Response of self-assembly for magnetite nanocrystal in magnetic fluid under an applied magnetic field

Yun Zou (邹 芸)[1,2], Yiyou Nie (聂义友)[1], Ziyun Di (狄子昀)[2], Dongchen Zhang (张冬琛)[2], Minghuang Sang (桑明煌)[1], and Xianfeng Chen (陈险峰)[2]

[1]*College of Physics and Communication Electronics, Jiangxi Normal University, Nanchang 330027*

[2]*Department of Physics, the State Key Laboratory on Fiber Optic Local Area Communication Networks and Advanced Optical Communication Systems, Shanghai Jiao Tong University, Shanghai 200240*

Received August 5, 2008

The response time and transmittivity of the magnetic fluid (MF) for different concentrations at room temperature were investigated in this letter. The volume fraction of the investigated sample ranged from 0.44% to 6.47%. It was found that the transmittivity decreased with increasing concentration under a given magnetic field, and the evolution time was changed with different concentrations. Moreover, the light intensity decreased rapidly at the beginning and then became stable when the magnetic field was applied.

OCIS codes: 160.3820, 210.3810, 310.6860.

doi: 10.3788/COL20080610.0767.

With the development of nanoscale technology and material science, the quality of magnetic fluid (MF) has been improved. This makes the MF have better optical properties. Most investigations concentrated on the magnetic birefringence and magneto-optical properties of the MF, which have been studied for more than a decade. Because the MF possesses the magnetism features of solid ferromagnetic matter and fluid behavior of liquid matter, it exhibits unique optical properties, for example, refractive index tunability[1−3], magnetochromatics[4,5], magneto-optic effect[6−15] etc. Based on these optical properties, many MF-based photonic devices can be made. Recently, applications of MF to photonic devices such as MF light modulator[16], MF optical switch[17,18], MF grating[19] etc. have been proposed by some researchers. The photonic devices that based on magnetic fluid have the advantages of low cost, low power, untangent, and easy to be tuned by external field. The response time of the MF based device is essential, if the response time is too long, it cannot meet the need of fast modern optical information technology. It is worth noting that Pu *et al.* and Yang *et al.* have investigated the response time depends on the magnetic field[20,21]. We found that the experimental data of their reports were not accurate because the response time of magnetic field was not considered. In this letter, we studied the dependence of the response time on the concentration at the room temperature. Much faster response time was achieved by our experimental approach.

The schematic of experimental setup is shown in Fig. 1. A semiconductor laser with a wavelength of 650 nm serves as a light source and the electromagnet is controlled by signal generator. Compared with Ref. [20], the response time of the electromagnet made by ourselves decreased from 300 to 40 ms which should be more precise. The investigated MF was water-based Fe_3O_4 and was sealed in a square cell 5.6 μm thick. It is well known that self-assembly will happen within the MF when applied magnetic field, which will scatter the light strongly. According to this, we can detect the response time by observing the variation of the light intensity as the external field switching-on or off. Silicon PV converts the light intensity to electric signal which is amplified via a amplifier so that can be observed from the oscillograph, and the magnitude of magnetic field is probed by Gauss meter. The concentration-dependent light intensity shown in Figs. 2(a) and (b) for the magnetic field strength of 650 Oe are the processes when turn on and off the magnetic field respectively. It is observed from the graphs that the variation of the intensity increases with concentration because the higher concentration leads to the less area of the liquid phase under fixed applied magnetic field. In a word, the transmissivity decreased as the concentration raised.

We can find that when the external magnetic field is turned on or off, it needs some time for the transmitted light intensity to reach the final steady value which is called the corresponding falling or rising response time. In this letter, we calculated the response time when light intensity dropped to or moved up to the half of the total variation.

Figure 3 depicts the falling response time as a function of the concentration. We find that the falling response time first increases and then decreases with the

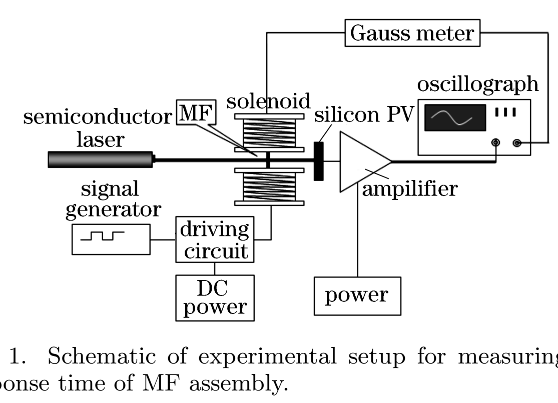

Fig. 1. Schematic of experimental setup for measuring the response time of MF assembly.

