Facile Approach to Magnetic Carbon Nanoparticles Using an Iron-Doped Polymer Precursor

Hyeonseok Yoon, *Jyongsik Jang*[*]

[1]Hyperstructured Organic Materials Research Center, School of Chemical and Biological Engineering, Seoul National University, Seoul, 151-742 Korea
jsjang@plaza.snu.ac.kr

Introduction

Currently, the large-scale production of nanomaterials with well-defined size and functionality is a great challenge in contemporary material science. Owing to the beneficial characteristics such as high magnetic anisotropy, enhanced coercivity, and the environmental protection of magnetic elements, magnetic carbon nanoparticles (MCNPs) have elicited a considerable interest over the last several decades. Nevertheless, MCNPs have been restricted in their practical applications due to a lack of a simple and reproducible synthetic method that allows the production of pure and uniform nanoparticles in bulk quantities. Although carbon-coated magnetic nanoparticles have been fabricated by arc-discharge techniques, most of these approaches have revealed irreproducible yields due to the generation of by-products such as carbides, graphitic flakes, and carbon nanotubes [1,2]. Herein, we report a breakthrough to fabricate large quantities of MCNPs with uniform size.

Experimental

Iron-doped polypyrrole (PPy) nanoparticles were used as the carbon precursor to generate MCNPs. In a typical synthesis, DTAB(47.5 g, 154 mmol) was stirred in the mixture containing decyl alcohol (37.5 g, 237 mmol) and distilled water (1 L) at 3°C. Subsequently, pyrrole (12.5 g, 186 mmol) was added dropwise to the surfactant solution, and ferric chloride (70.1 g, 432 mmol) was introduced into the pyrrole/surfactant solution. The chemical oxidation polymerization of pyrrole monomer was conducted for 2 h at 3°C. The resulting product was thoroughly washed with ethanol to remove the surfactant and other reagents and dried in a vacuum oven at room temperature. The amount of final product was very large as 12 g with a yield of 95 %. The carbonization process of the iron-doped polymer precursor was carried out in a quartz tubular furnace under nitrogen atmosphere. The sample was heated up to 850°C at a heating rate of 3°C min^{-1}, held for 5 h and then cooled to room temperature. Approximately 6 g of MCNPs could be obtained from 12 g of PPy precursor (a char yield of 50 %).

Results and discussion

Conductive PPy nanoparticles could be prepared by chemical oxidation polymerization in the nano-scale domains of micelle cores. Dodecyltrimethylammonium bromide (DTAB) was used to form micelles as the nanoreactor, and decyl alcohol was selected as a cosurfactant. Furthermore, PPy nanoparticles were transformed into MCNPs through carbonization process under the presence of iron-based species. This synthetic strategy using iron-doped polymer nanoparticles as the carbon precursor makes it possible to fabricate monodisperse MCNPs without any sophisticated encapsulation process [3,4].

Figure 1 displays a transmission electron microscopy (TEM) image of PPy nanoparticles. The TEM image revealed that PPy nanoparticles had a uniform diameter of 62 nm. The monodisperse PPy nanoparticles were synthesized by the chemical oxidation polymerization using ferric chloride ($FeCl_3$) as an oxidizing agent. During the polymerization process, iron cations are capable of forming a chelate complex with lone electron pairs on PPy chains because they are hard acid as well as potent Lewis acid [4]. The elemental analysis and the energy dispersive X-ray spectroscopy (EDX) analysis of PPy nanoparticles proved the presence of C (55.7 %), N (16.0 %), and Fe (2.5 %). These iron-doped PPy nanoparticles could be readily converted to MCNPs via the carbonization process at 850 C. A char yield was approximately 55 % under our experimental condition. Figure 2 exhibit TEM images of MCNPs in low- and high-magnification. The TEM images revealed that MCNPs was reasonably monodisperse and the average diameter was 48 nm. The textural and magnetic properties of MCNPs could be clarified through several instrumental analyses.

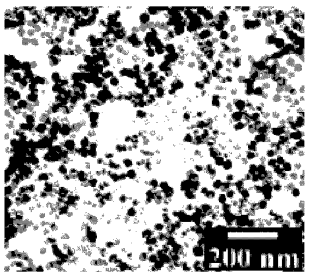

Figure 1. Transmission electron microscopy (TEM) image of PPy nanoparticles.

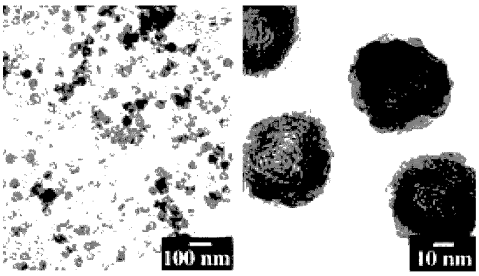

Figure 2. TEM images of MCNPs.

Conclusions

Multigram-scale fabrication of MCNPs could be readily achieved via the carbonization of an iron-doped polymer precursor. Importantly, our approach might be expanded to allow the large-scale manufacture of various nanoparticles with controlled dimensions.

References

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