries may lead to the novel nano-confined ion transport phenomena.

The findings have not been observed in traditional one dimensional nanochannels.

The Monash University team found that by manipulating weak interactions among neighbouring graphene layers allows interlayer spacing to be adjusted.

They devised a range of scenarios of ion transport through the cascading nanoslit system and how it was affected by structural geometry, which agreed with experiment data.

Simulations devised by the authors suggested that the material could be made tunable by adjusting the size of the spacings in the nanochannels.

"Although it was known that the behaviour of ion transport confined in nanochannels could be different to that in bulk, this had not been exploited in the context of an electrically conductive pore. Such materials based on graphene open exciting possibilities in materials science" said Garvey.

**More information:** C. Cheng et al. Ion transport in complex layered graphene-based membranes with tuneable interlayer spacing, *Science Advances* (2016). DOI: 10.1126/sciadv.1501272

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