Supplementary data

Magnetism as indirect tool for Carbon content assessment in Nickel nanoparticles

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Figure SI-1. Raman spectra for all Ni@C-*x* composites with *x* = 773 K, 798 K, 823 K, 848 K, 87 K, and 973 K.

Figure SI-2. Particles size histograms for all Ni@C-*x* composites with *x* = 773 K (A), 798 K (B), 823 K (C), 848 K (D), 873 K (E) and 973 K (F).

Figure SI-3. TGA curves under air and related derivatives for all Ni@C-x composites.

Figure SI-4. TEM images of Ni@C-798 (left) and Ni@C-823 (right) composites showing graphite layers developed around Ni nanoparticles.

Figure SI-5. The comparison between Ms measured and calculated following the equation proposed by Ishizaki *et al.* [1]

Figure SI-1. Raman spectra for all Ni@C-*x* composites with *x* = 773 K, 798 K, 823 K, 848 K, 87 K, and 973 K.

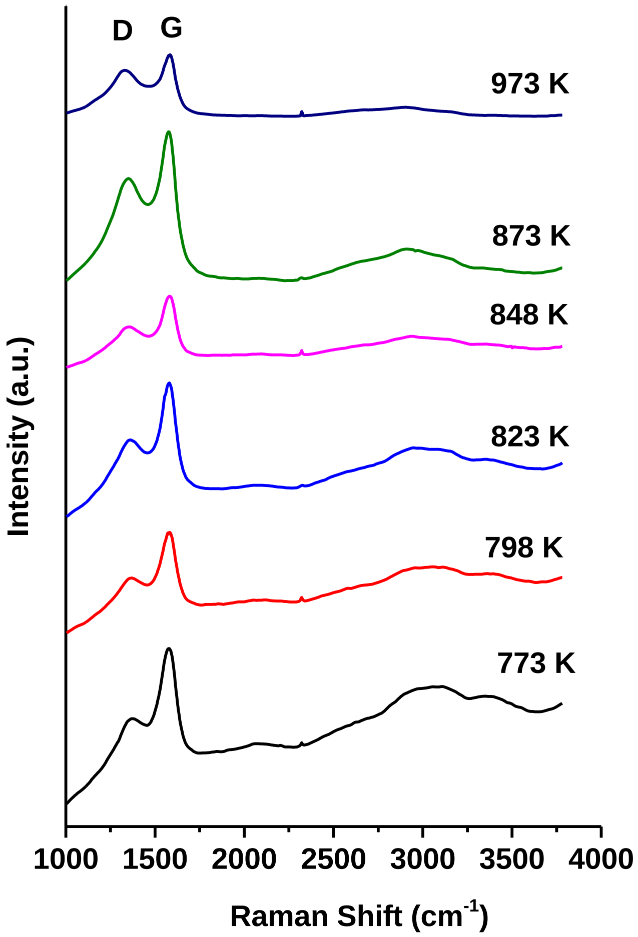


Figure SI-2. Particles size histograms for all Ni@C-x composites with x = 773 K (A), 798 K (B), 823 K (C), 848 K (D), 873 K (E) and 973 K (F).

