Study of carbon encapsulated iron nanoparticles produced by a modified arc discharge by applying nitrogen, argon and helium

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The influences of nitrogen, argon, and helium on the particle size, composition, crystallinity, and the magnetic properties of carbon encapsulated iron nanoparticles (CEINPs) produced at near-atmospheric pressure conditions ($5–8{\cdot}10^4$ Pa) were studied in this project. Core size and shell thickness have a direct effect on magnetic properties and on oxidation prevention of iron core, respectively. The observations by TEM and SEM revealed a straight relation between the nature of the inert gas and the sizes of both iron core and carbon shell. Energy-dispersive X-ray analysis (EDX) and electron energy loss spectroscopy (EELS) provided composition and elemental mapping of CEINPs. Raman Spectroscopy was used to study the degree of carbon order-disorder. Influences of nitrogen and argon on the plasma region evidenced higher evaporation of carbon content comparing to helium plasma. Consequently, large spherical carbon shell of 220 nm, 188 nm, and 41 nm encapsulate iron cores when nitrogen, argon and helium have been used, respectively (Figure 1). Ultra small iron core were synthesized by using nitrogen (2.5 nm) and argon (3.4 nm), while three fold bigger iron cores (7.7 nm) obtained when helium plasma was used (Figure 2). Argon provides important effects on the structure of Fe@C nanoparticles [1]. Applying only argon demonstrates most size monodispersion and spherical shape of iron core (Fe core size: 3.4 ± 0.7 nm). Based on the Raman Spectroscopy results, best carbon crystallinity is observed when argon has been used and followed by applying nitrogen and helium. All the particles show a superparamagnetic behavior at temperatures above 225 K as determined by SQUID measurements (Figure 3) which opens the possibility of room temperature applications. The lower blocking temperature of samples with smaller iron core has been observed in line with TEM observations. Moreover, magnetic diameters using nitrogen, argon and helium (2-7 nm range) were similar to the core diameters observed by TEM. EELS and EDX analysis showed no trace of oxygen in iron cores, hence samples were well protected by carbon shells. It has been reported that a particle size range of 50–300 nm is strictly demanded and desired due to the diameter limitation of capillary walls [2]. Moreover, an optimum geometry for endocytotic uptake is 50 nm and spherical shape [3,4]. Our particles fulfilled the requirements of drug delivery applications in terms of size and shape. In addition, carbon shells are biocompatible and thermally stable, and they can be functionalized to receive suitable organic radicals. It is also concluded that the gas nature of the arc discharge reactor used in the research project has significant effect on the morphological properties of CEINPs. Accordingly, CEINPs can be synthetized based on the desired applications in biomedicine such as drug delivery, imaging and hyperthermia.

References

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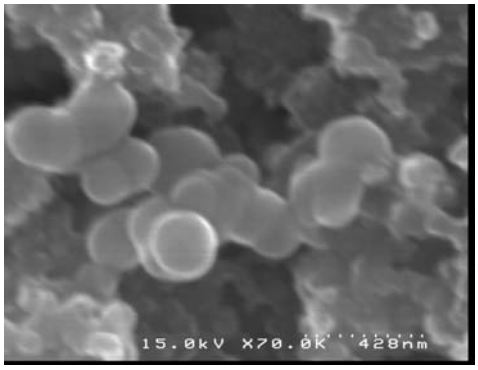
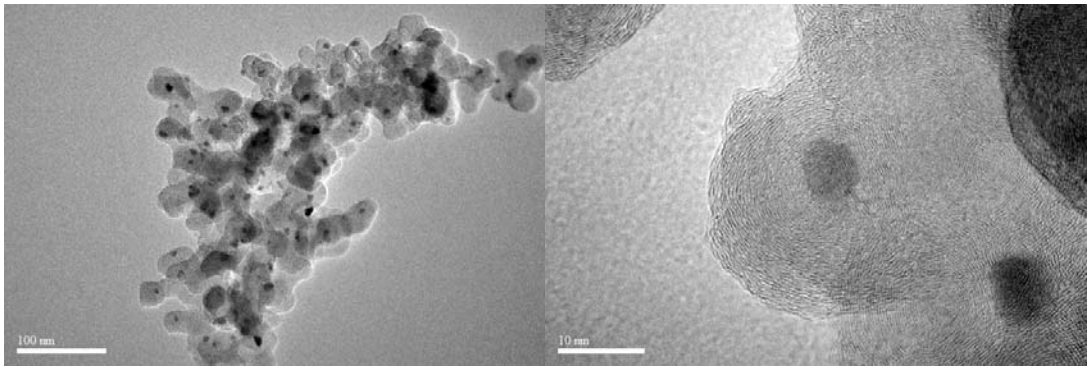
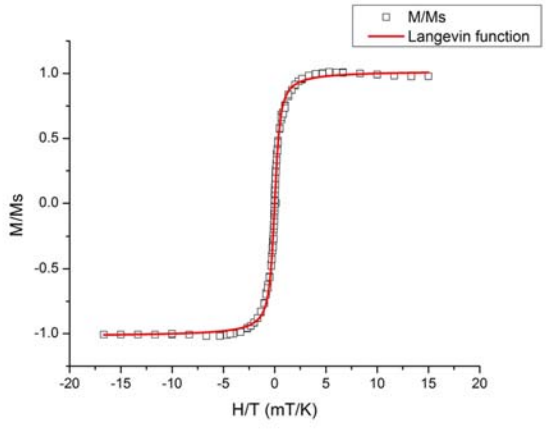


Figure 1. SEM image of spherical CEINPs



A **B**

Figure 2. A: TEM overview of CEINPs, B: HTEM image of iron at carbon shell



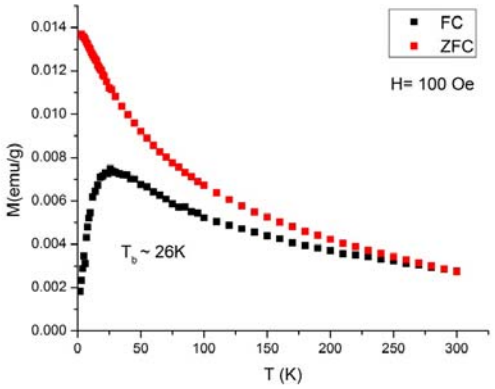


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Figure 3. A: Hysteresis loop of CEINPs at room temperature, B: Zero-field-cooled and field-cooled magnetization curves