Summary

In this thesis we present a detailed parametric analysis of permalloy nanostructures with variable shape (disk, cylinder and sphere) and size, for possible application in magnetically mediated hyperthermia, exploiting hysteresis losses for the heat release. Hyperthermia is a promising therapy for the cure of cancer, able to enhance the effect of already available therapies such as chemotherapy and radiotherapy, using a localized source of heat to increase the temperature of diseased tissues. In the case of magnetic hyperthermia, superparamagnetic iron oxide nanoparticles are typically used to increase the temperature of diseased tissues, when excited by alternating magnetic fields (with a frequency from 50 kHz to 1 MHz). However, they present a medium heating efficiency, requiring the injection of large quantity of material to obtain therapeutic effects, at the cost of potential toxicity.

In this framework, we aim at individuating more efficient heat mediators, focusing on multi-domain ferromagnetic nanostructures, which have recently attracted strong interest, due to the potential improvement of heating efficiency via hysteresis losses. The study is performed by means of in house developed micromagnetic codes, which are able to efficiently solve the Landau-Lifshitz-Gilbert (LLG) equation in 3D domains. In particular, we have implemented both a 3D solver for the modelling of 3D-shape nanostructures as well as a 2.5D solver for the simulation of thin-film like nanostructures randomly distributed in a 3D space. The solvers, which adopt a geometric time integration scheme for the integration of the LLG equation, are both written in CUDA Fortran to leverage the high parallelization performance offered by Graphical Processing Units.

By means of micromagnetic modelling, we have performed an extensive investigation of the influence of geometrical properties (shape and size) on the amount of heat generated via hysteresis losses. We have also obtained useful information on remanence magnetization configuration and on its implications in aggregation phenomena. Third, we have explored magnetization reversal process and determined saturation fields, which are required to obtain major hysteresis loops and thus maximize hysteresis losses. Regarding this last aspect, caution has been paid to not exceed acceptable biophysical limits for the maximum applicable field at a given frequency.

The attention is first focused on disk-shaped nanostructures, for which we present a detailed comparison between micromagnetic simulations and experimental results on samples arranged in both 2D array (intermediate production phase) and free-standing (in solution). Subsequently, we study the magnetization reversal process and the hysteresis properties of permalloy nanocylinders (diameter between 150 nm and 600 nm, thickness from 30 nm up to 150 nm) and permalloy nanospheres (size between 100 nm and 300 nm), to compare the relative heating performances of different nanostructures. Focusing on disk-shaped nanostructures, we also analyze the influence on the loss generation of the state of aggregation, concentration and spatial distribution. In particular, by means of the 2.5D micromagnetic code we investigate the hysteretic behavior of permalloy nanodisks randomly oriented in a 3D medium, analyzing the effects of magnetostatic interactions and variations in the orientation with respect to the applied field. This analysis has been conducted to have a more precise estimate of the heat delivery during hyperthermia treatment, trying to mimic the stochastic dispersion of nanomaterials in a tissue or in a biological fluid.

Finally, as an alternative use of magnetic nanostructures, we have studied the nucleation and control of vortex state, for possible applications in non-volatile magnetic random access memories (MRAMs). In particular, we have investigated bi-component magnetic nanodisks as potential storage systems, where the information unit is represented by vortex chirality (magnetization rotational direction).