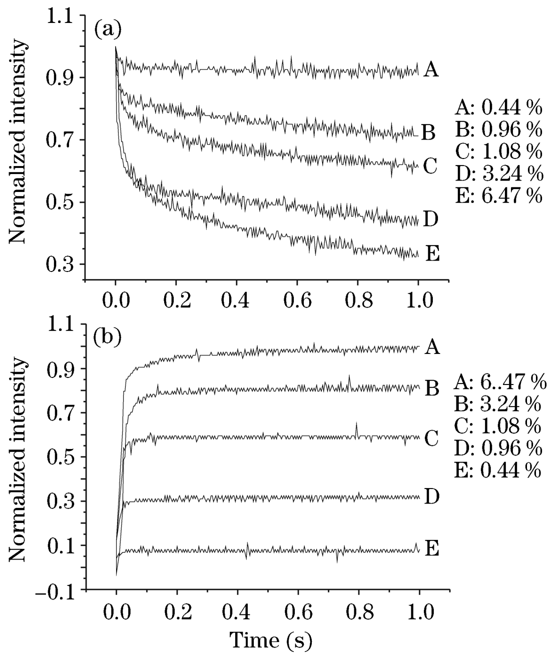

Fig. 2. Light intensity as function of time for MF sample with different particle volume fractions. (a) and (b) are the processes when turn on and off the magnetic field respectively.

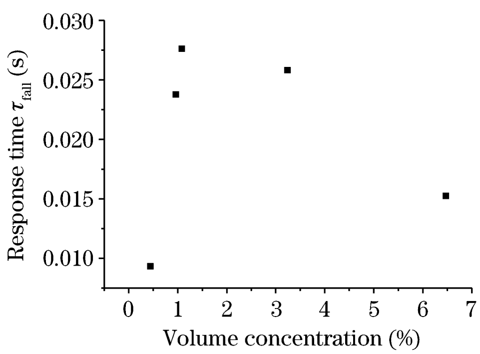

Fig. 3. Response time τ_{fall} versus the concentration.

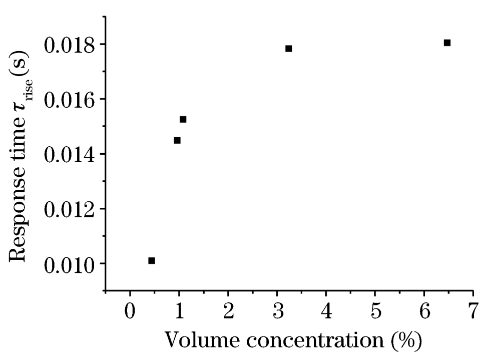

Fig. 4. Response time τ_{rise} versus the concentration.

concentration. The response time ranges from 10 to 28 ms when the concentration varies from 0.44% to 6.47%.

The rising response time of the sample as a function of concentration is plotted in Fig. 4. Obviously, the rising response time increases with the concentration and then tends to stable. The response time ranges from 10 to 18 ms when the concentration varies from 0.44% to 6.47%.

When applying the parallel magnetic field, the magnetic moment of the particles rotates to the direction of the external field and particles have to overcome the Brown motion to aggregates. Particles will be dispersed without magnetic field so the intensity ascend faster than descend. These phenomenas coincide with the experimental results as shown in Figs. 2(a) and (b). In Fig. 3. there are two main factors to determine the agglomeration or dispersion process, magnetic attraction and thermal agitation. During the falling relaxation process, magnetic energy of the particles per unit area increases with concentration, which is comparable to thermal energy when the concentration is low. So it costs more time to agglomerate when the concentration increases from 0.44% to 1.08% (volume concentration). The magnetic energy per unit area is much larger than thermal energy when the concentration is relatively high, and then the agglomeration factor is dominant over the disperse one, hence, the falling response time is more shorter when the concentration above 1.08%. By analyzing the curve shown in Fig. 4, the system has more difficulty to resume, in other words, under the same temperature, the higher concentration has more particles per unit area which need more time to get to the initial state because the particles have more collision times with higher concentration.

Although the response time of the electromagnet made by ourselves now decreases from 300 to 40 ms, the time to establish the eventual magnetic field is relatively long, so that the measured response time may not very accurate. In further study, we will adopt an electromagnet with lower establishing time.

