Nanoporous graphene for real-world gas sensing applications

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Bottom-up synthesised nanoporous graphene (NPG) [1] is a very promising material for applications in sensing, because of its technologically relevant bandgap (~1-2eV), high predicted intrinsic carrier mobilities [2], and a network of nanometer scale, atomically precise pores, which could serve as analyte interaction sites. However, the material has so far been grown and studied mainly in laboratory environment, far from operational conditions. Here, we demonstrate the key steps required to transition the material from laboratory-scale proof-of-concept devices and demonstrators, to real-world applications, encompassing large-area synthesis, investigation of stability and degradation pathways, and characterization of operational gas-sensing device arrays.

We demonstrate a scaled-up production process of high-quality NPG in a dedicated synthesis chamber. Samples with lateral sizes of about 2.5cm can be grown, preserving homogeneous material properties across macroscopic length scales. We systematically investigate NPG stability over long timescales (up to 6 months) by exposing the material to environmental factors relevant to its processing and applications, including air, humidity, light. The material initially seems to degrade rapidly in ambient air in the presence of ambient light, with the processes appearing both photo- and temperature-activated. Reactive gas-dosing experiments performed under ultrahigh vacuum, monitored by in-vacuum Raman and XPS spectroscopies, allow us to disentangle the effects of both factors, identify the destructive role of oxygen, and elucidate the material degradation pathways.

We then show that the material is stable in ambient conditions after transfer to silicon dioxide (SiO2), indicating that the degradation is linked to the catalytic activity of the Au(111) substrate, and paving the way towards its real-world deployment. Based on this result, we fabricate arrays of bottom-gate field-effect transistors with exposed NPG channels and evaluate their response under atmospheric pressure to several donor- and acceptor-type gases relevant for future applications, such as, nitric oxide, carbon dioxide, and carbon monoxide. We quantify performance metrics and their statistical variation across the arrays.

Our results show, that nanoporous graphene can be grown on large scale, with high quality and homogeneity, and is stable in ambient conditions after transfer to a technologically-relevant SiO_2 substrate. The potential of the NPG-based gas sensing devices is evaluated, demonstrating its potential for industrialization and downstream utilization.

References

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