Ellipsoidal Carbon Capsules Encapsulated Magnetite Nanorods

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A novel ellipsoidal carbon capsules, with submicrometer sized Fe3O4 nanorods inside, were fabricated by in situ carbonization-reduction process from sandwich α-Fe3O4@Air@ polypyrrole ellipsoidal spheres in vacuum at 823 K.

Since the discovery of carbon nanotubes1 in 1991, there has been a worldwide interest on hollow carbon products owing to their applications in broad areas of science and technology.2 Encapsulating second phase inside carbon hollow structures has been particularly focused on because carbon shell can immunize the encapsulated species against environmental degradation effects while retaining their intrinsic properties.3 Accordingly, magnetic elements or compound-encapsulated capsules are important materials of information technologies and biomedicines.4 The preparation of magnetic encapsulation core–shell capsules includes two routes: one-step and two-steps. The former, such as various modified pyrolysis techniques from complex compounds or organic–inorganic composites, is simultaneous preparation of carbon shell and magnetic core.5 The later involves the coating or filling of magnetic species into hollow structures.5 Up till now, although a number of carbon capsules have been reported, nonspherical hollow capsules have received much less attention. Previously, we reported the fabrication and characterization of sandwich Fe3O4@Air@polypyrrole ellipsoidal particles.6 Based on that work, novel ellipsoidal hollow carbon nanocapsules with movable magnetic cores have been successfully fabricated by in situ carbonization-reduction process in vacuum.

In a typical fabrication of Fe3O4@Air@C capsules, the ellipsoidal α-Fe3O4@Air@PPy core/shell precursor particles were firstly prepared as previous report.7 The pre-synthesized α-Fe3O4@Air@PPy capsules were placed in a quartz tube, then vacuum sealed and heated at a heating rate of 1 K/min. After 3 h of carbonization at 823 K, the quartz tube was cooled to room temperature on standing. Magnetic capsules were obtained after opening the sealed tube.

Fe3O4@Air@C capsules are shown in TEM image (Figure 1c). They inversely replicate the shape of the template particles (Figure 1a). And they have uniform ellipsoidal morphology with the narrow size distribution (See, Support Information, Figure S1).13 Because the hollow cavity of capsules provides enough space, submicrometer size of Fe3O4 nanorods with 450–120 nm length–width are encapsulated movably inside the capsules. The average diameter of carbonized nanocapsules is about 730/360 nm. Their carbon wall thickness is easily controllable because the polypyrrole wall thickness of the α-Fe3O4@Air@PPy template capsules has been realized between 20 to 60 nm.3 Therefore, the thickness of carbon wall after the carbonization

![Figure 1. TEM images of α-Fe3O4@Air@PPy (a) and Fe3O4@Air@C capsules with the 55 (b), 25 (c), and 15 (d) nm thickness carbon shell.](image-url)
for bulk magnetite particle. The coercivity of Fe is large. It is known that the coercive force is 500–800 Oe content in the carbon capsules, the coercive force for this sample (see inset in Figure 3), respectively. Considering the iron oxide nanorods encapsulated in the carbon cavity, has been measured in 300 K using a superconducting quantum interference device (SQUID) magnetometer. The saturation magnetization for FeO/C0 index.html 1.1770.

Figure 2. XRD patterns for Fe2O3@Air@PPy (a) and Fe3O4@Air@C (b) particles.

In summary, uniform ellipsoidal Fe3O4@Air@C capsules, with movable submicrometer sized Fe3O4 rod cores inside, were fabricated by in situ carbonization–reduction process in vacuum at 823 K. The wall thickness of Fe3O4@Air@C capsules can be controlled between 15 and 55 nm. It was found that Fe3O4@Air@C capsules were ferromagnetic at room temperature, which indicates that they may have important potential applications in biomolecular delivery or electromagnetic nanodevices, such as anisotropic colloidal particle assembly under exterior magnetic field.

The significance for the fabrication of ellipsoidal carbon capsules with magnetic rods inside from the sandwich α-Fe2O3@Air@PPy template is the in situ carbonization–reduction process. Because of the synchronous process of carbonization of polymer wall and the reduction of hematite cores, no additional reducing regent was needed during the reducing process of hematite cores, leaving to the Fe3O4@Air@C capsules without byproducts. It is a convenient route to obtain magnetic carbon capsules without further purifying.

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References and Notes