In conclusion, response time depends on the concentration under the fixed temperature and magnetic field are investigated. The falling response time ranges from 10 to 28 ms when the concentration varies from 0.44% to 6.47%, while the rising response time ranges from 10 to 28 ms when the concentration varies from 0.44% to 6.47%. Response time can be modulated by choosing MF with appropriate concentration. But MF with higher concentration will exhibit higher loss and lower concentration leads to lower contrast for the transmission light, so that concentration of MF should be carefully chosen to meet the appropriate requirement of practical applications. Besides MF concentration, the response time of the MF may depend on other parameters, for example, the kind, size, and temperature of the magnetite nanocrystal. Further study will focus on their influences on response time for self-assembly process under an applied magnetic field.

This work was supported by the National Natural Science Foundation of China (No. 10574092), the National Basic Research Program "973" of China (No. 2007CB307000), and the Shanghai Leading Academic Discipline Project (No. B201). X. Chen is the author to whom the correspondence should be addressed, his e-mail address is xfchen@sjtu.edu.cn.

References

1. S. Y. Yang, Y. F. Chen, H. E. Horng, C.-Y. Hong, W. S. Tse, and H. C. Yang, Appl. Phys. Lett. **81,** 4931 (2002).
2. H. E. Horng, C.-Y. Hong, S. Y. Yang, and H. C. Yang, Appl. Phys. Lett. **82,** 2434 (2003).

3. S. Y. Yang, J. J. Chieh, H. E. Horng, C.-Y. Hong, and H. C. Yang, Appl. Phys. Lett. **84,** 5204 (2004).
4. H. E. Horng, S. Y. Yang, S. L. Lee, C.-Y. Hong, and H. C. Yang, Appl. Phys. Lett. **79,** 350 (2001).
5. C.-Y. Hong, H. E. Horng, I. J. Jang, J. M. Wu, S. L. Lee, W. B. Yeung, and H. C. Yang, J. Appl. Phys. **83,** 6771 (1998).
6. M. M. Maiorov, J. Magn. Magn. Mater. **252,** 111 (2002).
7. C.-Y. Hong, J. Appl. Phys. **85,** 5962 (1999).
8. Z. Di, X. Chen, S. Pu, X. Hu, and Y. Xia, Appl. Phys. Lett. **89,** 211106 (2006).
9. Z. Di, X. Chen, J. Chen, and Y. Xia, Appl. Phys. Lett. **90,** 161129 (2007).
10. A. F. Bakuzis, K. Skeff Neto, P. P. Gravina, L. C. Figueiredo, P. C. Morais, L. P. Silva, R. B. Azevedo, and O. Silva, Appl. Phys. Lett. **84,** 2355 (2004).
11. P. C. Scholten, IEEE Trans. Magn. **16,** 221 (1980).
12. M. T. A. Eloi, R. B. Azevedo, E. C. D. Lima, A. C. M. Pimenta, and P. C. Morais, J. Magn. Magn. Mater. **293,** 220 (2005).
13. G. D. Benicio, F. Pelegrini, A. F. Bakuzis, K. L. C. Miranda, and P. P. C. Sartoratto, J. Appl. Phys. **101,** 09J106 (2007).
14. S. Taketomi, M. Ukita, M. Mizukami, H. Miyajima, and S. Chikazumi, J. Phys. Soc. Jpn. **56,** 3362 (1987).
15. V. Socoliuc, M. Rasa, V. Sofonea, D. Bica, L. Osvath, and D. Luca, J. Magn. Magn. Mater. **191,** 241 (1999).
16. J.-W. Seo, S. J. Park, and K. O. Jang, J. Appl. Phys. **85,** 5956 (1999).
17. C.-Y. Hong, J. Magn. Magn. Mater. **201,** 178 (1999).
18. H. E. Horng, C. S. Chen, K. L. Fang, S. Y. Yang, J. J. Chieh, C.-Y. Hong, and H. C. Yang, Appl. Phys. Lett. **85,** 5592 (2004).
19. S. Pu, X. Chen, L. Chen, W. Liao, Y. Chen, and Y. Xia, Appl. Phys. Lett. **87,** 021901 (2005).
20. S. Pu, X. Chen, Z. Di, and Y. Xia, J. Appl. Phys. Lett. **101,** 053532 (2007).
21. S. Y. Yang, Y. T. Hsiao, Y. W. Huang, H. E. Horng, Chin-Yih Hong, and H. C. Yang, J. Magn. Magn. Mater. **281,** 48 (2004).