Scientific report short visit grant 3526

Applicant: Dr. Pietro Tierno (Universitat de Barcelona, Spain)

Project: The role of noise on magnetic colloidal transport on garnet films.

Purpose of the visit

Dr. Pietro Tierno visited the group of Prof. Tom H. Johansen at University of Oslo from 18/10/2010 to 22/10/2010 for several purposes.

-First, Dr. Tierno started a project to experimentally investigate the effect of noise (i.e. thermal noise) on the magnetic transport of paramagnetic colloids above garnet films (i.e. the system described in Ref. [1]).

-Second, Dr. Tierno helped Dr. Vestgården with the numerical analysis of the magnetic ratchet system and its potentiality towards sorting of bi-disperse colloidal system.

-Third, since the group of Prof. Tom H. Johansen is a very important partner for the research of Dr. Tierno, and no previous direct interaction was made, the purpose of this visit was also to raise further interest and exchange of ideas between both scientists.

Activities

To study the effect of noise on the transport of paramagnetic colloids Dr. Tierno spent most of the time with Prof. Johansen to synthesize via epitaxial growth the best ferrite garnet film (FGF) for the magnetic transport of the colloids. FGFs are thin uniaxial ferromagnetic films grown by liquid phase epitaxy in which ferromagnetic domains organize into parallel stripes having opposite magnetization and spatial periodicity of few microns (Fig 1a). Close to the surface of these films, the strongest stray magnetic field appears concentrated at the domain walls (DW) which bridge two opposite magnetized domains. Thus, when no external field is applied, paramagnetic colloids deposited above the FGFs are pinned on the DWs by forming consecutive parallel lines. An externally applied periodic pulsating magnetic field oscillates the DWs and sequentially shifts the colloidal arrays creating a deterministic non-thermal parametric ratchet (Fig. 1b,c, more details in [1]).

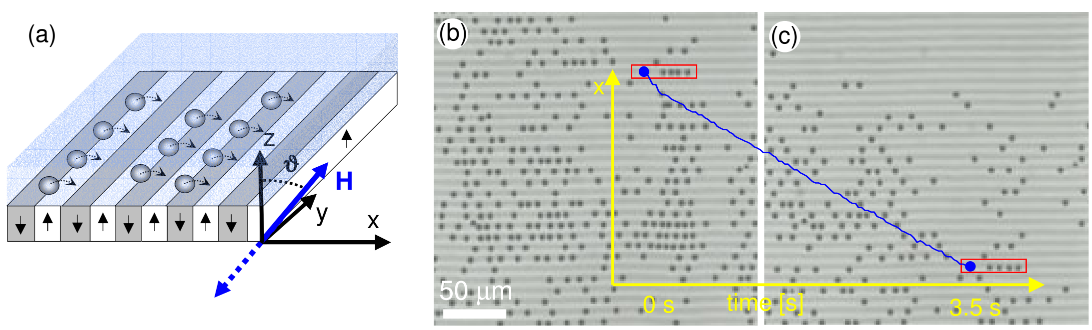

Fig 1 (a) Scheme of a FGF with an aqueous solution of paramagnetic particles. The applied magnetic field H oscillates in the (x,z)-plane: $(H_x,H_z) = H_0\,(\sin \omega t, 0, \sin \omega t)$
(b-c) Polarization microscope images showing the position of the colloids on a FGF at t=0 s (b) and t= 3.5 s (c) under a field with frequency $\omega = 31.4\ s^{-1}$. One particle (chain) is highlighted in blue (red) and its superimposed trajectory. The particles move normal to the stripe pattern along the x direction.

The domain wall represents a singularity of the magnetic field, and closer a particle may approach the singularity, the larger the trapping is. Thus to study the effect of noise it is essential to reduce the magnetic trapping strength by using FGF characterized by smaller stripe pattern or small saturation magnetization (M_s). During his stage at Univ. of Oslo, Dr. Tierno realized with Prof. Tom H Johansen 5 of such films with diameter 3 cm and growth on GGG (111 orientation) substrates. It is important to emphasize that the equipment used to growth the FGF (liquid phase epitaxy on GGG substrates) is unique and only this specific group at Univ. of Oslo has the know-how on how to use it.

