Cobalt ferrite nanoparticles as nanoheaters to treat cancer

Enhancing the tumours temperature to 41-46 °C represents an oncological therapy known as *moderate hyperthermia*. To selectively heat up cancer cells, avoiding any damage of the healthy tissues, magnetic nanoparticles (with sizes in the range 10^{-9}-10^{-7} m) stably dispersed in an water-based fluid (*ferrofluid*) can be injected in the body and used as nanoheaters once subjected to an external alternate magnetic field. Indeed, magnetic nanoparticles are able to release heat depending on the way they respond to the external magnetic field. A proper design of these nanoheaters should be therefore based on a proper optimisation of their magnetism in order to limit the amount of exogenous material to inject in the human body. Among the different magnetic materials, some iron oxides, known as spinel ferrites, are ideal systems because their magnetic properties can be strictly controlled through their chemical composition, their crystalline structure (i.e. the relative arrangement of the ions in an ordered and periodic structure), the size and shape of the nanoparticles, the capping molecules used to stabilise their aqueous dispersion, etc. Unfortunately, during the production of the nanoparticles many features can change at the same time (e.g., composition and particle size, etc.) and understanding how each single parameter affects the magnetic properties and the heating ability can be challenging.

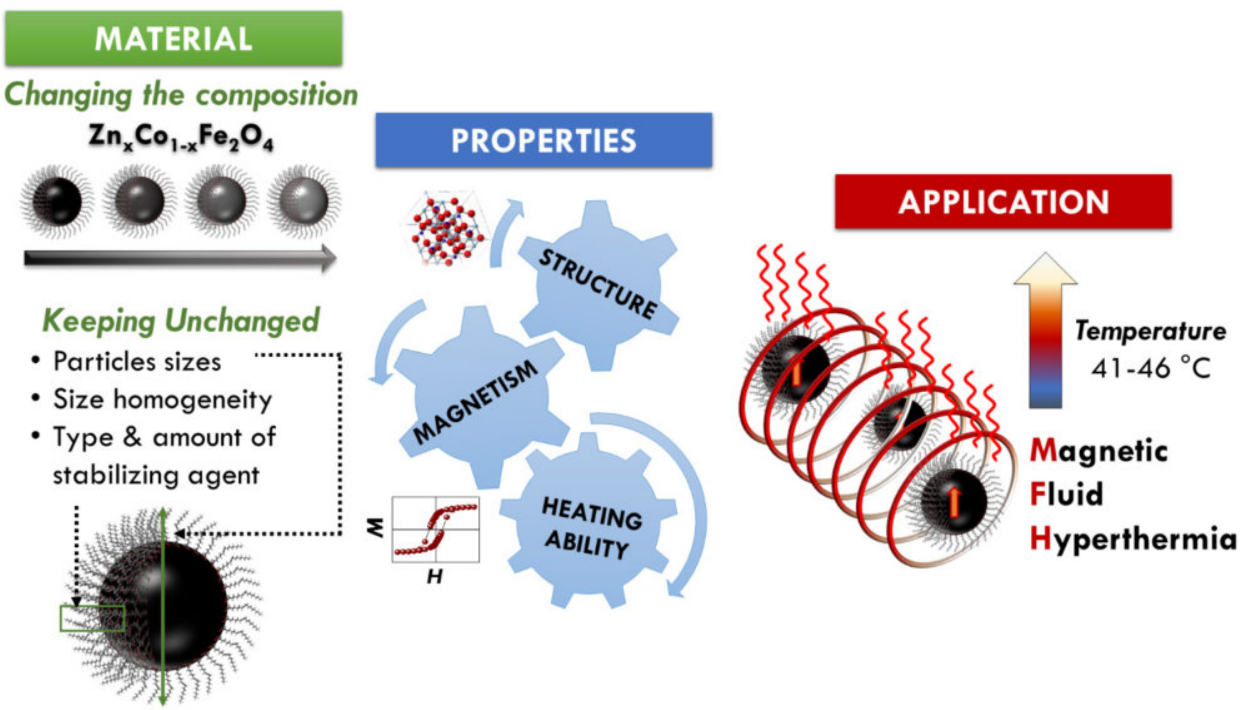

Fig. 1. The possibility to finely control the features of cobalt ferrite nanoparticles together with an accurate characterisation pave the way to design new promising nanoheaters for Magnetic Fluid Hyperthermia.

