Springer Link

Research Paper

Microfluidics and Nanofluidics

pp 1-13

First online: 01 October 2015

Manipulation of ferrofluids encapsulated in sandwich structures using alternating magnetic field for high contrast in transmittance

- Chung-Lin Li
- , Chih-Chia Cheng
- , Shiao-Wei Kuo
- , Chih-Feng Huang
- , Jem-Kun Chen

Abstract

In this study, we synthesized Fe_3O_4 magnetic nanoparticles (FMNPs, ca. 13.6 nm) that we dispersed in aqueous solutions at various concentrations to generate ferrofluids. Alternating magnetic field (AMF), generated by alternating currents with various frequencies, was exploited to manipulate the particle-chaining behavior in the ferrofluids. After encapsulating these ferrofluids in a sandwich-structured display (SSD), we evaluated the particle-chaining behavior of the FMNPs through measurements of their transmittance. The transmittance of the SSD encapsulating the 8.26 wt% ferrofluid changed significantly from 1.3 to 83 % under an AMF having a field strength of 87.5 G at a frequency of 700 Hz within a response time of <1 s. The high contrast could be observed by naked eyes due to 81.7 % of sufficient change in transmittance and 1:64 of the contrast ratio. Moreover, an iron plate featuring hollowed-out letters “NTUST” was exploited as a magnetic shielding material to verify the high contrast. When we placed the iron plate between SSD and AMF, a patterned AMF was generated with open and closed zones, respectively. The FMNPs in the SSD assembled as particle chains behind the open zone, resulting

in a transparent state, while the FMNPs remained well dispersed behind the closed zone, resulting in an opaque state. The letters “NTUST” were readily recognizable because of the high contrast between the transparent and opaque states. The FMNPs in this ferrofluid could be manipulated into particle chain assemblies reversibly for magnetic display applications.

Keywords

Ferrofluids Magnetodisplay Magnetic shielding Alternating magnetic field

Concepts found in this article

- Magnetic Dipole Moment
- Effective Magnetic Susceptibility
- Complex Magnetic Susceptibility
- Magnetic Anisotropy
- Brownian Relaxation
- Purification Cycle
- Brownian Relaxation Time
- AC Magnetic Susceptibility
- Magnetic Nanoparticles
- Detergents
- Magnetic Anisotropy Constant
- Fe3O4 Magnetic Nanoparticles
- Refractive Index
- Carrier Liquid

Explore content

Open

Related articles containing similar concepts

What is this?

Magnetic Dipole Moment from a One-Kiloton Underground Nuclear Explosion in a Cavity
Karlykhanov, G. N. · Kondrat'ev, A. A. · Matvienko, Yu. I., et al. in *Journal of Applied Mechanics and Technical Physics (1970)*

Magnetic Dipole Moment

Effect of Heat Treatment to Magnetic Susceptibility on SS 304 as Material for OIML Weight Standard
Hayu, R. · Purnomo, D. in *MAPAN (2014)*

Magnetic Dipole Moment

Radiative $\Omega Q* \to \Omega Q\gamma$ and $\Xi Q* \to \Xi Q'\gamma$ transitions in light cone QCD
Aliev, M. T. · Azizi, K. · Sundu,

H. in *The European Physical Journal C (2015)*

Magnetic Dipole Moment

Magnetic Nanoparticles in Magnetic Resonance Imaging and Diagnostics

Rümenapp, Christine · Gleich, Bernhard · Haase, Axel in *Pharmaceutical Research (2012)*

Magnetic Dipole Moment

Experimental realization of a model glass former in 2D

König, H. · Hund, R. · Zahn, K., et al. in *The European Physical Journal E (2005)*

Magnetic Dipole Moment

» View more suggestions in Relationship Map

Page 1 of 50

References

1. *Andersson H, van den Berg A (2003) Microfluidic devices for cellomics: a review. Sens Actuators B Chem 92(3):315–325CrossRef (http://dx.doi.org/10.1016/S0925-4005(03)00266-1)*
2. *Aoshima M, Satoh A (2005) Two-dimensional Monte Carlo simulations of a colloidal dispersion composed of polydisperse ferromagnetic particles in an applied magnetic field. J Colloid Interface Sci 288(2):475–488CrossRef (http://dx.doi.org/10.1016/j.jcis.2005.02.093)*
3. *Bubenhofer SB, Athanassiou EK, Grass RN, Koehler FM, Rossier M, Stark WJ (2009) Magnetic switching of optical reflectivity in nanomagnet/micromirror suspensions: colloid displays as a potential alternative to liquid crystal displays. Nanotechnology 20:485302CrossRef (http://dx.doi.org/10.1088/0957-4484/20/48/485302)*