Secondly, Dr. Tierno performed numerical calculations with Dr. Jørn Inge Vestgården who is an expert in numerical simulation of Garnet Films and Superconducting Vortices [2]. The idea was to simulate the sorting properties of the magnetically modulated potential above the GF in case of bi-disperse paramagnetic colloids. Dr. Tierno discovered experimentally in Ref. [3] that two size particle can be separated by using a Lissajou-like magnetic modulation of the form $(H_x,H_z) = H_0 (\sin 3\omega t, 0, \sin \omega t)$, where the in-plane component oscillates with triple the frequency of the normal component (H_0 = field amplitude, ω = field frequency). Fig. 2 shows the particle separation.

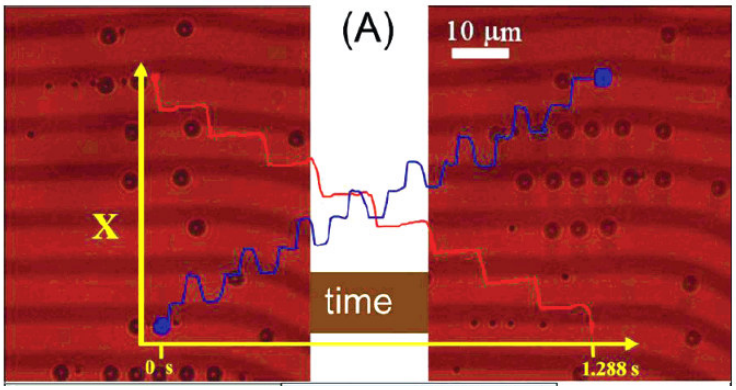

Figure 2. Polarization microscope images of a garnet film with small (radii = 0.5 micron, red) and large (radii = 1.4 micron, blue) particles. Trajectories of both particles are superimposed. The motion occurs in discrete steps that lead to a net motion in opposite directions separating the particles. Image taken from Ref. [2]

At Univ. of Oslo, the simulation of the overdamped equation of motion of the colloids in the magnetic landscape created by the stray field of the FGF plus the external magnetic field enabled to observe the same particle dynamics as in the experimental case. It was also found that more complex modulations, such us:
$(H_x,H_z) = H_0(\sin 5\omega t, 0, \sin\omega t)$ can be used to single out mid-sized particles (moving in the positive x-direction) from both larger and smaller particles (moving in the negative x-direction) at the same time. Moreover Dr. Tierno helped Dr. Vestgården in analyzing the data resulting from the numerical simulations and choose the right parameters (close to the experimental one) to observe the particle separation.

The most important out coming of this visit was that it further strength the cooperation between two consolidate research groups located at University of Barcelona (Spain, P.I. Prof. Francesc Sagués) and at University of Oslo (Norway, P.I. Prof. Tom H. Johansen). Should be also mention that Dr. Tierno during this short visit had the possibility to meet other well know scientists in the field of superconducting devices and magneto-optical imaging (where the group of Prof. Johansen is leader) with witch he had scientific discussions and exchange of ideas.

Dr. Tierno on 20/10 presented a talk entitled:
"Colloidal transport on magnetic garnet films"
in front of a large scientific audience and received useful comments from other members of the group, and from scientist outside Prof. Johansen group.

Future Plans

The next stage of the project initiated at Univ. of Oslo will consists in implementing the FGF to explore experimentally the effect of thermal noise on the dynamics of the paramagnetic colloids. The FGFs will be covered by a thin layer of an organic film (PMMA or SU-8 resin) by using standard deposition (spin coating) which will allow to obtain uniform films with thickness spanning from 100 nm to microns. Increasing the film thickness will increase the elevation of the colloids from the pinning walls and reduce their attractions thus facilitating thermal forces since the magnetic stray field of the garnet film decrease exponentially from the surface. In Barcelona

Dr. Tierno will use these technique to explore how the thermal noise will affect the particle motion and for which particle elevation the magnetic transport will not work. Also object of current investigation are noise induce effects such us current inversion (i.e. the particles will move against the direction of motion imposed by the field) or chaotic particle trajectories. For all this research, Dr. Tierno will use the FGF which have been synthesize with Prof. Johansen in this short visit.

<u>References</u>

[1] Pietro Tierno, Sathavaram V. Reddy, Tom H. Johansen and Thomas M. Fischer, *Phys. Rev. E* 75, 041404, 2007.

[2] J. I. Vestgården, D. V. Shantsev, Å. A. Olsen, Y. M. Galperin, V. V. Yurchenko, P. E. Goa, and T. H. Johansen, *Phys. Rev. Lett* 98, 11702 (2007)

[2] Pietro Tierno, Sathavaram V. Reddy, Michael Roper, Tom H. Johansen and Thomas M. Fischer, *Journal of Physical Chemistry B*, 2007; 112, 3833-3837.