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Thermal activated variation in the ordered structures in magnetic fluids films

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Abstract

A hexagonal ordered structure of magnetic columns is achieved in a highly homogeneous magnetic fluid film under an external magnetic field perpendicular to the film surface. At a fixed temperature, the magnetic columns are stable. When the temperature rises, the columns remain unchanged initially, and then some of them disappear as the temperature exceeds a critical value. Furthermore, all columns disappear when the temperature is further raised. The column disappearance was due to the dispersion of column particles into the liquid at a higher temperature. The critical temperature, at which the column particles start to melt, was found to increase under a stronger magnetic field. The relationships between the critical temperature and the fluid concentration, as well as the film thickness, are investigated. Thus, the role of temperature in the stability of ordered structures in the magnetic fluid film is clarified.

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Keywords: Magnetic fluid; Ordered structure; Thermal stability

1. Introduction

Studies on structures in magnetic fluid films under external magnetic fields have been attracting the interest of many scientists and engineers because of the rich patterns in these structures. In the 1970s, the agglomeration of magnetic particles in magnetic fluid films under magnetic fields was observed [1]. Rosensweig and Popplewell then theoretically discussed the agglomeration of magnetic particles in magnetic fluid films under external magnetic fields [2]. Later, a series of structural patterns due to the either phase separation [3–5] or the fingering of microdrops [6–8] in magnetic fluid films under the influence of magnetic fields was reported. It is believed that the kinetic energy of the magnetic particles and the external magnetic field are crucial to the agglomeration process.

In 1997, ordered hexagonal structures formed by magnetic columns in highly homogeneous magnetic fluid films subjected to magnetic fields were discovered by Hong et al. [5]. Also, a multi-level ordered structural evolution was observed [9]. It was further indicated that the ordered structure formation in the magnetic fluid film could be dominated by magnetic field strength, the sweep rate of the field, film thickness and fluid concentration, etc. [10–12]. Since column agglomeration is affected by the kinetic energy of the particles, temperature must also be influential on ordered structure formation in magnetic fluid films under magnetic

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fields. To clarify the role played by temperature in the formation of ordered structures in magnetic fluid films, structure evolutions within magnetic fields are investigated at various temperatures.

2. Experimental details

Kerosene-based $MnFe_2O_4$ magnetic fluid used has a saturated magnetization of 7.7 emu/g. The mean diameter of the particles is 12.4 nm with a standard deviation of 2.4 nm. The magnetic fluid was injected into a 6 μm-thick glass cell to form a magnetic fluid thin film. This film was positioned inside a vacuum cell, whose temperature was controlled with a circulating water system [12]. A LakeShore Pt-111 temperature sensor, which was located beside the film, was used to monitor the temperature within 0.1 °C. Then, the film, as well as the cell, was subjected to a pair of solenoids, which generated a uniform magnetic field perpendicular to the plane of the film. To obtain an ordered structure in the film, a magnetic field was applied normally to the film and was increased from zero to the desired strength at a given sweep rate and a fixed temperature. Thereafter, the field was fixed at the desired strength. After the structure reached equilibrium, the ordered structure was recorded with the aid of a CCD camera and an optical microscope. The temperature was then increased gradually to a higher value, at which point the temperature was held for 15 min, so that the structure was able to reach to another equilibrium state. The temperature was then increased in this way to a final temperature. Thus, the structural evolution during a heating process under a given field strength was investigated.

3. Results and discussion

To investigate the evolution of an ordered structure in the magnetic fluid film during a heating process, an external field was increased to certain strength, here 120 Oe, at 26.0 °C to obtain an initially ordered structure. An image of the structural pattern at equilibrium is shown in Fig. 1(a). As the temperature increased, the structural pattern remained almost unchanged until the temperature exceeded a critical temperature (= 35.0 °C here), at which point the column particles started to disperse into the liquid carrier, and the number of columns reduced. When the temperature rose from 35.0 °C, more columns disappeared, and the interaction between magnetic columns was reduced. As the temperature reached 40.0 °C, the column–column interaction nearly vanished, and hence the structural pattern evolved to a disordered state, as shown in Fig. 1(c). At temperatures higher than 56.0 °C, the influence of the thermal energy completely suppressed that of the magnetic energy on the magnetic particles. As a result, all the originally agglomerated magnetic particles were dispersed into the liquid, as shown in Fig. 1(d), and the magnetic particles became monodispersed.

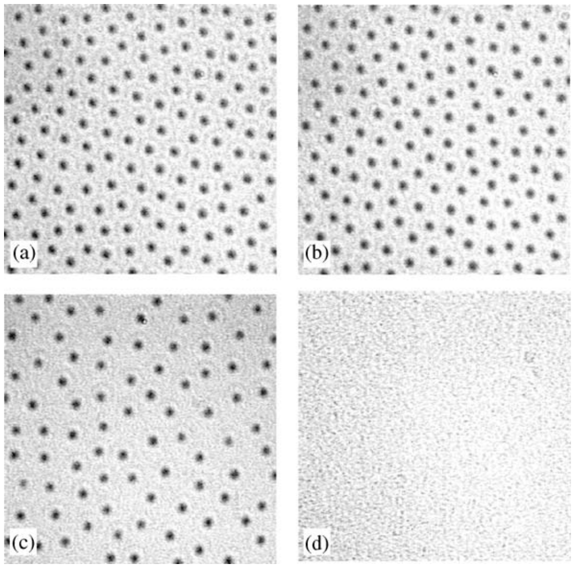

Fig. 1. Structural evolution in the magnetic fluid film under a perpendicular field of 120 Oe when the temperature rose from 26 °C to 56 °C. The $M_s = 7.7$ emu/g $dH/dt = 5$ Oe/s $L = 6.0$ μm.

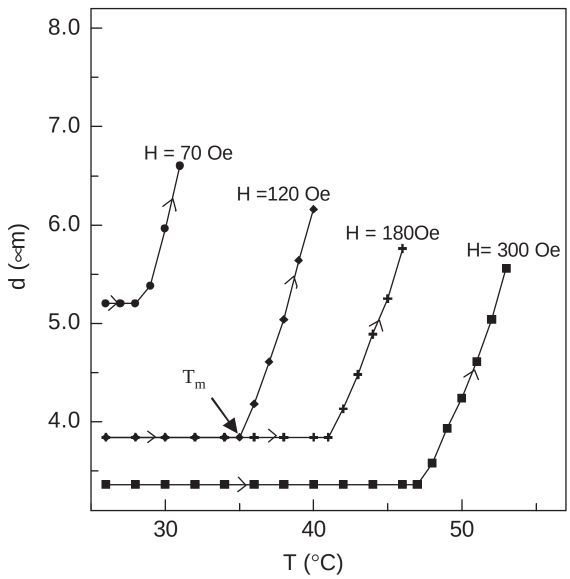

Fig. 2. Characteristic *d-T* curves under various values of field strength *H*. The $M_s = 7.7$ emu/g $dH/dt = 5$ Oe/s $L = 6.0$ μm.

To qualitatively describe the structural evolution during a heating process, the structures shown in Fig. 1 are analyzed. As mentioned above, the structural