Precession of Silver Dendrites in a Magnetic Field Due to MHD Induced Convection

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The "in situ" observation of the growth of dendrites was carried out in the superconducting magnet. The small dendrites showed the precession in the magnetic field. The precession was caused by Lorentz force on silver ions, and the boundary condition promoted the motion. The boundary-assisted MHD is main mechanism of the precession.

Magnetic field effects on chemical reactions are a very interesting topic. Our group has observed interesting results from the use of a superconducting magnet for some years: magnetic orientation of diamagnetic crystals,[1–5] drastic changes of metal dendrites because of magnetic force,[6–10] and so on. Our previous studies have investigated magnetic field effects on the growth of silver dendrites that was produced by the reaction between silver ion and zinc metal. We observed particular magnetic orientation.[11] To elucidate that orientation, we investigated magnetic field effects on the reaction between silver ion and zinc metal and the growth of silver metal two-dimensional (2D) dendrites. We have also undertaken in situ observation of dendrite growth using a CCD camera, which revealed the unique motion of dendrites.

A superconducting magnet (Spectromag-1000; Oxford Instruments PLC) was used in our experiment. This magnet had a room temperature horizontal bore tube of 50 mm diameter. Its maximum field and gradient field were 8 T and $\pm 410\,T^2/m$, respectively. Details are described in previous papers.[9] Silver nitrate (GR grade; Nacalai Tesque Inc.) was used as received. Distilled water was used. A zinc metal sheet (thickness: 1.0 mm, 99.5%; Nilaco Corp.) was polished just before the experiment. A silver nitrate solution (0.05 mol/L) was filled into a cylindrical vessel (volume: ca. 30 mL). A reaction system was constructed using a metal sheet sandwiched between two acrylic plates, as described in a previous paper.[11] The reaction volume was adjusted with the thickness of the metal sheet. Dendrites grew two-dimensionally from the upper and lower surfaces of the sheet; the dendrites grew parallel to the magnetic field. The vessel was capped with a rubber stopper. It was placed at the position in the horizontal bore tube, of which magnetic conditions are 8.0 T and $0\,T^2/m$. All experiments were carried out at room temperature. In situ observation was carried out using a CCD camera (OH-411; Olympus Optical Co., Ltd.) installed in a fiber scope (R100-095-090-50; Olympus Optical Co., Ltd.)

We observed the following redox reaction.

$$Zn + 2Ag^{+} \rightarrow Zn^{2+} + 2Ag$$

The silver metal appears on zinc metal sheet as dendrites. This reaction involves only diamagnetic species.

Figure 1 shows the results of in situ observation at 8 T and $0\,T^2/m$. Here, magnetic forces can be neglected. The magnetic field was applied in a longitudinal direction on these images. During the reaction, which proceeded for 5 min, some small dendrites (ca. 0.5 mm high) grew and began to rotate along the magnetic field. The precession occurred counterclockwise in view from the zinc metal plate. One period was about 0.5 s. Precession stopped suddenly and started again. The precession occurs intermittently until the dendrites are too large to rotate without contact with the wall. The dendrites, however, continue growing without the precession.

According to SEM pictures, the dendrites comprised of many nano-sized dendrites.[11] For that reason, the dendrites were very flexible for a perturbation such as that of a magnetic field.

Because the phenomena were observed at no magnetic field gradient, magnetic forces did not operate on the reaction system. One possible mechanism is the Lorentz force on silver ions (Figure 2). The silver ion in the solution undergoes a Lorentz force in the left side for traveling direction. Subsequently, counterclockwise convection occurred; finally, the dendrites rotate along the magnetic field. The mechanism is similar to a micro-MHD mechanism.[12] Ion motions are reflected in the dendrites'

