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Thermodiffusion study in ferrofluids through collinear mirage effect

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Abstract

We studied some thermodiffusion effects for ferrofluid samples with two different kinds of surfactant by mirage effect technique. We focused a laser beam in the sample introducing a heat gradient that provoked ferroparticles mobility (thermodiffusion) and analyzed the behavior of the mirage signal as a function of the pump laser beam intensity, for a fixed frequency. The main results showed that for the ferrofluid with anionic surfactant no thermodiffusion variation was verified, even for the most concentrated sample. On the other hand, for the cationic one we observed an increase in the thermodiffusion with greater ferroparticles concentration. Therefore, we showed that collinear mirage effect technique can be used for detecting Soret effect generated by the thermal interactions between the laser radiation and the highly absorbing material.

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Keywords: Thermodiffusion; Ferrofluids; Photothermal; Mirage effect

1. Introduction

A photothermal analysis, using the Collinear Mirage Effect technique, had shown that the photothermal signal increases with the ferrofluid (FF) concentrations [1]. The question about how the thermal properties variations are related to the absorption of the fluid arose from the obtained results, since FF are strong light absorbents. The thermal interaction between the laser radiation and the highly absorbing material can account for the presence of a Soret effect, which may have a remarkable influence on the spacial particles redistribution, due to thermal diffusion [2]. The magnetic fluid's Soret effect was first discovered by Dikanskii and Cebers [3] and several authors [4–6] have already studied general magnetic thermodiffusive effects of the magnetic fluids. Nevertheless, the thermodiffusion phenomenon on FFs has not yet been reported by using mirage technique measurements. It is well known [2–6] that the free particles in surfacted FFs should move towards decreasing temperatures. Furthermore, it was verified that the thermodiffusion movement is directly related to peculiar features of interactions between the colloidal particles and its solution [5]. We use collinear mirage technique to observe some differences between the thermodiffusion on surfacted FFs with negative (anionic) or positive (cationic) charged coatings. The aim of this paper is not the mathematical determination of the Soret coefficient, but the relation of the thermodiffusive effects (ferroparticles mobility) observed from mirage measurements as a function of the heat variation for different surfacted FFs.

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2. Theory

The collinear mirage effect is accomplished by the absorption of a modulated exciting beam, which heats the medium, generating a refractive index gradient within the sample. A second (probe) laser beam runs, through the sample, collinearly and in a direction opposite to that of the pump beam. The probe beam deflection comes up from the refractive index gradient generated by the incidence of the exciting beam. The magnitude of the beam deflection, known as the mirage signal, carries information about the thermal and optical properties of the sample. A theoretical 3D model for the calculation of the collinear mirage signal is presented in details elsewhere [7]. This model leads to several different linear relations, whose slope gives directly the thermal properties, being each one indicated for a specific type of material and experimental setup.

The expression for the collinear mirage signal Φ is given by [8]

$$\Phi = -\frac{1}{n}\frac{\mathrm{d}n}{\mathrm{d}T}\int_0^l \left(\frac{\partial}{\partial r}T\right)_{r_0} \mathrm{d}\bar{z}\cdot\hat{\theta}_0,$$

where n is the refractive index and T is the absolute temperature.

From this gradient of temperature, obtained also experimentally by a modulated pump laser beam, a mass flow ($\nabla\varphi$) is generated and, consequently, the gradient of the refractive index as well. By resolving the heat conduction equation above we obtain the thermal diffusion property and, consequently, its Soret coefficient, which is related to the mass flow, as shown below [9]

$$S_T = -\frac{1}{\varphi}\frac{\nabla\varphi}{\nabla T},$$

where ∇T is related to the gradient of temperature discussed in the mirage theory and to the mass flow ($\nabla\varphi$), by the above equation.

3. Experiment

FFs are composed by magnetic particles, with typical dimensions of about 10 nm, dispersed in water [10]. Each particle is coated with a dispersive agent to prevent their aggregation. The nanoparticles are magnetic monodomains of magnetite (Fe_3O_4). We have used two FFs with different surfactant coating nature, i.e. anionic and cationic. The samples were encapsulated in cuvettes 0.5 cm thick on the side and 1.0 cm large. The measurements were performed at room temperature ($T = 22\,^{\circ}$C). Different concentrations of such FFs were used, by adding small amounts of distilled water, varying the volume fractions of pure FF from 2.5% to 100%. Both the probe and pump beams are assumed to be single rays (r) directed collinearly to the sample, but in an opposite direction as shown in Fig. 1. They are separated by a distance r_0 and oriented relative to the z-axis by an angle θ_0 (Eq. (1)). A variable power (0–2 W) VERDI laser provided the pump beam, which allowed us to easily vary the power intensity being focused at the sample. We varied this intensity from 10 up to 200 mW. For the probe beam we used a He–Ne 10 mW laser. The amplitude of the deflected probe beam was provided by a position-sensitive detector and a lock-in amplifier registered the data shown in Fig. 2.

Mirage signal is obtained from a gradient of the refractive index of the sample measured, then it is important to analyse the behavior of this parameter as a function of the ferroparticles concentration. From these data we can obtain the refractive index (n) as a function of the heat variation $\left(\frac{\mathrm{d}n}{\mathrm{d}T}\right)$, which is directly related to the

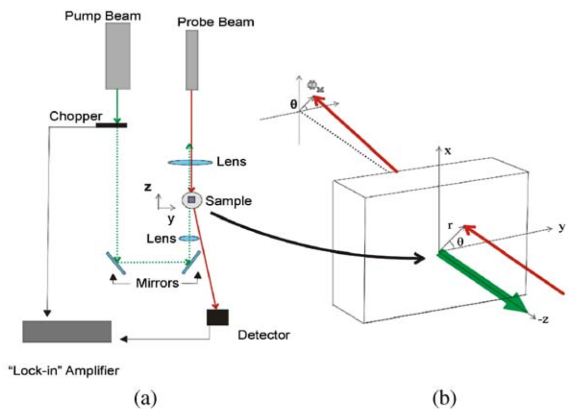

Fig. 1. (a) Experimental setup for collinear mirage effect technique and (b) relevant parameters in collinear geometry.

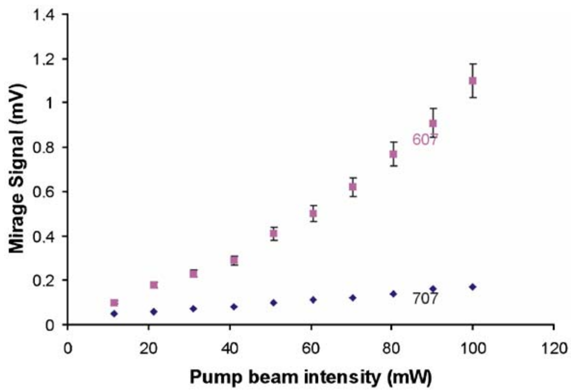

Fig. 2. The graph of the mirage signal (Φ) as a function of the pump laser beam intensity, of a fixed frequency (10 Hz) for the raw data of the FF samples with the highest FF concentration. The data of both FF coated with cationic and anionic surfactant, are labeled as 607 and 707, respectively.