MICRO-SCALE NUMERICAL SIMULATION
OF THE MAGNETIC RECORDING

ADELINA BORDIANU, VALENTIN IONIȚĂ, LUCIAN PETRESCU

Key words: Nanoparticles, Micro-scale magnetic characterization, LLG equation.

The paper presents the micro-scale numerical simulation of the longitudinal magnetic recording for a three layered structure, considering the quasi-static regime. The magnetization of the recording medium was calculated for different cases using the Landau-Lifshitz-Gilbert equation, implemented in Magsimus software.

1. INTRODUCTION

The continuous development of technology has lead to the necessity of constant improvement in all areas of engineering. Magnetic recording domain is one of these complex areas that are in constant change. In the last years, the information storage capacity is in a continuous increase and in the same time the performances of the recording media improved. In order to obtain these performances, the recording medium must have, among others, a high remanent magnetization (for a good reading amplitude without a significant influence on the recording resolution), a high coercivity of the magnetic layer (but without the saturation of the writing magnetic head), a thin configuration etc. [1–3].

This paper presents the micro-scale numerical simulation of the magnetization process of the magnetic recording medium. Because the magnetic recording layer consists of a semi-hard magnetic material, it is important that the magnetization process is carefully conducted in order to obtain a high remanent magnetization. The material model and the applied field parameters must be chosen with care. The micro-scale simulation is implemented in Magsimus©.

2. MICRO-SCALE APPROACH

Magsimus© is a commercial software program used for the design and analysis of three-dimensional micro-magnetic systems. The modelling techniques
used by this software are based on the micro-magnetic theory for calculating the equilibrium magnetic states of a system. The solver computes the solution of the Landau-Lifshitz (LL) or Landau-Lifshitz-Gilbert (LLG) equation, which is a time-dependent differential equation that expresses the damped-precession motion of the magnetization vector under the influence of an applied field [4]. For each magnetic element of the simulated system, one equation is written. The LL equation used by Magsimus is:

\[ \frac{dM}{dt} = -\gamma M \times H - \lambda M \times (M \times H), \]  

where \( t \) is the time, \( \gamma \) is the precession factor, \( \lambda \) is the damping factor, \( H \) is the total effective magnetic field strength vector acting on the magnetization and \( M \) is the magnetization vector. In general the damping factor \( \lambda \) is a positive phenomenological constant characterizing the magnetic material [5–8].

The first right-hand term of (1) is called the precession term and it represents the tendency of an unconstrained magnetization vector to precess indefinitely around the applied field. The second right-hand term is called the damping term because it simulates the energy loss mechanisms in real materials that cause the magnetization vector to tend to line up with the applied field. The user can choose the other model (LLG) and the graphical interface of the software solver allows the setting of the main parameters of the LLG equation:

\[ \frac{dM}{dt} = -\gamma_G M \times H + \alpha_G (M \times \frac{dM}{dt}), \]  

where \( \gamma_G \) is the Gilbert precession factor (\( \gamma_G = 1.105 \times 10^5 \text{ g} \)) and \( \alpha_G \) is the Gilbert damping factor. The two equations are mathematically equivalent and in general the LLG form is more often used [5].

3. MICRO-SCALE SIMULATION

The study is focused on the influence of various external magnetic fields and the damping and precession factors on the remanent magnetization of a recording medium for quasi-static regime. The purpose of this analysis is to improve the performances of this medium by optimizing its remanent magnetization.

The considered recording medium has a rectangular prism shape (250 nm × 200 nm area and 213 nm thickness), meshed using several hundreds of brick-shape cells. As one can see in Fig. 1, the geometric model consists of a top magnetic recording layer (12 nm thickness), a spacer made of a non-magnetic material (1 nm thickness) and a soft magnetic material under layer (200 nm
thickness). The medium has uniaxial magnetic anisotropy, the easy magnetization axis being the long axis.

![Diagram showing the geometrical configuration with layers labeled CoCrPt, non-magnet, and FeAlSi (pseudo-soft magnet).]

Fig. 1 – Geometrical configuration.

The top layer was defined as a “normal magnet” – this means that the magnetization vector has a fixed magnitude and is free to rotate in all three dimensions under the influence of an external field. Such an element is characterized by the magnitude and the angular orientation of its magnetization vector [4]. The non-magnetic spacer layer was defined as “non-magnet”, meaning that a magnetization vector is not present. Finally, the third layer was defined as “pseudo-soft magnet” where the magnetization vector is not fixed in magnitude and can rotate freely in three dimensions under the influence of an external field. This last layer is characterized by the relative magnetic permeability tensor and the saturation magnetization [4].

For the magnetization process, different pulses of external applied magnetic field, produced by a magnetizer coil, are applied along the longitudinal axis and the pulse parameters (shape, amplitude, duration, rise time) are varied. The mesh was refined and the parameters of Landau-Lifshitz-Gilbert equation were varied according to the simulation demands.