4. *Butter K, Bomans PH, Frederik PM, Vroege GJ, Philipse AP (2003a) Direct observation of dipolar chains in iron ferrofluids by cryogenic electron microscopy. Nat Mater 2(2):88–91CrossRef (http://dx.doi.org/10.1038/nmat811)*
5. *Butter K, Bomans PH, Frederik PM, Vroege GJ, Pilipse AP (2003b) Direct observation of dipolar chains in iron ferrofluids by cryogenic electron microscopy. Nat Mater 2:88–91CrossRef (http://dx.doi.org/10.1038/nmat811)*
6. *Chen D-X, Sanchez A, Xu H, Gu H, Shi D (2008) Size-independent residual magnetic moments of colloidal Fe_3O_4-polystyrene nanospheres detected by ac susceptibility measurements. J Appl Phys 104(9):093902CrossRef (http://dx.doi.org/10.1063/1.3005988)*
7. *Donolato M, Sogne E, Dalslet BT, Cantoni M, Petti D, Cao J, Cardoso F, Cardoso S, Freitas PP, Hansen MF, Bertacco R (2011) On-chip measurement of the Brownian relaxation frequency of magnetic beads using magnetic tunneling junctions. Appl Phys Lett 98(7):073702CrossRef (http://dx.doi.org/10.1063/1.3554374)*
8. *Du T, Luo W (1998) Nonlinear optical effects in ferrofluids induced by temperature and concentration cross coupling. Appl Phys Lett 72:272CrossRef (http://dx.doi.org/10.1063/1.120710)*
9. *Erné BH, Butter K, Kuipers BWM, Vroege GJ (2003) Rotational diffusion in iron ferrofluids. Langmuir 19(20):8218–8225CrossRef (http://dx.doi.org/10.1021/la0346393)*
10. *Fang FF, Kim JH, Choi HJ (2009) Synthesis of core–shell structured PS/Fe_3O_4 microbeads and their magnetorheology. Polymer 50:2290–2293CrossRef (http://dx.doi.org/10.1016/j.polymer.2009.03.023)*
11. *Fornara A, Johansson P, Petersson K, Gustafsson S, Qin J, Olsson E, Ilver D, Krozer A, Muhammed M, Johansson C (2008) Tailored magnetic nanoparticles for direct and sensitive detection of biomolecules in biological samples. Nano Lett 8(10):3423–3428CrossRef (http://dx.doi.org/10.1021/nl8022498)*
12. *Ge J, Hu Y, Yin Y (2007) Highly tunable superparamagnetic colloidal photonic crystals. Angew Chem Int Ed 46:7428–7431CrossRef (http://dx.doi.org/10.1002/anie.200701992)*
13. *Inaba N, Miyajima H, Takahashi H, Taketomi S, Chikazumi S (1989) Magneto-optical absorption in infrared region for magnetic fluid thin film. IEEE Trans Magn 25:3866–3868CrossRef (http://dx.doi.org/10.1109/20.42459)*
14. *Jones TB (1995) Electromechanics of particles. Cambridge University Press, New York CityCrossRef (http://dx.doi.org/10.1017/CBO9780511574498)*
15. *Kim H, Ge J, Kim J, Choi S-E, Lee H, Lee H, Park W, Yin Y, Kwon S (2009) Structural color printing using a magnetically tunable and lithographically fixable photonic crystal. Nat Photonics 3:534–540CrossRef (http://dx.doi.org/10.1038/nphoton.2009.141)*
16. *Konstantin IM, Mark IS (2004b) Ferrofluids: flexibility of magnetic particle chains. J Phys Condens Mater 16(23):3807–3818CrossRef (http://dx.doi.org/10.1088/0953-8984/16/23/001)*
17. *Lai Y, Yin W, Liu J, Xi R, Zhan J (2009) One-pot green synthesis and bioapplication of l-arginine-capped superparamagnetic Fe_3O_4 nanoparticles. Nanoscale Res Lett 5(2):302–307CrossRef (http://dx.doi.org/10.1007/s11671-*

