Effects of shear flow on shear cell diffusion experiments

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Abstract

We report the technological development of shear flow visualization to clarify the effect of shear flow on the diffusion experiments. The experimental equipment was developed to visualize the flow pattern and the penetration depth of flow. A pair of test cells, which can slide each other, was used for the simulation of shear cell. The flow pattern was investigated by both a tracer tacking method and a photochromic method. The flow patterns during the shear motion were visualized clearly. It was found that the mass exchanges between the each cells occurrs after the shear motion was stopped.

1. Introduction

Properties in the liquid states of metals and semiconductors are of paramount importance from both scientific and industrial point of view (e.g. metallurgy, crystal growth, etc.). However, there are not enough such data and the liquid is less understood compared with solids and gases. This might be a major reason why no idealized model still exists for liquid. One objective of our project study is to establish the diffusion model for liquids including a wide range of complexity.

In order to understand the diffusion mechanism or its relation to the microscopic structure of the liquid from a scientific point of view, the highly precise diffusivity data are essential. Diffusion coefficients of liquid metals and semiconductors have been measured under both terrestrial and microgravity conditions [1-7]. The order of diffusion coefficient in liquids ranges from 10^{-9} to 10^{-8} m^2/s which is much smaller than the variations observed in viscosity of liquids metal and semiconductors. Therefore, diffusion measurements can be affected even in the presence of a weak convection flow. Frohberg *et al.* [2] demonstrated that the diffusion coefficients could be measured under microgravity far more precisely than on the earth. As for liquid Ge, Itami *et al.* with a long capillary method [3] and Yoda *et al.* with a shear cell method [4] have carried out diffusivity measurements aboard a TR-IA Japanese sounding rocket. These experiments were the first attempt to measure the diffusion coefficients of liquid Ge under microgravity conditions.

To obtain the highly precise data, the error factors must be removed or minimized. One of the sources of error on using the shear cell method is interflow during a shear motion, which induces the shear flow in liquids. Matthiesen *et al.*[8] and Zeng *et al.* [9,10] carried out the numerical simulation to estimate the interflow depth of tracer liquid to another cell. In this report, we introduce the preparatory experimental study for the clarification of the effect of shear flow on shear cell diffusion experiments. The technological development of flow visualization by using the test fluid is done and the experimental results are shown.

2. Experimental

2.1 Setup

Our target materials of diffusion experiment are metals or semiconductors, which usually have very high melting point and are opaque in visible light. It is too difficult to visualize the liquid motion in these materials. Therefore, silicone oil as a model fluid is used to observe the liquid motion during the shear operation. A schematic figure of flow visualization experiment is shown in Fig. 1. A pair of the sample cell with a cylindrical hole, whose diameter is 10 mm and depth is 50 mm, is made of transparent acrylic plastic (Photo. 1). One of the sample cells is driven by a motor to simulate the shear cell and can be slid with desired speed. Another cell is tightly fixed. Silicone oil is filled in cylindrical holes and the shear flow occurred in the oil is visualized when sample cell is slid. To observe the flow pattern, tracer particles (Japan Microcapsule Product, RM-4446) are previously mixed in the silicone oil. The photochromic method [11] is also employed to measure the interflow depth. The photochromic dye is mixed in silicone oil of the fixed cell. UV laser is radiated near the diffusion interface in this fixed cell and silicone oil in this region is colored with blue dye. The behavior of shear flow is recorded onto the videotape.

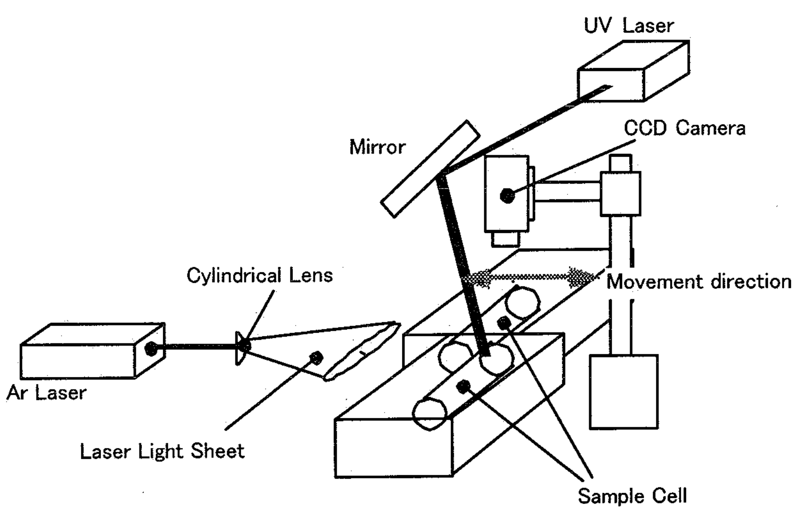


Fig.1 Schematic figure of Flow Visualization Apparatus

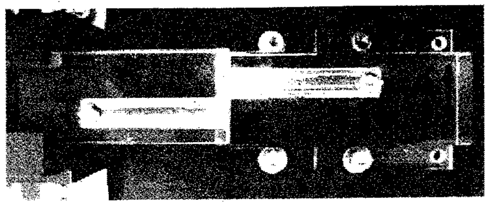


Photo. 1 Photograph of Sample Cells

2.2 Experimental conditions

An actual diameter of shear cell method is about 1 mm. As describe above, 10 mm diameter cell was employed to observe the shear flow clearly. We introduce a non-dimensional number called Reynolds number, *Re*, which is defined as blow.

