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Carbon Nanomaterials Formed by the Catalytic Cracking of Methane

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Hydrogen is predicted to become a major source of energy in the future [1]. Existing methods of hydrogen production from either natural gas (steam reformation) or coal (gasification combined with water-shift reaction), however, generate significant amounts of unwanted carbon dioxide or carbon monoxide by-products. The alternative approach of direct cracking methane to hydrogen and carbon ($CH_4 \rightarrow 2H_2 + C$) over a catalyst provides a clean method of producing hydrogen from methane rich gases, such as natural gas and bio-methane, without the emission of CO_2 or CO. More importantly, this process captures the carbon content of methane in its elemental form, resulting in the creation of a diverse range of carbon nanomaterials (see Fig. 1) with potential applications in lubricants, reinforced composites or nanoelectronics.

The carbon structures have been studied using various characterization techniques including SEM, TEM, XRD and Raman spectroscopy. Analysis of the material by SEM revealed that the individual carbon structures have a predominantly rounded morphology and form large interconnected surfaces. TEM imaging revealed that the carbon forms a diverse range of structures including onions, tubes, spirals, chains and sheets (Fig. 1). The carbon is graphitic (Fig. 2), and many of the carbon structures encapsulate catalyst particles (Fig 1 and Fig 2). One of the major goals of the project was to investigate the abundance of each nanostructure and any relationship that exists between the composition of the encapsulated catalyst and the shape of the carbon formed, with a view to tailoring the process to the production of specific carbon structures.

Energy-filtered TEM (EFTEM) tomography has been applied to further investigate the 3D morphology of the carbon nanostructures by reconstructing a tilt sequence of carbon elemental maps (Fig. 3). EFTEM, EELS and HRTEM have also been used to investigate the composition and structure of the catalyst particles.

References

[1] J.N. Armor, *Appl. Catal. A* 176 (1999) 159.
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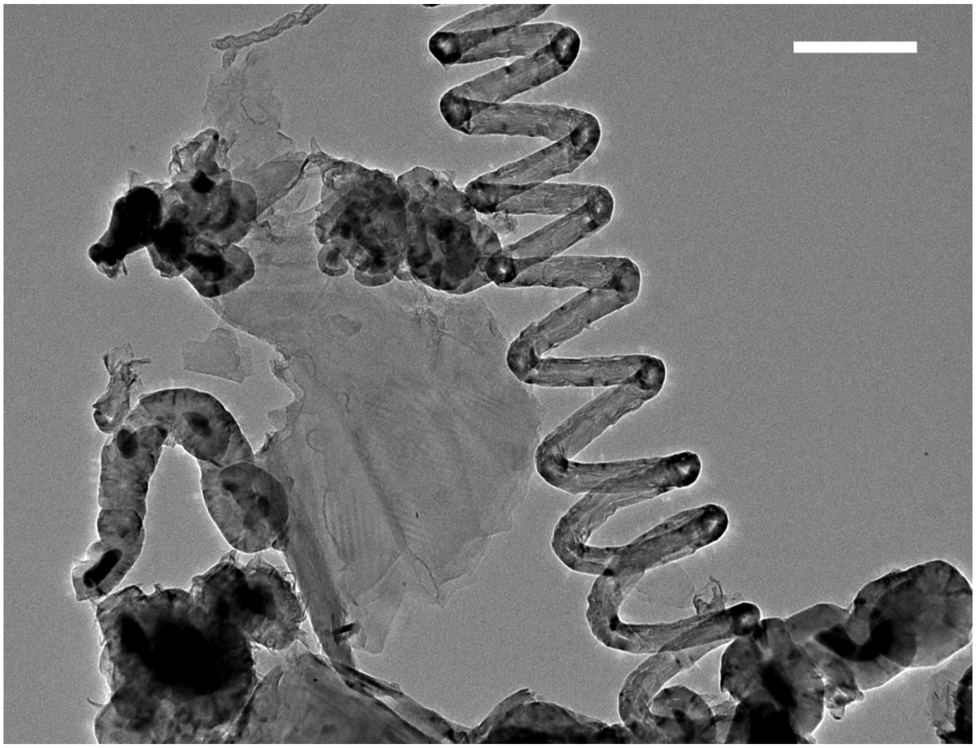

FIG. 1. TEM image showing the different carbon nanostructure morphologies present. Encapsulated catalyst particles can be observed in some of the carbon materials. Scale bar: 100 nm.

