

## Production methods of carbon materials

Nowadays, a lot of methods were developed to fabricate carbon nanomaterials. However, the most interested ones in recent times are using energy saving reactions and low-cost starting materials. The majority of carbon materials are derived from carbon rich organic precursors by heat treatment in inert atmospheres (a process referred to as carbonization). The ultimate properties of these carbons are dependent on a number of critical factors, e.g., the carbon precursor, its dominant aggregation state during carbonization (i.e., gas, liquid or solid), processing conditions, and the structural and textural features of the products.

During carbonization, carbon precursors go through a thermal decomposition (pyrolysis), which eliminates volatile materials that include heteroatoms. With increasing temperature, condensation reactions are initiated and localized graphitic units commence to grow and become aligned into small 'graphite like' microcrystallites, i.e., stacks of aromatic layers or 'graphene sheets'. The carbon precursor and its processing conditions will determine the size of the graphene sheets, the stacking number of graphene sheets and the relative orientation of the crystallites. The size and orientation of the crystallites are very important as they define the materials' texture and the degree of electrical conductivity.

Some carbon precursors (e.g., petroleum pitch, coal pitch, some polymers) pass through a fluid stage (referred to as mesophase) during carbonization that allows large aromatic molecules to align with each other and form a more extensive pre-graphitic structure. Upon further high-temperature treatment ( $>2500^{\circ}\text{C}$ ), these carbons can be converted into highly ordered graphite and are referred to as graphitising carbons. Other carbon precursors retain a solid phase during carbonization, and the limited mobility of the crystallites leads to the formation of a rigid amorphous structure that consist of randomly-oriented graphene layers. These materials cannot be readily converted to graphite by further high temperature treatment and are referred to as non-graphitizing carbons. Non-graphitizing carbons are produced from materials such as biomass (e.g., wood, nut shells, etc.), non-fusing coals and many thermosetting polymers (e.g., polyvinylidene chloride, PVDC). The loss of volatiles and the retention of a rigid and complex molecular structure during the carbonization of many non-graphitizable carbons can lead to a highly porous structure without the need for further activation.

One of the great attractions of using carbon as an electrode material in devices is that it can be readily converted into a form that has very high specific surface-area. Generally speaking, the process employed to increase surface area (and porosity) from a carbonised organic precursor (a 'char') is referred to as 'activation' and the resulting broad group of materials is referred to as activated carbons. Chars usually have a relatively low porosity and

their structure consists of elementary crystallites with a large number of interstices between them. The interstices tend to be filled with 'disorganized' carbon residues (tars) that block the pore entrances. Activation opens these pores and can also create additional porosity. Varying the carbon precursor and activation conditions (particularly temperature, time and gaseous environment) allows some control over the resulting porosity, pore-size distribution, and the nature of the internal surfaces.

Activated carbons are generally prepared in two steps. These steps are carbonization of the starting raw materials and followed by carbon activation through chemical or physical methods. In the carbonization step or process, the raw materials are thermally decomposed, removing all other species that are non-carbon and creating fixed carbon mass with a very small pore structure. The other step (activation method) is usually carried out to enhance the diameters of the small pores by increasing the area and also to generate new pores. It is normally achieved through chemical or physical means. Chemical activation is generally accomplished through thermal disintegration of the precursor impregnated with mostly KOH, H<sub>3</sub>PO<sub>4</sub>, ZnCl<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, NaOH.

However, physical activation also popularly known as thermal activation is conducted using an oxidizing gas CO<sub>2</sub> to activate the carbon material after carbonization in the temperature range between 800 to 1100°C. The analytical pyrolysis or carbonization of the material is usually conducted in a tube furnace, muffle furnace and glass reactors sited in a modified microwave oven. Currently, the majority of the precursors used in the production of activated carbon are mostly originated from lignocellulosic materials such as wood, coconut shells, palm oil wastes, etc.

One of the most speculated and researched nanomaterials, graphene in the past decade. It should be recalled that since its isolation in 2004, several methods have been employed for the manufacture of graphene which includes micromechanical cleavage, epitaxial growth on SiC substrates, chemical reduction of exfoliated graphene oxide, chemical vapor deposition (CVD) liquid phase exfoliation of graphite, electrochemical exfoliation of graphite, and unzipping of carbon nanotubes etc. Each method has proven its merits and limitations, respectively, depending on its intended application. The influence of graphene as the future material for the fabrication of lightweight, miniaturized, ultra fast and high frequency electronic and optoelectronic devices has been forecasted as a brighter one. However, this can only be achieved if the quality of the 2D material is not compromised during its production. Therefore, the most suitable form of this material for this kind of

applications is considered to conform with a few layers thin films of large area graphene with great domain size and consistent thickness, absolutely pure and devoid of any form of structural disarray. For this reason, the only method that can be considered suitable to fabricate graphene with most of the qualities mentioned above is by the use of chemical vapor deposition (CVD).

Carbon nanotubes (CNTs) are produced by arc discharge, laser ablation, high-pressure carbon monoxide disproportionation, and chemical vapor deposition (CVD) methods. Most of these processes take place in a vacuum or with process gases. CVD growth of CNTs can occur in vacuum or at atmospheric pressure. Large quantities of nanotubes can be synthesized by these methods; advances in catalysis and continuous growth are making CNTs more commercially viable. Several carbon precursors, including xylene, acetylene, toluene, methane, benzene etc. have been used as a carbon source to synthesize carbon nanotubes. However, it is alarming that these carbon feed stocks are fossil fuels-based materials; therefore, they are not renewable and sustainable.

## References

1. *Journal of Power Sources* 157 (2006) 11–27.
2. *Applied Surface Science* 357 (2015) 696–703.

