100 μM THICK FERROFLUID LAYER AS A RESETTABLE MEMORY CELL

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Abstract: We report an experimental work in which a 100 μm thick ferrofluid layer is exposed to Nd:Yag laser light and an external magnetic field. The ferrofluid layer is illuminated by the interference pattern of the laser light gone through the optical system. The interference fringes of the laser light induce the temperature grating in the sample. In the magnetic field the magnetostatic interaction occurs, tending to create a hexagonal pattern [1],[2]. The outcome image, whether hexagonal cells or interference pattern of the warming light, is dependent on the order of excitation applied.

1. Introduction

Ferrofluids are colloidal solutions that typically consist of magnetic nanoparticles. Each particle has a constant magnetic dipole moment proportional to its size that can align with an external magnetic field [3]. So ferrofluids are systems capable of unique pattern forming behavior spontaneous phase separation and formation of ordered and disordered patterns in layers of magnetic colloid may occur under the influence of external magnetic fields [4]. These patterns are the consequence of magnetic dipole-dipole interactions and the reversible agglomeration of the magnetic nanoparticles.

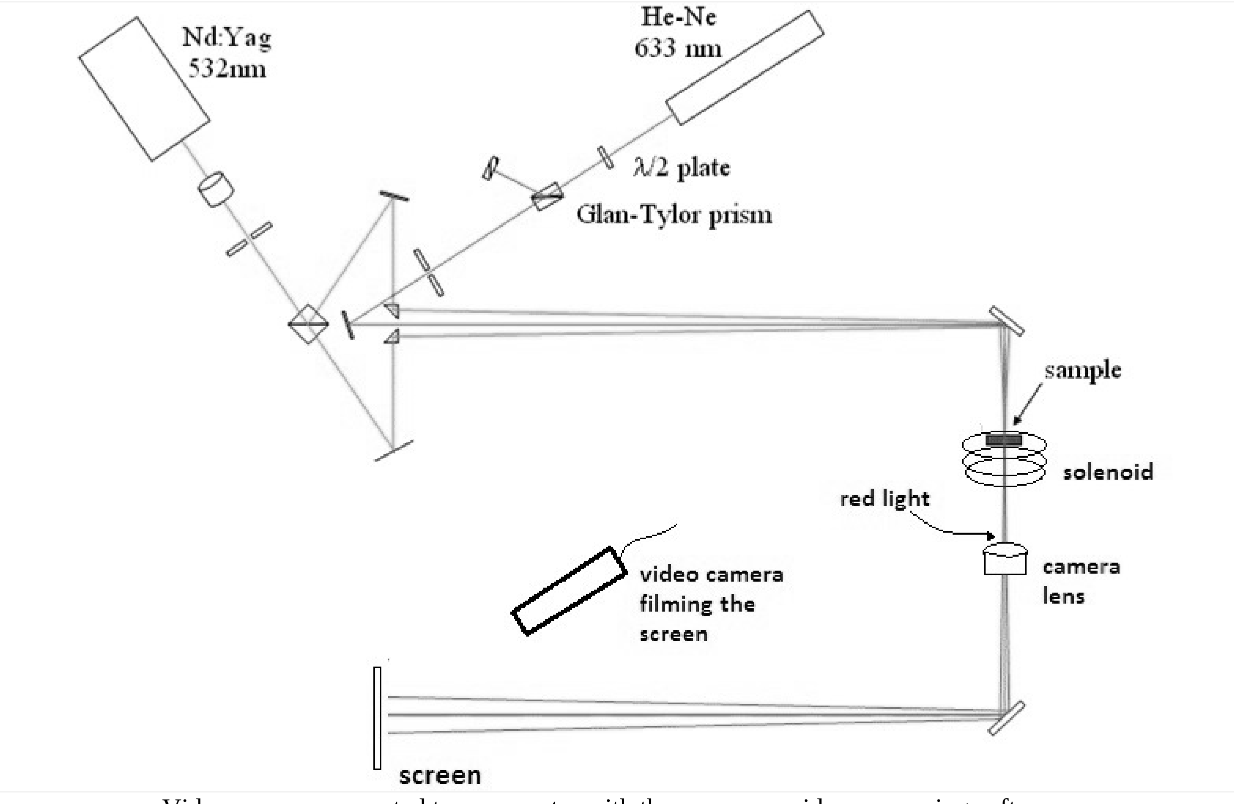
In this work, we studied the interaction between a concentration grating of colloidal nanoparticles, induced by means of a laser beam and an external magnetic field in 100 μm thick ferrofluid layer. This research demonstrates that the concentration grating of the ferrofluid layer differs by the order of external excitations that are applied to it. The external magnetic field can be applied as the first, as the last one or at the same time as the warming laser light.