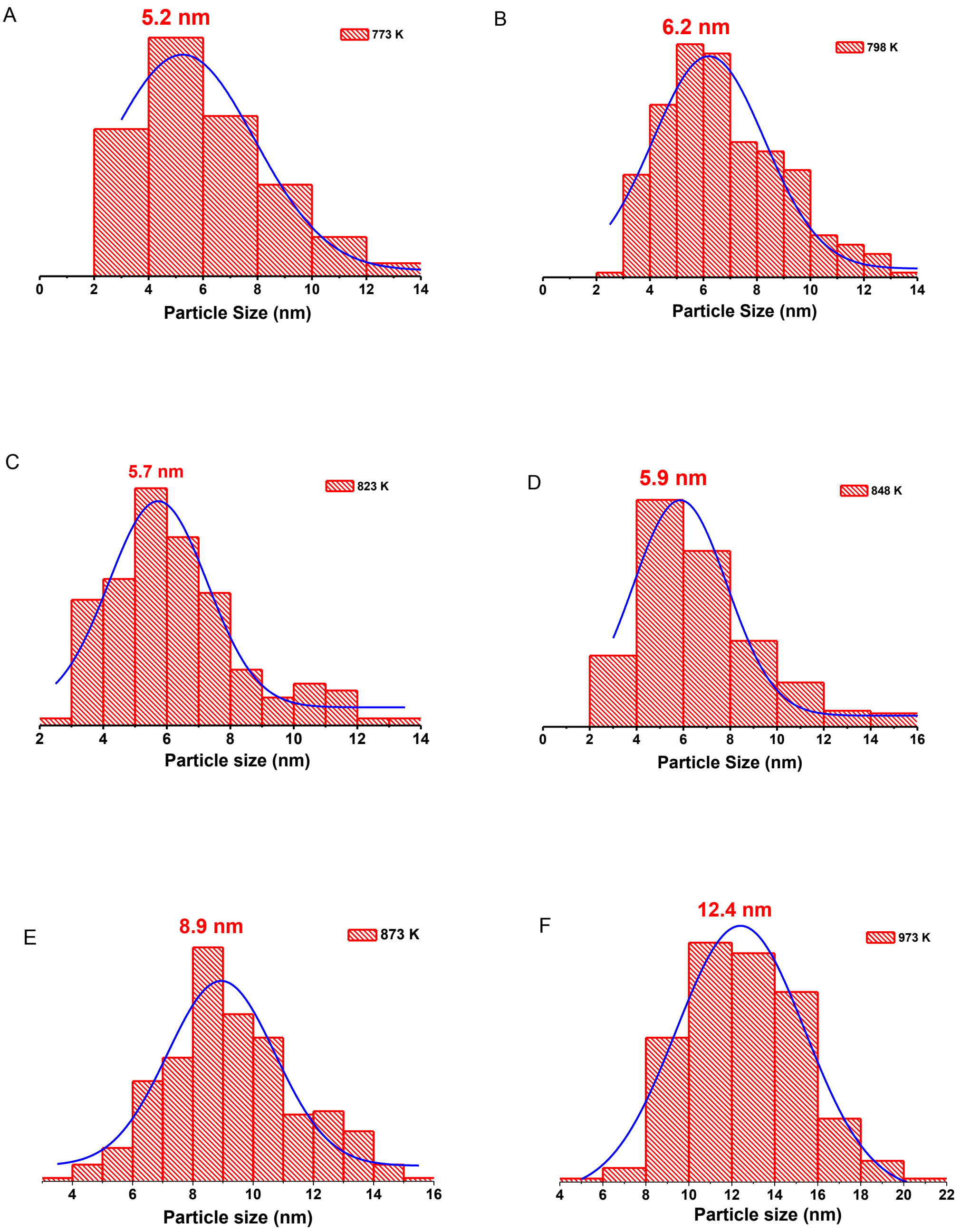


Figure SI-3. TGA curves under air and related derivatives for all Ni@C-*x* composites.

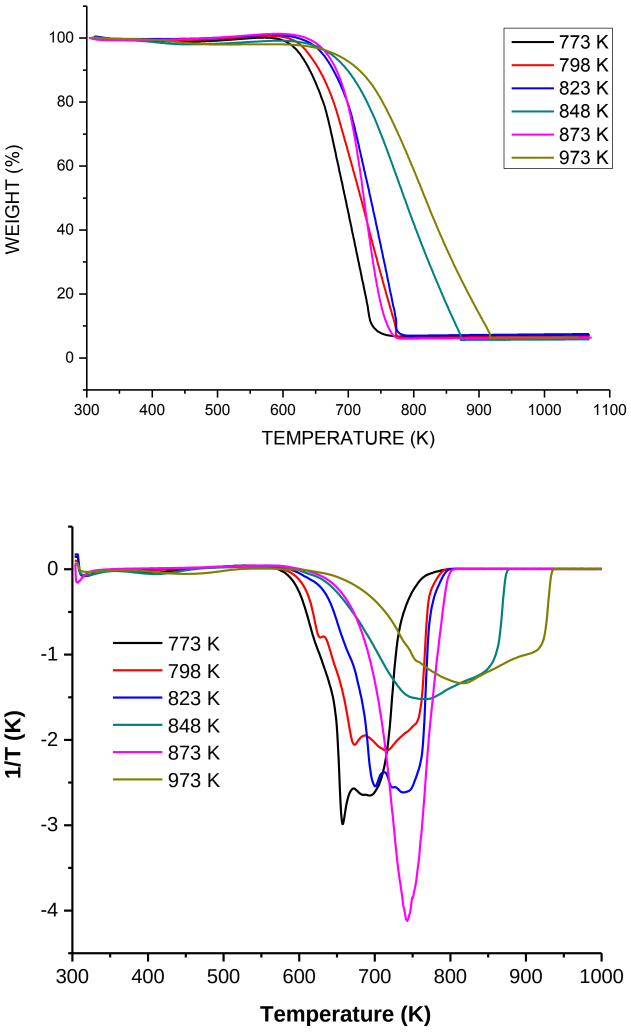


Figure SI-4. TEM images of Ni@C-973 (left) and Ni@C-823 (right) composites showing graphite layers developed around Ni nanoparticles.