4. TEST RESULTS

For all the simulations is considered that the top layer is made of CoCrPt (the magnetization vector has a magnitude of 330 kA/m at saturation, the exchange stiffness constant $A = 25$ pJ/m, the anisotropy constant $K = 182$ kJ/m$^3$) and the bottom layer material is of FeAlSi (the magnetization vector has a magnitude of 662 kA/m at saturation, the relative permeability is 590, the exchange stiffness
constant $A = 0.13$ pJ/m, the anisotropy constant $K = 500$ J/m$^3$). The Landau-Lifshitz-Gilbert equation was used for obtaining the solutions.

The simulation is split into two different cases: the first case analyses the magnetization process of a magnetic recording medium that is non-magnetized and for the second one it is considered that the recording medium that had been magnetized before. The external magnetic field is applied along the easy magnetization axis, it has a trapezoidal pulse shape (Fig. 2) and its amplitude increases from zero to 80 kA/m, during the rise interval.

![Fig. 2 – Evolution of the applied magnetic field.](image)

The first case is divided into several tests. The first test considers a variable time for which the magnetic field remains constant: a pulse duration interval of 10 ns, then 15 ns and finally 22 ns. The pulse rise and fall intervals are considered 10 ns each. Analyzing the results, one can observed that the remanent magnetization of the sample is higher if the pulse duration interval increases, but the differences are very small: 0.1 kA/m between 10 ns and 22 ns.

The second test analyses the importance of the rise phase of the trapezoidal field pulse. The pulse rise was varied (2, 5 and 10 ns), while the pulse amplitude (80 kA/m), the pulse fall and duration intervals (10 ns each) were maintained constant (Fig. 3). It was observed that the remanent magnetization is higher if the magnetic field increases rapidly – $M_r = 24.62$ kA/m for 2 ns, $M_r = 23.9$ kA/m for 5 ns and $M_r = 21.89$ kA/m for 10 ns.

The third test analysis was made to see the influence of the pulse fall time on the remanent magnetization values. It was noticed that the remanent magnetization values remain around the same value – 21.89 kA/m.

A stronger external field means a larger remanent magnetization, but the amplitude of the applied field must be carefully chosen. This was verified by applying a field with higher amplitude $H = 110$ kA/m. The obtained magnetization is $M_r = 48.27$ kA/m, value that is bigger than the one obtained for $H = 80$ kA/m ($M_r = 24.62$ kA/m).
In all the previous simulations, a damping factor $\alpha_G = 0.3$ and a gyromagnetic ratio $g = 1.5$ were considered in the LLG equation. These factors influence the magnetization process; for example, if an another model is used – CoCrPt layer with $\alpha_G = 0.1$, $g = 1.9$ and FeAlSi layer having $\alpha_G = 0.3$ and $g = 1.5$ – then the remanent magnetization is almost three time smaller than in the first case.

Other simulations were also performed and it was observed that the remanent magnetization is smaller if the damping factor is reduced ($M_r = 21.9$ kA/m for $\alpha_G = 0.3$ and $M_r = 4.6$ kA/m for $\alpha_G = 0.03$). The same evolution occurs if the gyromagnetic ratio is varied and the damping factor is maintained constant in both simulations. If both factors are varied in the same time, the results depends, obtaining in some cases higher magnetization than the ones obtained for the first simulations and in other cases smaller remanent magnetizations.

The second family of simulations considers that the recording medium was magnetized before, as one can see in Fig. 4.a. In this case a two times refined mesh was used. After the magnetization process is finished, the first layer of the recording medium is magnetized in the same direction as the applied magnetic field. The remanent magnetization is bigger in this case (327.33 kA/m) than in the previous ones, when it was considered a non magnetized magnetic recording medium. At the same time, the magnetization vector varies more easily in the “pseudo-soft magnet” layer and in the cells that are near the borders of the recording medium.
5. CONCLUSIONS

This analysis was based on the equations of Landau-Lifshitz-Gilbert which are very useful for studying the micro-scale problems. Different trapezoidal pulses of applied magnetic field were used for the simulation of the magnetization process of a chosen magnetic recording medium. The values of the remanent magnetization are bigger if the pulse duration time increases. Not the same thing happens if the numbers of the pulse rise time increases, the values being smaller in this case. This result is verified in practice and a macroscopic explanation could be that the eddy currents are not so important if the field increasing is moderate, but a pulse having a higher gradient produces strong superficial eddy currents which influence the value of the remanent magnetization.

A stronger external field produces a larger remanent magnetization, but the amplitude of the applied magnetic field must be carefully chosen because it is possible to saturate the magnetic reading/writing head if the field is too big. An optimum for all the magnetic field parameters can be found in order to obtain the desired values of remanent magnetization. The modelling microscopic mechanism for the medium magnetization is the magnetization vector rotation; in simulation,
more adjacent cells could have the same orientation of the magnetization vector and they can be considered as single magnetic domains. The two parameters that appear in the Landau-Lifshitz-Gilbert, the damping factor and the gyromagnetic ratio, influence the values of the obtained magnetization.

The final result of the magnetization process depends both on the material intrinsic properties (e.g. saturation magnetization or the anisotropy constant), and on the material composition, the geometry of particles or grains, the exchange interactions between particles and the orientations of their magnetization axes. The magnetization history of the material is very important too.

Received on 28 July 2011

REFERENCES