2. Experimental setup

Simplified optical scheme of experimental setup is shown in Fig.1. Nd:Yag laser with a wavelength of 532 nm is used as a power laser. The work was done with the continuous laser forced scattering setup in combined scattering mode. The latter means that agglomerated particles form objects the characteristic size of which is compatible with the laser wavelength, therefore light scattering outsteps Rayleigh type. Theoretical model for that situation, which is not a subject of the present paper, becomes complicated because Rayleight scattering creates the index optical grating whereas agglomerated particles cause Tyndall scattering and absorption. In the first degree of explanation, the combined scattering results with seeing the grating picture in a correct geometry but with an excessive contrast. Due to uncertain focus plane of combined scattering image, we take the pictures from a diffusive reflecting screen, (Fig. 1). In order to exclude the thermo gravitation convection, the Nd:Yag laser beam transmits the sample layer from above. Power laser beam is expanded and entered into the prism and mirror system, where it is split into two beams. Both beams are focused in a narrow angle on the sample at the same place where they interfere. As the ferrofluid absorbs most of the green light, the interference fringes of the laser light induce a sinusoidal 1D temperature grating in the sample. The optical setup can be modified to more complicated by splitting the two narrow angle beams once again. As a result, two interfering beam pairs induce sinusoidal square-shaped 2D temperature grating. Due to the Soret effect, the temperature grating in the sample induces the corresponding particle concentration grating.

The low power reading He-Ne red laser beam has the same direction through the sample. The Rayleigh type scattering causes the appearance of diffracted intensities of the reading beam (optical index grating). Since the diffracted intensities are hundred times weaker than zero order transmitted beam, the camera lens must be focused on the optical index grating image plane. With the present geometry this plane is ca. 10 mm after the ferrofluid layer. That is close enough to the sample to see Tyndall and absorption effects rather clearly. It means, we see the optical grating of single particles (low contrast regular grating) and agglomeration of particles (high contrast structures) simultaneously. The intensity distribution of the reading laser's beam along the diameter has a shape of a Gausian. In order to avoid Gaussian distribution in presented pictures it is necessary to subtract the stationary background picture with the same Gausian intensity distribution from the recorded video. The stationary background picture is obtained by filming the screen with the grating projection before any excitation is applied to the sample.

The sample is put into a solenoid so that its magnetic field direction coincides with that of laser beams. The intensity of the external magnetic field can be applied up to 50 mT. The solenoid heats up as a current passes through it, therefore a little fan is used to cool the solenoid. Additional heat would affect the results of the experiment.



Video camera connected to a computer with the necessary video processing software.

Figure 1: Simplified scheme of the observation of concentration grating in ferrofluid layer induced by means of a laser beam and an external magnetic field.

Our ferrofluid sample contains Fe_2CoO_4 particles, the mean magnetic diameter of which is 8…10 nm. The Soret coefficient of the ferrofluid is 0.15 1/K, measured by the forced Rayleigh scattering method.

3. Discussion and results

If the sample is exposed only to the laser light the ferrofluid layer stores plain image of the interference pattern of the warming light, either parallel lines or square shaped lattice depending whether the optical setup for 1D or 2D interference was used. If the sample is exposed only to the external magnetic field, the image of hexagonal cells can be observed instead. The cells start to form from one center and the pattern evenly expands (Fig. 2. a).

In our experiment, we exposed the sample to both those excitations (warming light or magnetic field). We changed the sequence of excitation, the intensity of the external magnetic field.

We observed that the pattern mostly preserves the shape of the first excitation.