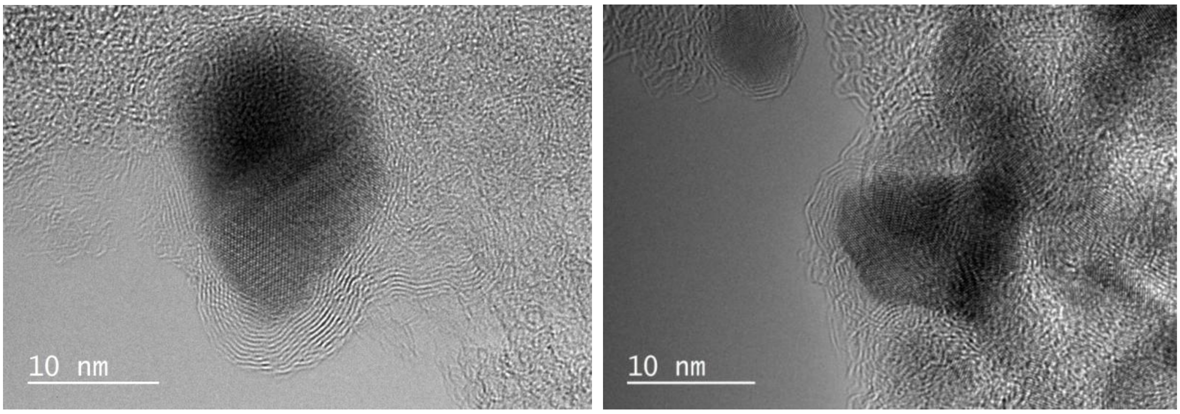
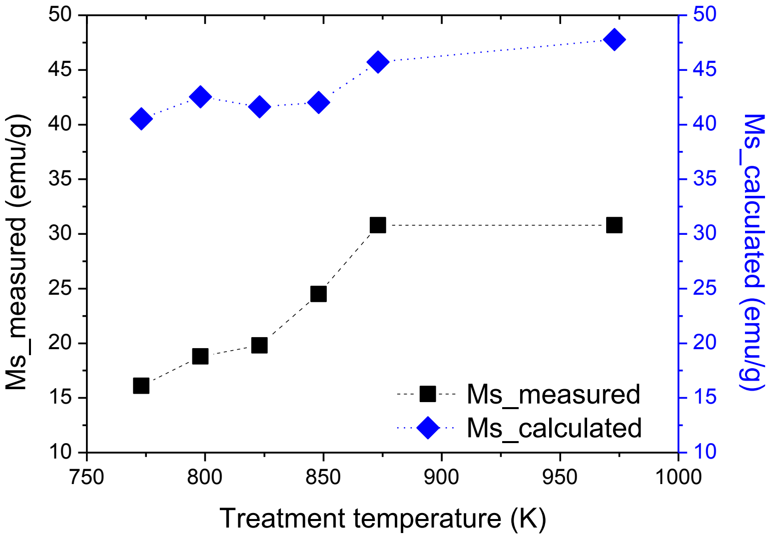


Figure SI-5. The comparison between M_S measured and calculated following the equation proposed by Ishizaki *et al.*[1].



The observed variation of Ms might be due only to a size effect, as suggested in reference[1]. Under this hypothesis, only Ni atoms within the core are contributing to the M_S whereas, the surface atoms are not. The calculation of M_S, within this hypothesis, is based on the formula below:

$$V = \frac{\pi D_m^3}{6}$$

$$A = \pi D_m^2$$

$$N_V = 4/a^3$$

$$N_A = 2/\frac{\sqrt{3}}{2}a^2$$

$$M_{S\_calc} = M_{S\_Ni} \times R_{Ni} \times \frac{VN_V - AN_A}{VN_V}$$

where,
V is the volume of Ni nanoparticles,
A is the surface area,
N_V is the number of Ni atoms per unit volume,
N_A is the number of Ni atoms per unit surface,
a is the lattice parameter (0.353 nm, in our case)
$M_{S\text{-}Ni}$ = 53 emu/g is the bulk Ni saturation magnetization at 300 K and
R_{Ni} is the Ni atomic ratio of the Ni nanoparticles.

R_{Ni} = 1 in our case since our nanoparticles are composed of Ni atoms only under the assumption that the observed variation of M_S is not due to carbon atoms dissolved into Ni nanoparticles.

As expected, the calculated M_S decreases with decreasing the size (*i.e*, treatment temperature) from 48 to 40 emu/g whereas, the experimentally observed M_S drops from 31 to 16 emu/g. The drop of M_S is more significant in our Ni nanoparticles and the magnetization range is very different relative to the calculated M_S. In conclusion, only size effect cannot be solely invoked to explain the strong drop of M_S observed in our nanoparticles.

Reference:

[1] T. Ishizaki, K. Yatsugi, and K. Akedo, Nanomaterials **6**, 172 (2016).