009-9480-x)

18. Laurent S, Forge D, Port M, Roch A, Robic C, Vander Elst L, Muller RN (2008) Magnetic iron oxide nanoparticles: synthesis, stabilization, vectorization, physicochemical characterizations, and biological applications. Chem Rev 108(6):2064–2110CrossRef (http://dx.doi.org/10.1021/cr068445e)
19. Lee SY, Lim YS, Choi IH, Lee DI, Kim SB (2012) Effective combination of soft magnetic materials for magnetic shielding. IEEE Trans Magn 48(11):4550–4553CrossRef (http://dx.doi.org/10.1109/TMAG.2012.2196682)
20. Li CL, Chen JK, Fan SK, Ko FH, Chang FC (2012) Electrorheological operation of low-/high-permittivity core/shell SiO_2/Au nanoparticle microspheres for display media. ACS Appl Mater Interfaces 4(10):5650–5661CrossRef (http://dx.doi.org/10.1021/am301543h)
21. Li C, Chang C, Chen J (2015) Fabrication of sandwich structured devices encapsulating core/shell SiO_2/Fe_3O_4 nanoparticle microspheres as media for magneto-responsive transmittance. Sens Actuators B Chem 210:46–55CrossRef (http://dx.doi.org/10.1016/j.snb.2014.12.094)
22. Liu J, Lawrence EM, Wu A, Ivey ML, Flores GA, Javier K, Bibette J, Richard J (1995) Field-induced structures in ferrofluid emulsions. Phys Rev Lett 74:2828–2831CrossRef (http://dx.doi.org/10.1103/PhysRevLett.74.2828)
23. Liu XL, Choo ESG, Ahmed AS, Zhao LY, Yang Y, Ramanujan RV, Xue JM, Di Fan D, Fan HM, Ding J (2014) Magnetic nanoparticle-loaded polymer nanospheres as magnetic hyperthermia agents. J Mater Chem B 2(1):120–128CrossRef (http://dx.doi.org/10.1039/C3TB21146K)
24. Lopez-Lopez MT, Gomez-Ramirez A, Rodriguez-Arco L, Duran JD, Iskakova L, Zubarev A (2012) Colloids on the frontier of ferrofluids. Rheological properties. Langmuir 28(15):6232–6245CrossRef (http://dx.doi.org/10.1021/la204112w)
25. Mao Y, Liu J, Ge J (2012) Tuning the transmittance of colloidal solution by changing the orientation of Ag nanoplates in ferrofluid. Langmuir 28:13112–13117CrossRef (http://dx.doi.org/10.1021/la302353t)
26. Morozov KI, Shliomis MI (2004) Ferrofluids: flexibility of magnetic particle chains. J Phys Condens Mater 16(23):3807–3818CrossRef (http://dx.doi.org/10.1088/0953-8984/16/23/001)
27. Néel L (1955) Some theoretical aspects of rock-magnetism. Adv Phys 4(14):191–243CrossRef (http://dx.doi.org/10.1080/00018735500101204)
28. Odenbach S (2002a) Colloidal magnetic fluids. Springer, Berlin
29. Odenbach S (2002b) Ferrofluids. Springer, BerlinMATH (http://www.emis.de/MATH-item?$0994.76002) CrossRef (http://dx.doi.org/10.1007/3-540-45646-5)
30. Olsen RG, Moreno P (1996) Some observations about shielding extremely low-frequency magnetic fields by finite width shields. IEEE Trans Electromagn C 38(3):460–468CrossRef (http://dx.doi.org/10.1109/15.536076)
31. Park SY, Handa H, Sandhu A (2009) High speed magneto-optical valve: rapid control of the optical transmittance of aqueous solutions by magnetically induced self-assembly of superparamagnetic particle chains. J Appl Phys 105:07B526
32. Perez JM, Josephson L, O'Loughlin T, Hogemann D, Weissleder R (2002) Magnetic relaxation switches capable of sensing molecular interactions. Nat Biotechnol 20:816–820CrossRef (http://dx.doi.org/10.1038/nbt720)