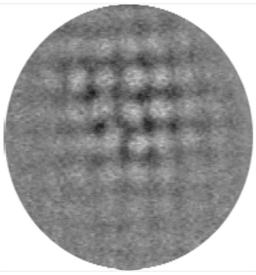
In the experiments where the magnetic field was applied first, whatever the time after which the power laser was turned on or the intensity of the magnetic field, the Soret effect is too weak to change created hexagonal structures. In some experiments we turned out the magnetic field, but did not turned out the warming laser yet. After turning out the magnetic field the pattern still remains, although only the power laser is turned on. The pattern of course fades out by switching off the power laser too (Fig. 2.b).

A If the magnetic field is applied, the magnetostatic interaction occurs, tending to create a hexagonal pattern. The cells start to form from one center.

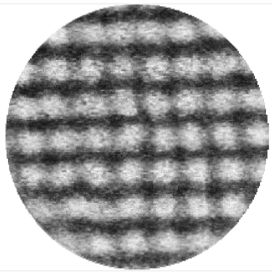
B The pattern while the external magnetic field is not applied any more, but the power laser is still turned on.

Figure 2: Patterns of concentration grating of the ferrofluid layer if the magnetic field is applied before the warming light.

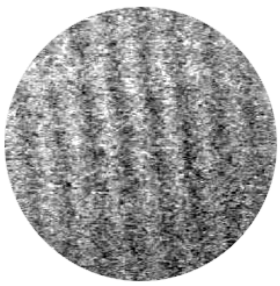
In the experiments with reverse order of excitations - the temperature grid was induced first. Due to the Soret effect, during the characteristic time the particle concentration grid was created. We observed that the external magnetic field turned on afterwards does affect the image. Interference fringes (the concentration gradient) became more contrasted (Fig. 3. a, b) after the magnetic field's application. If the intensity of the magnetic field was set at its maximum (50 mT) the shape of the interference fringes was slightly deformed (Fig. 4. a, b).



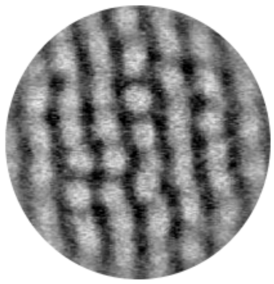
A 2D pattern short after the magnetic field is turned on. Square-shaped 2D grating starts to become more contrasted starting from one center. (The period of the structure is 100 µm)



B 2D pattern after the magnetic field is turned on. (The period of the structure is 100 µm)



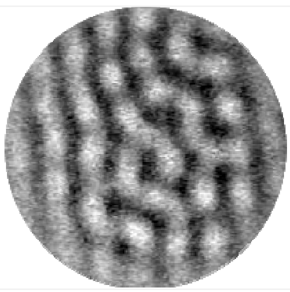
B 1D pattern before the magnetic field is turned on. (The period of the structure is 100 µm)



C 1D pattern after the magnetic field is turned on its maximum. (The period of the structure is 100 µm).

Figure 3: Patterns of concentration grating of the ferrofluid layer if the warming light is applied before the magnetic field.

In the experiments where both excitations were applied simultaneously the competition of the both patterns could be seen. The hexagonal cells started to appear at one spot at the same time as the interference fringes started to form (Fig. 4).



The mixing between the 1D interference fringes and the hexagonal cells as both excitations are applied at the same time. (The width of the image represents 800 µm)

Figure4: Patterns of concentration grating of the ferrofluid layer if the warming light and the magnetic field are applied simultaneously.

This effect is completely resettable – after both excitations are switched off, the aggregation disappears and the sample is ready for the next exercise.

4. Conclusions

Summing up the observed behavior of a 100 μm thick ferrofluid layer under experimental conditions, it could be pointed out:

1. If the magnetic field to the ferrofluid layer is applied first, a pattern of concentration grating preserves a hexagonal shape.
2. If the warming light to the ferrofluid layer is applied first, a pattern of concentration grating tends to preserve its shape during the experiment, but could be slightly damaged if the intensity of the magnetic field is too high.
3. If the warming light and the magnetic field to the ferrofluid layer are applied simultaneously hexagonal cells and the pattern representing interference fringes appear.

5. References

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