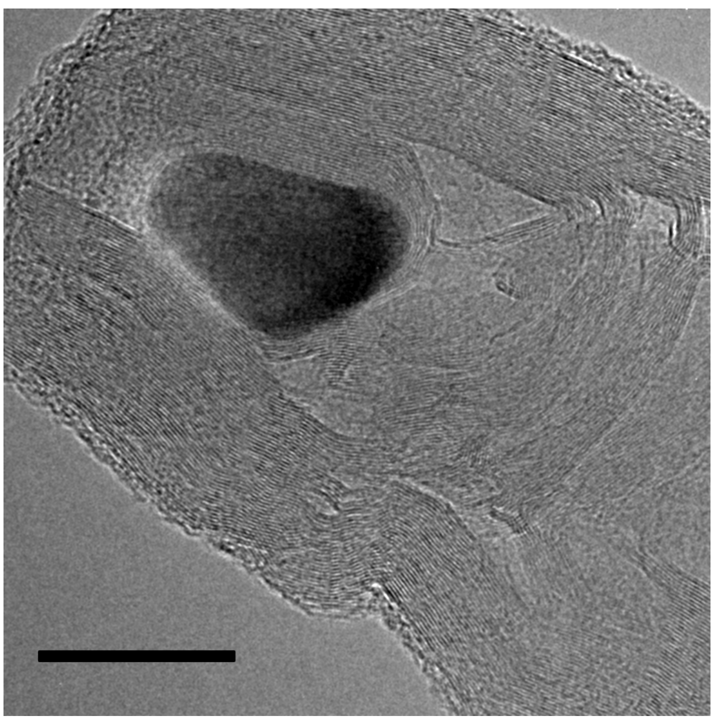

FIG. 2. HRTEM image showing graphitic nature of the carbon encapsulating a catalyst particle.
Scale bar: 10 nm.

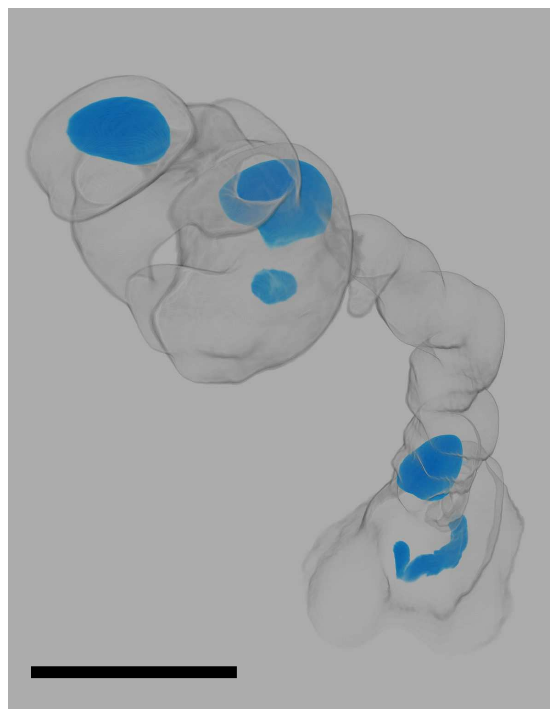

FIG. 3. Tomographic reconstruction showing 3-d morphology of the carbon surface and encapsulated catalyst particles (blue). Scale bar: 200 nm.

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