33. *Promislow JHE, Gast AP (1996) Magnetorheological fluid structure in a pulsed magnetic field. Langmuir 12(17):4095–4102CrossRef (http://dx.doi.org/10.1021/la960104g)*
34. *Rao GN, Yao YD, Chen YL, Wu KT, Chen JW (2005) Particle size and magnetic field-induced optical properties of magnetic fluid nanoparticles. Phys Rev E 72:031408CrossRef (http://dx.doi.org/10.1103/PhysRevE.72.031408)*
35. *Sasada I, Inoue I, Harada K (1991) An improved mesh shaking coil and its application to a magnetic shielding panel. IEEE Trans Magn 27(6):5435–5437CrossRef (http://dx.doi.org/10.1109/20.278863)*
36. *Tu L, Klein T, Wang W, Feng Y, Wang Y, Wang J-P (2013) Measurement of Brownian and Néel relaxation of magnetic nanoparticles by a mixing-frequency method. IEEE Trans Magn 49(1):227–230CrossRef (http://dx.doi.org/10.1109/TMAG.2012.2224853)*
37. *Wu KT, Yao YD, Wu TC (2003) Transmittance and dynamic properties of Fe_3O_4 ferrofluid emulsion in hexanes and oleic acid. Phys B 327:319–323CrossRef (http://dx.doi.org/10.1016/S0921-4526(02)01778-7)*
38. *Xuan RY, Ge JP (2011) Photonic printing through the orientational tuning of photonic structures and its application to anticounterfeiting labels. Langmuir 27:5694–5699CrossRef (http://dx.doi.org/10.1021/la200571y)*
39. *Yavuz CT, Mayo JT, Yu WW, Prakash A, Falkner JC, Yean S, Cong L, Shipley HJ, Kan A, Tomson M, Natelson D, Colvin VL (2006) Low-field magnetic separation of monodisperse Fe_3O_4 nanocrystals. Science 314(5801):964–967CrossRef (http://dx.doi.org/10.1126/science.1131475)*
40. *Zeltner M, Toedtli LM, Hild N, Fuhrer R, Rossier M, Gerber LC, Raso RA, Grass RN, Stark WJ (2013) Ferromagnetic inks facilitate large scale paper recycling and reduce bleach chemical consumption. Langmuir 29(16):5093–5098CrossRef (http://dx.doi.org/10.1021/la400165v)*
41. *Zhao Y, Zhang YY, Lv RQ, Wang Q (2011) Novel optical devices based on the tunable refractive index of magnetic fluid and their characteristics. J Magn Magn Mater 323:2987–2996CrossRef (http://dx.doi.org/10.1016/j.jmmm.2011.06.025)*

About this Article

Title

Manipulation of ferrofluids encapsulated in sandwich structures using alternating magnetic field for high contrast in transmittance

Journal

Microfluidics and Nanofluidics

DOI

10.1007/s10404-015-1658-1

Print ISSN

1613-4982

Online ISSN

1613-4990
Publisher
Springer Berlin Heidelberg

Additional Links

- *Register for Journal Updates*
- *Editorial Board*
- *About This Journal*
- *Manuscript Submission*

Topics

- *Engineering Fluid Dynamics*
- *Biomedical Engineering*
- *Analytical Chemistry*
- *Nanotechnology and Microengineering*

Keywords

- Ferrofluids
- Magnetodisplay
- Magnetic shielding
- Alternating magnetic field

Industry Sectors

- *Pharma*
- *Materials & Steel*
- *Automotive*
- *Chemical Manufacturing*
- *Biotechnology*
- *Electronics*
- *IT & Software*
- *Telecommunications*
- *Consumer Packaged Goods*
- *Aerospace*
- *Oil, Gas & Geosciences*
- *Engineering*

Authors

- *Chung-Lin Li* (1)
- *Chih-Chia Cheng* (1)
- *Shiao-Wei Kuo* (2)
- *Chih-Feng Huang* (3)
- *Jem-Kun Chen* (1)

Author Affiliations

- 1. Department of Materials Science and Engineering, National Taiwan

University of Science and Technology, 43, Sec. 4, Keelung Road, Taipei, 106, Taiwan, ROC

- 2. Department of Materials and Optoelectronic Science, Center for Nanoscience, and Nanotechnology, National Sun Yat-Sen University, Kaohsiung, 804, Taiwan, ROC
- 3. Department of Chemical Engineering, National Chung Hsing University, Eng Bld 3, 250 Kuo Kuang Road, Taichung, 402, Taiwan, ROC