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Exposing graphene?s surface without sacrificing quality

The synthesis of high-quality hexagonal-boron nitride (hBN) marked a turning point in two-dimensional (2D) materials research. By encapsulating a 2D material (for instance, graphene) in between hBN layers, the relevant 2D material is protected from harsh environmental degradation, ensuring its highest quality and unique functionalities.
Some applications, however, require direct access to the material surface. Yet removing the hBN layer is not an option, as it would severely compromise its quality. To overcome this limitation, ICFO researchers have now developed a new technique capable of selectively removing the top hBN layer while preserving the electronic quality of graphene. Their approach, reported in the Journal of Physics: Materials, opens the door to a wide range of applications such as high-resolution probing, biochemical sensing, and plasmonics.

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Experiments involving two-dimensional materials, which are just one atom thick, typically require protective layers to encapsulate them and preserve their exceptional electronic properties. A common configuration places graphene between two layers of hexagonal boron nitride (hBN): the bottom hBN protects graphene from rough substrates, and the top layer isolates it from the environment, maximizing device performance.

While this encapsulation strategy works remarkably well, certain applications demand direct access to graphene's surface -for instance, to probe it with high resolution techniques, or for biochemical sensing applications. However, partially removing the hBN to expose the surface dramatically degrades graphene's electronic quality -a price too high for researchers to pay.

Now, ICFO researchers **Dr. Hitesh Agarwal**, **Dr. Antoine Reserbat-Plantey**, **Dr. David Barcons Ruiz**, **Dr. Karuppasamy Pandian Soundarapandian**, **Dr. Geng Li**, **Dr. Vahagn Mkhitaryan**, **Dr. Johann Osmond**, **Dr. Helena Lozano**, **Dr. Petr Stepanov**, led by **ICREA Prof. Frank Koppens** and **Dr. Roshan Krishna Kumar,** have demonstrated a reliable method to selectively remove the top hBN encapsulant from graphene devices without significantly compromising graphene's exceptional electronic quality. Thus, the technique breaks for the first time the longstanding trade-off between protection and accessibility. The results, reported in the Journal of Physics: Materials, were obtained in collaboration with the Universite Cote d'Azur, the National Institute for Materials Science (Tsukuba, Japan) and the University of Notre Dame.

To achieve this milestone, the team first fabricated fully encapsulated hBN/graphene/hBN devices. They then patterned the regions where graphene would later be exposed. Before proceeding with etching, the researchers carefully cleaned the surface in a two-step process: first, removing resist residues, and then, mechanically sweeping away contaminants from the top hBN. Next, using the so-called SF? reactive ion etching method, they selectively removed the top hBN layer in the predefined areas, leaving the underlying graphene and bottom hBN intact.

i¿½We were very surprised by the quantum transport measurements of Hitesh that show
d graphene's electrons still move ballistically after this etching stepi¿½ shares Dr. Ro
han Krishna Kumar, lead author of the study. i¿½That's how he convinced us of the potenti
l and capabilities of this technique not just for device applications but also fundamental studi
si¿½,
e adds. In the end, **the etching method proved highly effective, enabling a controlled and clean exposure of chosen regions**. i¿½Now researchers will be able to fabricate hBN-encapsulat
d graphene devices and later expose graphene locally, on demand, while preserving i
s intrinsic qualityi¿½, shares Dr. Hitesh Agarwal, first author of the article. i¿½I think th
 next step for the field should be applying the technique to fundamental materials studi
s and device engineeri

Reference:

Hitesh Agarwal et al, In situ engineering hexagonal boron nitride in van der Waals heterostructures with selective SF6 etching, J. Phys. Mater. 8 045006 (2025).
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a-h) Schematics of the work flow presented in this work. Source: the Journal of Physics: Materials.