DYNAMICS OF A FERROFLUID IN CONTACT WITH Co MICRO-SQUARE ARRAYS

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In this work the dynamical behaviour of a highly diluted ferrofluid in direct contact with an array of micro-squares of Co is studied. The dynamic response of the system is obtained by focusing a polarised He-Ne laser on the array and measuring the intensity changes at the transmitted diffracted beams when the magnetization of the array with time-dependent external magnetic fields.

The square arrays are fabricated by e-beam lithography on polycrystalline Co sputtered on glass substrates. First, a continuous layer, 1000 nm thick, of polycrystalline Co is grown. This thickness guarantees optical opacity for the light used in the experiments, a 632.8 nm wavelength 1.5 mW laser. Secondly, the continuous Co layer is locally etched (all the way through to the glass substrate) to form an array of 5 x 5 μm^2 Co squares separated by 0.5 μm using ion milling technique. The ferrofluid used is formed by spherical cobalt ferrite ($CoFe_2O_4$) nanoparticles (average diameter 12.3 nm) stabilised in water. We use a volume fraction of 7.84 %.

When a strong uniform magnetic field is applied on a dilute ferrofluid, the magnetic nanoparticles will form fibrillated structures aligned with the field as it has been directly observed by cryogenic electron microscopy experiments [1]. Many experiments have been reported on the last years to study the aggregate formation on model magnetic fluids (magnetorheological fluids and ferrofluid emulsions). These oriented structures lead to linear dichroism, that is, greater absorption along the long-axis of those field-induced structures than along the perpendicular direction [2,3].

Our study refers to a related but substantially different effect: nanoparticles in the ferrofluid are now pulled by magnetic field gradients created at a micromagnet array immersed in the fluid as similarly to the classic domain wall Bitter decoration technique. Moreover, periodic distribution magnetic fringe fields at domain walls and edges of the microsquares create linear nanoparticles chains. This periodic magnetic chains induce clear changes on the transmitted and diffracted light that is analyzed as a function of the different diffraction orders [4].

We have studied the optical response of the system when time-dependent external magnetic fields are applied. The field is generated by two orthogonal pairs of Hemholtz coils controlled by two function generators that allow us to change both, amplitude, relative phase, and frequency. The maximum field amplitude achieved with this system, 1200 Oe, is large enough to saturate the Co even along the Co hard axis. Micromagnetic simulations have been performed in order to interpret the magnetization distribution at the edges of the microsquares.

In our configuration the laser beam impinging on the sample is polarized parallel to the direction of the Co easy axis. In the absence of a ferrofluid, when a rotating field is applied in the plane of the sample, the intensity on the diffraction spots produced by the Co square array changes only slightly due to diffraction magneto-optic effects. However, when a ferrofluid is put in contact with the Co-square array and a rotating magnetic field is applied, we observe that the intensity of the diffracted beams switches ON and OFF in phase with the applied low amplitude ac field, as shown in Fig. 1. The dynamical response of the ferrofluid has been deduced from the measurements carried out as a function of the magnetic field amplitude and frequency. When increasing magnetic field frequency the variation of the intensity at the diffracted spots decreases (see Fig. 2).

When the applied field is strong enough to saturate each individual Co square, a huge field gradient between consecutive squares appears in the direction of the applied field since M_s^{Co} = 21000 Oe. Thus, the ferrofluid particles will be attracted to the edges of the squares forming linear structures. As a consequence, ferrofluid particles block the space between adjacent squares in the direction of the applied field leading to an increase of the intensity measured on the diffraction spot orthogonal to the direction of the field. This effect depends strongly on the amplitude and frequency of the applied field but is strong enough to prevail up to high frequencies so it could be useful for optical switches.

References:

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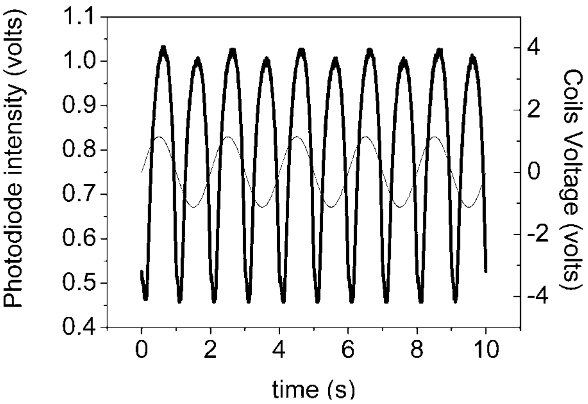

Figure 1

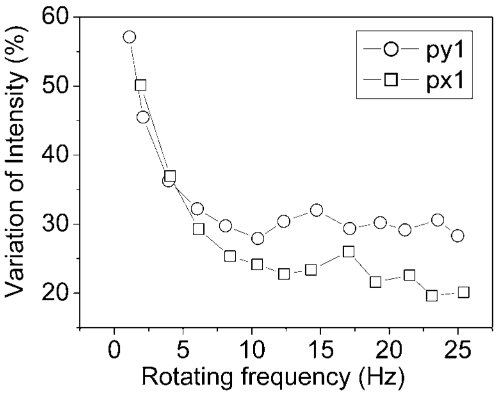

Figure2

Figure 1: Applied signal to one pair of Hemholtz coils and variation of the intensity at the first order diffracted spot when applying a rotating magnetic field with amplitude 200 Oe and frequency 0.5 Hz. A variation of the intensity of 72% is obtained.

Figure 2: Intensity variation versus magnetic field frequency on the first order diffracted spots (horizontal and vertical) when we applied a magnetic field of 470 Oe.