In this framework, cobalt ferrite, a mixed spinel ferrite with chemical formula $CoFe_2O_4$, was chosen as a starting material being characterised by good magnetic properties. Moreover, other systems were produced by substituting part of the cobalt ions by non-magnetic zinc ones (mixed cobalt-zinc ferrites) keeping all the other features similar (Fig. 1), with the aim of (*i*) lowering the intrinsic toxicity of cobalt ions and (*ii*) tuning the magnetic properties.

Our study shows that, within the adopted experimental conditions, pure cobalt ferrite nanoparticles are more efficient in the heat release than the zinc-substituted ones due to the critical role of the *magnetic anisotropy*, a magnetic property associated with the existence of preferential directions for the spontaneous magnetisation process. The necessity of a magnetic characterisation by using an alternate magnetic field, that better simulate the application condition, instead of a static one is straightforward, together with the deep and detailed investigation of the magnetic behaviour of the samples at low temperature (5 K) (Magnetometry and M?ssbauer Spectroscopy). The magnetic behaviour was explained in terms of the positions occupied by the metal ions (Co^{2+}, Zn^{2+}, Fe^{3+}) within the crystalline structure. Is in fact the distribution of the cations among these sites that affect the magnetic properties.

Finally, this work demonstrates how such systematic studies based on a multitechnique approach (X-ray Diffraction, Transmission Electron Microscopy, Thermal analysis, ICP-OES, Dynamic Light Scattering, Infrared Spectroscopy, DC and AC magnetometry, M?ssbauer Spectroscopy) are crucial for a proper understanding of the role of the different parameters in the heating ability of the magnetic nanoparticles and, therefore, for a suitable design of the next generation of nanoheaters.

***V. Mameli* [1,2]*, A. Musinu* [1,2]*, A. Ardu* [1,2,3]*, G. Ennas* [1,2]*, D. Peddis* [4]*, D. Niznansky* [5]*, C. Sangregorio* [2,6]*, C. Innocenti* [2,7]*, Nguyen T. K. Thanh* [8,9] *and C. Cannas* [1,2,3]**
[1]*Department of Chemical and Geological Sciences, University of Cagliari, Monserrato, CA, Italy*
[2]*Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (INSTM), Italy*
[3]*Consorzio AUSI, CREATE, Palazzo Bellavista Monteponi, Iglesias, Italy*
[4]*Istituto di Struttura della Materia, Consiglio Nazionale delle Ricerche (ISM-CNR), Italy*
[5]*Department of Inorganic Chemistry, Charles University of Prague, Czech Republic*
[6]*Istituto di Chimica dei Composti OrganoMetallici, Consiglio Nazionale delle Ricerche (ICCOM-CNR), Sesto Fiorentino, Italy*
[7]*LAboratorio di Magnetismo Molecolare (LA.M.M), Department of Chemistry, University of Florence, Sesto Fiorentino, Italy*
[8]*Biophysics Group, Department of Physics and Astronomy, University College London, Gower Street, London, UK*
[9]*UCL Healthcare Biomagnetic and Nanomaterials Laboratory, 21 Albemarle Street, London, UK*

Publication

Studying the effect of Zn-substitution on the magnetic and hyperthermic properties of cobalt ferrite nanoparticles.
Mameli V, Musinu A, Ardu A, Ennas G, Peddis D, Niznansky D, Sangregorio C, Innocenti C, Thanh NT, Cannas C.
Nanoscale. 2016 May 21