Surface independent synthesis of nanographenes

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Rapid development and miniaturization of electronic devices forces to search for alternatives to current technologies. One of the promising concepts is based on application of organic materials like graphene nanoribbons (GNRs), nanographenes (NGs) or 2-dimensional molecular nanoarchitectures. They could be regarded as promising candidates for versatile tailor-made materials applicable in (opto)electronics, spintronics, gas storage or chemical sensing. For instance atomically precise GNRs exhibit promising electronic properties for post-silicon transistor technologies and nanographenes could be applied e.g. as nonlinear optical materials or conductive layers in optoelectronics. The development requires toolkits for efficient fabrication with reproducibility down to single atom level. Despite the continuous, rapid and extensive development of chemical synthesis, one of the bottleneckes limiting development originates from the ineffective or even unattainable wet chemistry synthesis of desired molecular units. Alternative solutions, e.g. surface chemistry, are currently in the development phase and, despite being successfully applied in prototype solutions, exhibit fundamental limitations that hamper their application implementation. One of the main problems is the incompatibility with technologically and application-critical semiconductor materials. This necessitates the development of complex and multi-stage construction pathways leading to the transfer of graphene-derived functional nanostructures synthesized on metallic substrates onto target semiconductor units.

We now report a strategy, which may pave the way to overcoming this barrier by conducting the efficient synthesis of graphene-based nanoflakes and GNRs directly on a wide range of technologically attractive substrates, including semiconductors, metals and insulators [1, 2]. This is achieved by transferring the catalytic activity from the metallic substrates into externally dosed atomic hydrogen, which takes over the indispensable role of a catalyst. The proposed solution enables conversion of molecular precursors generated by wet chemistry synthesis into the desired graphene-like nanostructures with high efficiency and without involving the substrate. For this reason, our approach gives attractive prospects for combination of technologically relevant semiconductor/insulator substrates and well-controlled and developed solution chemistry providing flexible and tunable molecular precursors as building blocks for precisely designed graphene-based target units. The proposed pathway creates the foundations for the effective implementation of the final synthetic step providing the necessary graphene-derived systems with precisely defined structure, as well as electronic, magnetic and chemical properties.

In the proposed approach flexible molecular precursors are deposited on a surface of selected crystals in ultra high vacuum (UHV) conditions. These precursors are subsequently transformed into planar graphene – based units by application of atomic hydrogen as a catalyst for cyclodehydrogenation reaction in relatively mild conditions at approximately 220 °C. This process leads to efficient planarization yielding desired nanographenes and has been optimized on a range of substrates including metals (gold), semiconductors (titanium dioxide, hydrogenated germanium) or insulators (silicon dioxide), which are widely applied in (opto)electronics, photovoltaics and catalysis.

Independence from the catalytic role of the substrate gives hope for further development of the approach with prospects for efficient synthesis of graphene-derived systems on a larger scale and also in powder form for various applications.

The key aspect of the uniqueness of the proposed solution is its complete independence from the influence of the substrate on which the synthesis is carried out thanks to the use of atomic hydrogen as a catalyst. This paves the way toward synthesis of nanographenes and GNRs directly on the desired substrates or functional devices.

graphene nanoribbons, nanographenes, atomically precise synthesis, atomic hydrogen, hydrogen as a catalyst

[1] patent applications: “A method for producing graphene nanostructures”, PCT/EP2023/060258,
A method for producing graphene nanostructures US 18/855,341

[2] R. Zuzak et al. Nat. Commun. 16 (2025 691 “Cyclodehydrogenation of molecular nanographene precursors catalyzed by atomic hydrogen”.