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Catalyst free silica templated porous carbon nanoparticles from bio-waste materials†

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Porous Carbon Nanoparticles (PCNs) with well-developed microporosity were obtained from bio-waste oil palm leaves (OPL) using single step pyrolysis in nitrogen atmosphere at 500–600 °C in tube-furnace without any catalysis support. The key approach was using silica (SiO_2) bodies of OPL as a template in the synthesis of microporous carbon nanoparticles with very small particle sizes of 35–85 nm and pore sizes between 1.9–2 nm.

In modern-day scientific applications, porous nanocarbons are ubiquitous and indispensable. Porous carbon,[1] carbon nanotubes,[2] fullerenes,[3] and graphenes[4] formed an innovative class of nanocarbons having various applications in electronics,[5] environment,[6] energy,[7] and catalyses,[8] *etc.* Porous carbons can be classified according to their pore diameters as microporous (pore size <2 nm), mesoporous (2 nm < pore size < 50 nm), and/or macroporous (pore size >50 nm).[9] The nanoporous carbons are fabricated by templating methods.[10] In template synthesis, an artificial silica template is formed along with the carbon source. Afterward, the template is carbonized and the excess silica is removed *via* a chemical process to obtain porous carbon.[11] However, the template and the carbon sources are usually two incompatible materials.[12] Hard-templating and soft-templating are the two main templating methods used in the fabrication of porous carbons; both these methods have certain limitations and drawbacks.[13] The synthesis route involves the impregnation of a silica template with a carbon precursor followed by the carbonization of the resulting composite and template removal known as hard template.[14]

The silica based template is commonly used to fabricate the well-developed porous carbons because silica have natural porous structures and provide an appropriate platform for porous carbon fabrication.[14] Resorcinol formaldehyde, furfuryl alcohol, phenol, and sucrose are mainly used as carbon precursors and inorganic templates, including zeolites, colloidal silica, and mesoporous silica.[15] In this two-step template synthesis, the porous carbons have precise pore size and pore structure but have certain limitations such as high cost, time consuming infiltration steps, and the formation of nonporous carbon on template.[16] One-step template synthesis of porous carbon carried out by the carbonization of organic aerogels (supercritical CO_2)[17] and the nanocomposite of carbon precursor and silica precursor was followed by polymerization and carbonization steps.[18]

Herein, we describe a new carbon precursor referred to as oil palm leaves (OPL), a waste lignocellulose biomass from oil palm industries which is abundant in south-east Asia.[19] OPL consists of 47.7% holocellulose, 44.53% α-cellulose and 27.35% lignin and extractives of around 20.60%.[20] We have analysed the distribution and locations of silica particles in OPL using electron microscopy (FESEM) (Fig. S1a–d, ESI†) and energy dispersive X-ray (EDX) analysis. The EDX result estimate was around 13.30% of silica in raw OPL (Fig. S1e, ESI†). The silica particles are accumulated in the epidermal tissue or the cell wall of leaves where transpiration induces loss of water, which in turn increases the concentration of silica.[21] The occurrence of Si within the plant is because of its uptake, in the form of soluble $Si(OH)_4$ or $Si(OH)_3O$–, from soil and its controlled polymerization at a final location.[22] The individual silica bodies consist of about 100 000 silica rods, and the silica particles in each rod have a diameter of 1–2 nm.[23]

The FTIR analysis of OPL revealed the presence of the Si–H bond; namely the absorption bands at 655 cm^{-1} are attributed to the stretching mode of the mono-hydrogen bond (Si–H).[24] An absorption band at 1409 cm^{-1} appearing for Si–CH_3 confirms the presence of Si in OPL (Fig. S2a, ESI†). The Si–O vibrations at 1050 cm^{-1} are because of stretching vibration where the

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