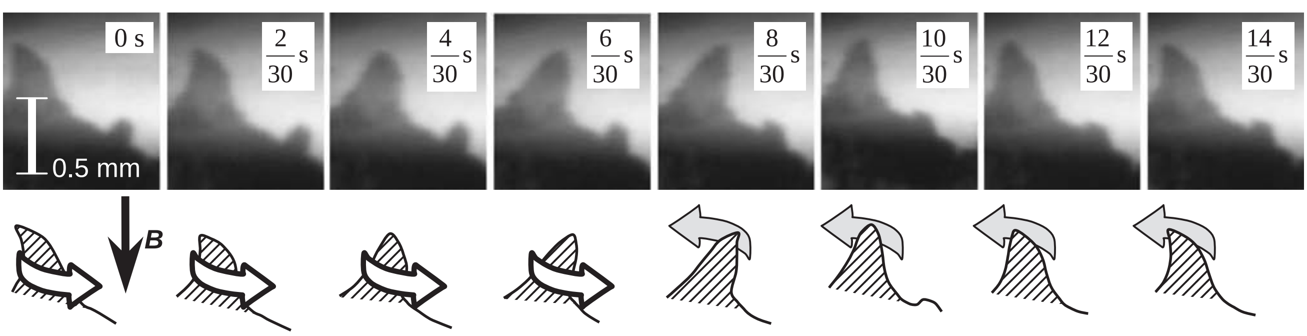

Figure 1. Image sequence of the precession of silver dendrites produced at the Zn–Ag^{+} system in a horizontal magnetic field (8 T). Drawings are included to guide the eye in locating the dendrite positions. The magnetic field direction is a perpendicular one. All images are obtained with a rate of 30 frame/s. The scale bar represents 0.5 mm.

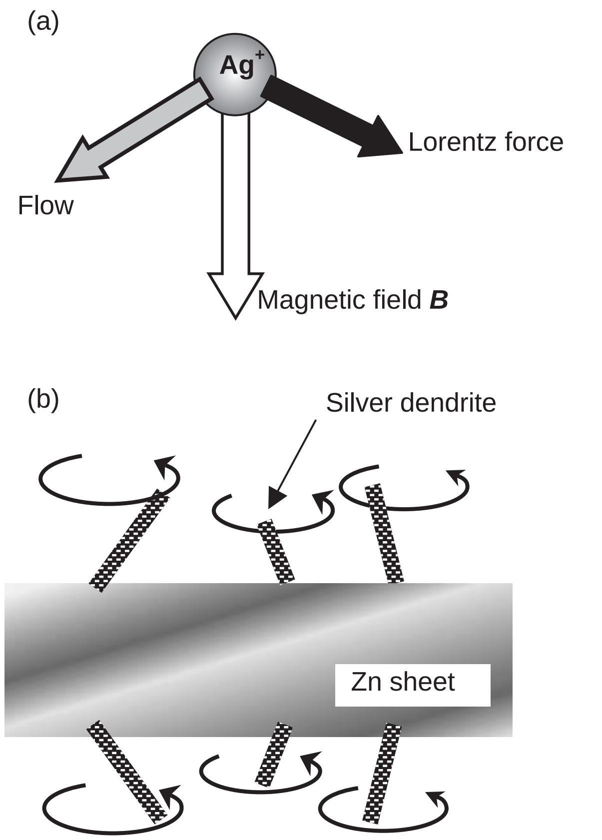

Figure 2. Possible mechanism of precession. (a) The Lorentz force on a silver ion. The silver ion receives the force in the right hand for traveling direction. (b) Many silver dendrites are caused by precession resulting from the Lorentz force.

behavior. When the silver ions' concentration around the dendrite decreases by a local redox reaction, the precession stops until the concentration is recovered.

Moreover, boundary-assisted MHD mechanism promotes precession. Uechi et al. reported that a zinc silicate membrane tube grew spirally by Lorentz force.[13] Usually, because ions in bulk solution move in all directions, the Lorentz forces on them are averaged and thereby become inconsequential. However, at the boundary, such as a wall of a vessel, the ions move anisotropically. The Lorentz forces are not averaged and a certain component of the Lorentz force remains effective. Therefore, the boundary-assisted MHD causes one-way convection, thereby promoting the spiral structure. In our system, one-way convection will occur by the boundary-assisted MHD mechanism. In the moving components of the silver ions, some small perpendicular components to the magnetic field triggers the generation of the Lorentz force. Furthermore, the boundary, such as the wall, emphasizes the anisotropy of the Lorentz force, which causes the one-way convection. The silver dendrites are tethered to the zinc sheet surface. Therefore, they precess by the convection. It is important that the phenomenon shows the transformation from chemical potential to mechanical energy by the magnetic field.

The magnetic field causes a unique motion similar to that created by a micromotor. Boundary-assisted MHD is the main mechanism of the precession. This phenomenon suggests that the magnetic field still offers the potential to control general redox reactions.

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