Multiwall Carbon Nanotubes Continuously Filled with Micrometer Length Single Crystals of Ferromagnetic α-Fe

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Multiwall carbon nanotubes (MWCNTs) continuously filled with single crystals of the ferromagnetic phase α-Fe were produced with a new chemical vapor deposition approach.
We report a new perturbed vapor method of synthesis in which the MWCNTs nucleate and form in a flower-like arrangement departing from homogeneously nucleated particles (See Fig.1). These particles are produced by the creation of a local perturbation in a vapor with a high density of Fe and C species obtained from the pyrolysis of a laminar ferrocene/Ar flow. Single-phase filling was achieved by a post-synthesis annealing at 500 ºC for 15 hours in Ar flow.
Previously reported synthesis routes use steady-state conditions to guarantee single crystals continuity but result only in small (less than one-micrometre length) single crystals comprising isolated or mixed phases of either α-Fe, Fe_3C, or γ-Fe [1-5].
Here, in this new method, a local perturbation was created by a hole in an otherwise flat substrate. This perturbation induces the homogeneous nucleation of nanoparticles when the pyrolysing ferrocene/Ar vapor reaches particular super-saturation conditions. We demonstrate that these conditions can be reached by using high quantities of ferrocene and low vapor flow rates.
Once deposited in the substrate, the homogeneously nucleated particles play a fundamental role in the growth of the continuously filled flower-like structures.
The large cross-sections of the flower-like structures growing from these particles ensures high capture and delivery feedstock to the base, and the absence of close packing in the emerging MWCNTs ensures a well-defined vapor-capture volume at the tips.
Transmission electron microscopy (see Fig. 2) investigations revealed that the continuous single crystals present a diameter much lower than the critical diameter for a single magnetic domain of α-Fe (~ 66 nm).
The single crystals show mainly a diameter of ~ 30 nm and ~ 55 nm, with uniform single crystals/MWCNTs-walls interfaces and an average length of 19-21 μm.
DC magnetization measurements at 5 K show that the flower-like structures present a very high saturation magnetization of 189.5 emu/g and a high coercivity of 580 Oe.
These ferromagnetic-systems can be ideal candidates for many magnetic applications. For example in magnetic data recording for quantum disk fabrication, as probes for magnetic force microscopy, or for enhancement of the magnetic loss in microwave absorption applications, enhancement of the torque when placed in a constant magnetic field, and oscillatory response on a time-varying magnetic field.

References

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Figures

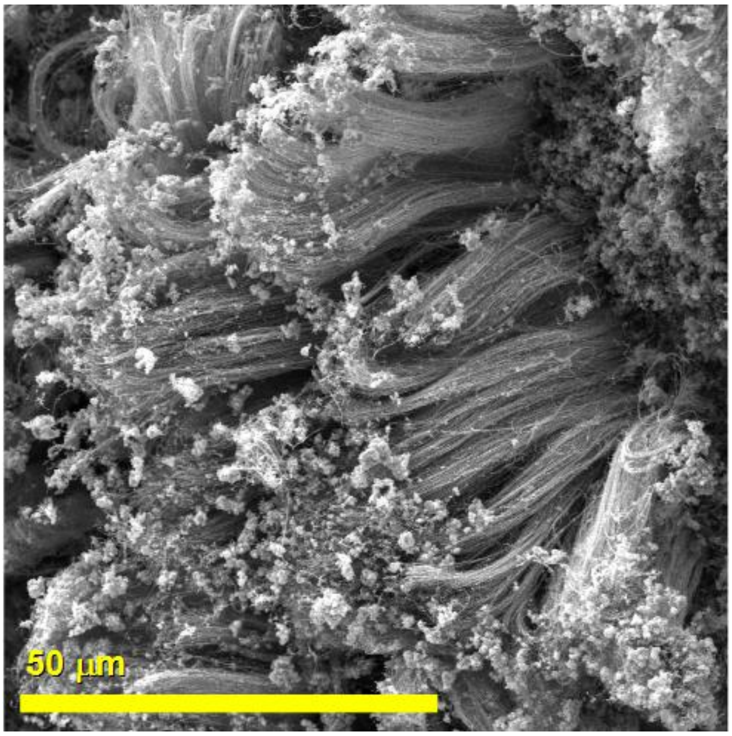

Fig.1: Scanning electron micrograph showing the multiwall carbon nanotubes arranged in flower-like structures.

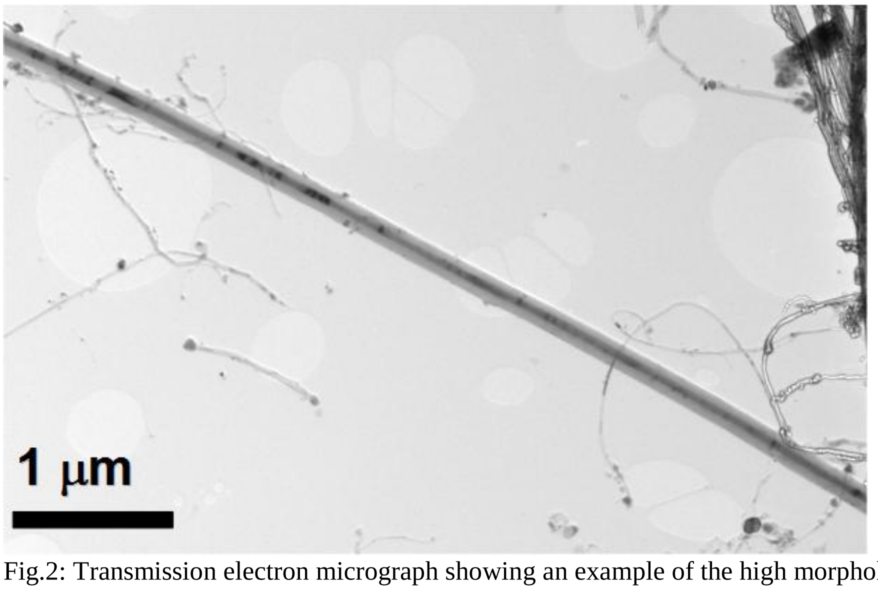

Fig.2: Transmission electron micrograph showing an example of the high morphological quality of the single-crystals that fill continuously the MWCNTs of the flower-like structures.