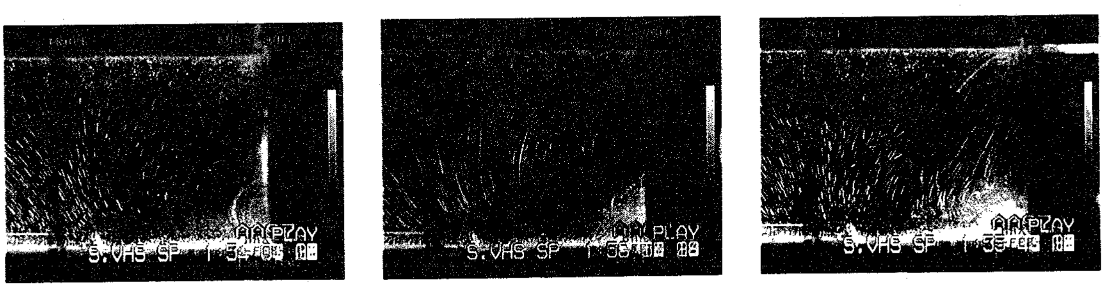
$$Re \equiv \frac{ud}{\nu}, \qquad (1)$$

where u, d, and ν are shearing speed, diameter, and kinematic viscosity, respectively. In the case of our shear cell developed for the germanium sample, Reynolds number changes from 1 to 10 with the variation of the rotating speed. To cover this range of Reynolds number, we used four types of silicone oils of which viscosity are 0.65, 2, 20 and 100 mm^2/s and adopted the sliding speed from 0.5 to 11 mm/s in this experiment. So, Reynolds number varied from 0.2 to 100.

3. Preliminary Results

We carried out a preliminary test to check our visualization equipment. The snapshots of flow pattern are shown in Photo. 2. It is found that the liquid motions are different in each stage which are solid-fluid shear, fluid-fluid shear and stopping of shear. The interflow between each cell occurs after the stop of shear motion due to the inertial flow.

For future work, we will systematically perform the experiment and clarify the effect of shear flow on diffusion experiments. The results of this work will give experimentalists of diffusion measurements the information to optimize the experimental conditions.



(i) Solid-Fluid Shear Flow (ii) Fluid-Fluid Shear Flow (iii) Inertial Flow

Photo. 2 Video Images of Flow Patterns (ν = 20 mm^2/s)

4. Summary

To make clear the effect of shear flow on the diffusion experiments, we developed the experimental equipment to visualize the flow pattern and the penetration depth. A pair of test cells, which can be slid each other, was used and both a tracer tacking method and a photochromic method were employed. The flow patterns during the shear motion were visualized clearly. It was found that the mass exchanges between the each cells occurrs after the shear motion was stopped.

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References

[1] Pavlov, P.V. and Dobrokhotov, E.V., *Soviet Phys. Solid State*, **12** , 225 (1970)

[2] Frohberg, G., Kraatz, K. -H., and Wever, H., *5th European Symposium on Material Sciences under Microgravity - Results of Spacelab-1 (ESA-SP-222)*, 201 (1984)

[3] Itami, T., Aoki, H., Higashimoto, N., Onogi, T., Sugimura, K. , Kaneko, M.,Abe, Y., Arai, Y., Tanji, A., Uchida, M., *et al.*, *J. Jpn. Soc. Microgravity Appl.*, **16**, 79 (1999)

[4] Yoda, S., Oda, H., Nakamura, T., Masaki, T., Koshikawa, N., Matsumoto, S., Tanji, A., Kaneko, M., Arai, Y., Goto, K., and Tateiwa, T., *J. Jpn. Soc. Microgravity Appl.*, **14** , 331 (1997)

[5] Uchida, M., Itami, T., Kaneko, M., Shisa, A., Amano, S, Ooida, T., Masaki, T., and Yoda, S., *J. Jpn. Soc. Microgravity Appl.*, **16**, 38 (1999)

[6] Mathiak, G., Grieshie, A., Kraatz, K.H., and Frohberg, G., *J. Non-Cryst. Solids*, **205-207**, 412 (1996)

[7] Bräuer, P., and Müller-Vogt , G., *J. Crystal Growth*, **186**, 520 (1998)

[8] D.H. Matthiesen, K. Davidson and W.A. Arnold, Physical Modeling of the Effect of Shearing on the Concentration Profile in a Shear Cell, *J. Electrochem. Soc.*, 146 (1999) 3087-3091

[9] Z. Zeng, H. Mizuseki, K. Ichinoseki and Y. Kawazoe, Numerical Study of Dynamic Behavior of Melting Sample in Shear Cell under Microgravity, *Numer. Heat Transfer*, A 34 (1998) 709-718

[10] Z. Zeng, H. Mizuseki, K. Ichinoseki K. Higashino and Y. Kawazoe, Numerical Simulation of Convection Depth in Shear Cell under, *Adv. Space Res.* 24 (1999) 1321-1324

[11] M. Kawaji, Two-Phase Flow Measurements using a Photochromic Dye Activation Technique, *Nuclear Engineering and Design*, 184 (1998) 379-392