Correlation between current applied and crystallinity of carbon in Fe@C nanoparticles obtained by plasma arc

Noemí Aguiló-Aguayo, Enric Bertran

FEMAN Group, IN^{2}UB, Martí I Franquès 1, Barcelona, Catalonia, Spain
noemiaguilo@ub.edu

In recent years, a wide range of interesting materials in the nanoscience and nanotechnology field has been developed. Among them, carbon-based nanostructures, such as fullerenes, carbon nanotubes (CNTs) or carbon encapsulated magnetic nanoparticles (CEMNPs) should be emphasized as one of the most promising materials due to their unique properties and expected applications in biomedicine, electronics, chemical processing or energy storage [1-4].

All methods used to synthesize this kind of nanostructures aim for high purity and uniformity in morphological and structural properties. The degree of crystallization has been deeply studied in carbon nanostructures; Raman spectroscopy has been widely used in order to characterize them [5, 6]. There are several mechanisms to achieve higher crystallization in carbon-based nanomaterials. For example, it is known that annealing treatments may promote a higher degree of carbon crystallization [7]. Besides, the use of metal nanoparticles [8, 9] or even a specific buffer gas [10] during the growth process may act as a catalyst to aid in the carbon crystallization.

Here we present CEMNPs produced by the plasma arc technique. Different currents (15 A, 25 A and 40 A) have been applied in order to observe the dependence between carbon crystallization and the arc current. Transmission electron microscopy (TEM) observations reveal a high yield of iron nanoparticles embedded in a carbon matrix (Fe@C) depending on the current applied. It is shown that lower currents involve the generation of a large ratio of iron nanoparticles in comparison with the carbon content. In contrast, high-resolution transmission electron microscopy (HRTEM) images (fig. 1) show better carbon crystallization of CEMNPs when higher currents are used.

Micro-Raman (MR) spectroscopy using an ion-Ar laser excitation of 514.4 nm, an objective magnification of X50 and an incident power of 2 mW, has been carried out into the different samples (fig. 2). The found D and G peaks are located at 1349 cm^{-1} and 1604 cm^{-1} Raman shifts, while, for graphite, peaks are positioned at 1350 cm^{-1} and 1582 cm^{-1}, respectively [11]. The up-shift of the G band may be due to some disordered of the system [12]. The higher intensity spectrum corresponds to the sample obtained at 25 A. In addition, in order to assess the degree of crystallinity in carbon samples we have depicted I_D/I_G versus the current applied (inset fig. 2). Lower I_D/I_G ratio corresponds to the sample obtained at 25 A, which means that higher carbon crystallinity is achieved at this current value.

Comparing TEM and HRTEM results with MR analysis, we conclude that higher currents produce better local carbon crystallinity but in contrast, it also leads to an increase of carbonaceous species. We reasoned that there are two mechanisms involved in the catalytic carbon crystallization of the samples, the ratio of iron nanoparticles and the temperature used during the synthesis process. Higher currents imply increased temperatures during the process, thus higher degree of crystallization surrounding the iron nanoparticle. However, more carbon atoms from the graphite electrodes are ejected in a non-crystalline state promoting lower carbon crystallinity on the whole sample. In contrast, low currents such as 15 A are not enough to create a crystalline carbon coating. On the other hand, currents of 25 A evaporate metal and carbon together, the amount of iron nanoparticles cooled versus carbon segregated onto the surface is closer than for higher currents. Further studies are required, but these first results point to an existence of an optimum value between the current applied and crystallinity of carbon in CEMNPs produced by plasma arc, suitable for obtaining higher qualified samples.

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Figures

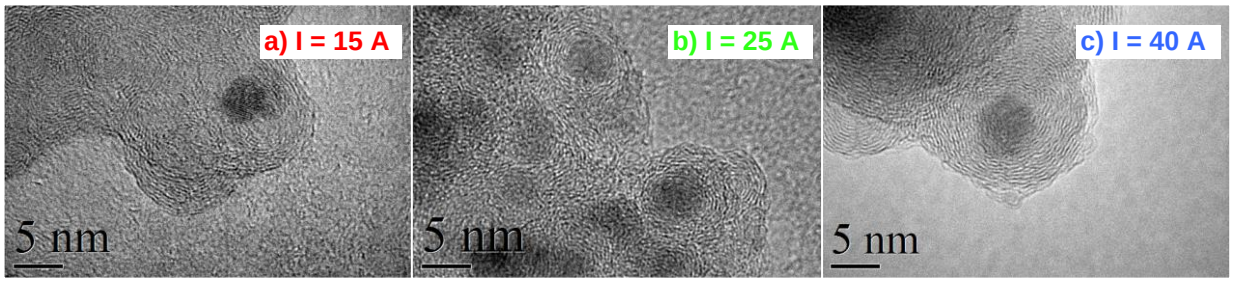

Fig. 1. HRTEM images of CEMNPs nanoparticles from different samples. Image (a) corresponds to a sample obtained by using a current applied of 15 A, (b) of 25 A, and (c) of 40 A.

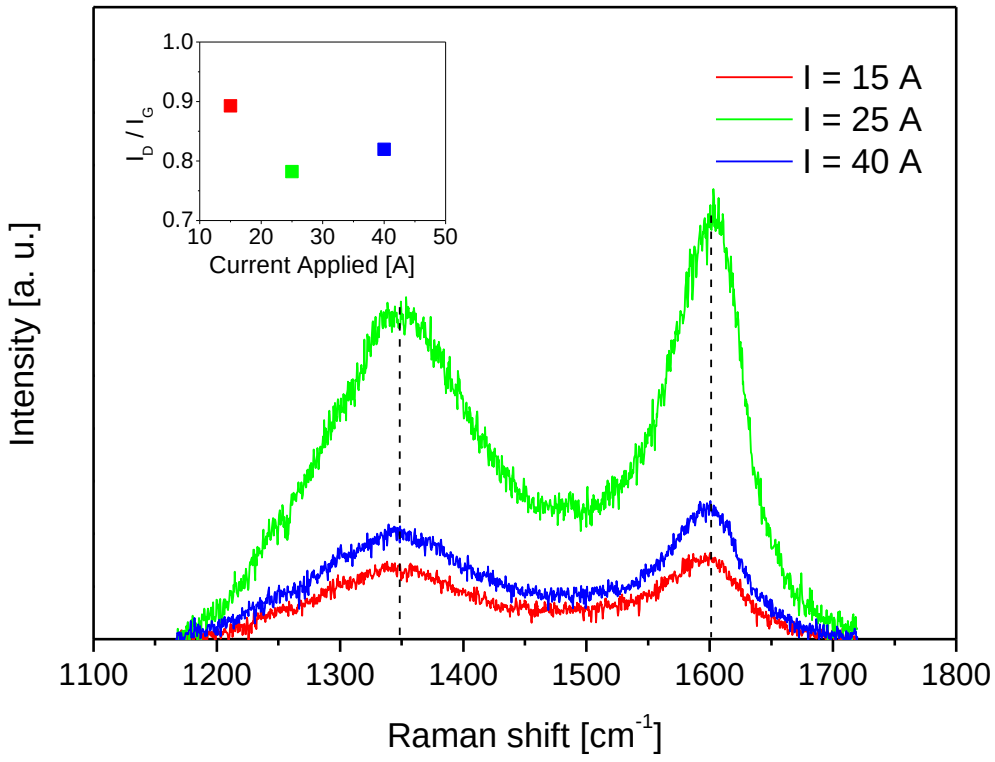

Fig. 2. Raman spectra of the three different samples obtained at 15, 25 and 40 A.