

Current status of the development of shear cell technique in ground base research and towards JEM on ISS

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Abstract: The microgravity condition is one of the ideal conditions for the measurements of diffusion coefficients in high temperature melts because of the absence of convection in the liquid sample. The many kinds of experimental techniques, such as, the long capillary method and the shear cell method, have been devised in the ground base research for the measurement of diffusion coefficient in such high temperature melts. Recently, the shear cell technique coupled with the microgravity condition was applied to the measurements of high temperature metallic melts. This technique enables us to measure the diffusion coefficient with high precision. In this paper, a brief discussion is given for the trends of previous diffusion experiments in space performed by Japanese researchers. Recently, Japanese space agency, JAXA, is developing the shear cell technique for the future space experiments in JEM. The current status of the development of our shear cell technique is summarized and new results are presented for typical experiments on the ground by using test samples, for example, liquid silver-gold alloys.

Keywords: shear cell, diffusion coefficient, liquid metals

1. INTRODUCTION

The transport properties in molten states are one of the important features for the understanding of the liquid nature of materials and also are important for the industrial processing such as the crystal growth of semiconductors. Especially, the diffusion coefficient is directly related to the mass transport in liquids. Therefore, the many efforts have been devoted to the developments of measurement techniques [1]. The tracer method is the most popular way for the direct measurement of diffusion coefficient. Two kinds of materials (a diffusion pair) are contacted in a vessel and the diffusion sample is formed. The time development is investigated for the tracer concentration profiles in this sample. Several kinds of elements are selected for the tracer of diffusion depending on the aim of measurements. The isotopes are selected as the tracer of the measurements of self-diffusion coefficient. The impurity atoms are selected as that of the impurity diffusion coefficient. In the case of inter diffusion coefficient, the analysis of the time development of component concentration is performed for a diffusion pair whose initial concentration is different between constituent pieces.

The long capillary method has been widely used because of its simplicity on the experiments and the data analysis. The sample materials are contained in a narrow capillary whose diameter is 1–2 millimeter. Frequently, the diffusion couple is selected as the initial configuration of diffusion. The diffusion couple is composed of two kinds of sample materials with equal length which is connected at the center of capillary. Usually, one of sample material is enriched by the tracer elements. The change of concentration is described in terms of the diffusion equation as shown in following equation,

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}, \quad (1)$$

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, where c is the concentration of tracer, t is the time, x is the distance and D is the diffusion coefficient.

Since this method is applicable to various kinds of materials, the many variations of long capillary method have been developed. Ozelton and Swalin [2] applied this technique to the measurements of self-diffusion coefficient of liquid sodium at the constant volume and the constant pressure. After the diffusion experiments, the profile of sodium isotope distribution was fitted to the error function which is the analytical solution of equation (1) corresponding to the step function as the initial concentration profile. In addition to the diffusion couple method, the several kind of the initial configuration is selected, for example, a small piece of tracer is placed only at the end of capillary, which corresponds to the delta function as the initial concentration profile. Larsson *et al.* [3] measured the self-diffusion coefficient of liquid gallium with the use of this configuration.

The long capillary method is the most conventionally employed for the diffusion experiments in liquids. However, it is a fact that this method is easily affected by the convection under the normal gravity condition. For the suppression of convection in liquid samples, the sample is contained in a narrow capillary. Nevertheless, the convective flow in the liquid sample spoils the concentration profile of tracer in the diffusion sample on the ground. Figure 1 shows the comparison of self-diffusion coefficients of liquid tin measured on the ground and those under microgravity. The diffusion coefficients measured under the normal gravity are widely scattered depending on the data source [4–8]. It can be easily seen that the measured diffusion coefficient is disturbed by the convection, which is remarkable at the higher temperature. The measurements of diffusion coefficient under microgravity were performed by Froberg *et al.* [9], Itami *et al.* [10] and Yoda *et al.* [11]. The microgravity diffusion data of them shows a common temperature dependence without large data scattering. This indicates that the microgravity provides an ideal circumstance for diffusion measurements with no convection. Another point we must consider is that the long capillary method experiences the melting and solidification process during the diffusion experiment. The concentration profile of tracer in the long capillary is disturbed easily by the segregation or the volume change on melting and solidification of liquid sample.

If the liquid diffusion couple can be connected into one piece and separated into many pieces of segments at temperature higher than the melting temperature, it is not necessary to be bothered about the volume change or segregation on melting and solidification. The shear cell technique was innovated in order to eliminate these experimental error sources. The shear cell is constructed from the thin disks which can rotate co-axially. A few small holes are prepared around the center axis to contain the sample. The positions of holes are designed correspondingly to the rotation angle of each disk. The liquid sample can be joined and separated with the rotation of each disk. Nachtrieb *et al.* [12, 13] developed the shear cell for the measurement of self-diffusion coefficient of liquid mercury and gallium. Barras *et al.* [14] measured the diffusion coefficient of liquid thallium. Bruson *et al.* [7, 15] measured diffusion coefficients of tin isotope, antimony, silver and gold atom in liquid tin and in liquid copper respectively. In the early stage, the shear cell was made of metal. Then, the shear cell was made of sintered graphite and sintered boron nitride and was applied to the wide variety of liquid metals. Recently, the shear cell method was applied to the measurement of diffusion coefficient of GaSb [16] and aluminum in liquid gallium and indium [17].

Since 1970th, the microgravity condition has been regarded as an ideal condition for the measurement of diffusion coefficient because of the absence of convective flow due to the weightless condition. Ukanwa [18] performed the first diffusion experiments in space on the Skylab in 1973 and showed us the efficiency of microgravity condition. Reeds *et al.* [19] performed the diffusion experiment of gold in liq-

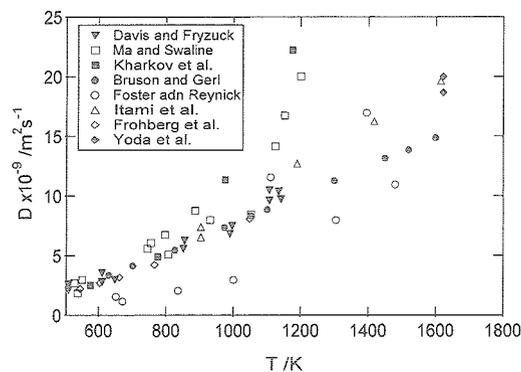


Fig. 1 Self-diffusion coefficient of liquid tin. Data of Davis and Fryzuck[8], Ma and Swaline[5], Kharkov *et al.*[4], Bruson and Gerl[7] and Foster and Reynick[6] are measured in the normal gravity. Data of Froberg *et al.*[9], Itami *et al.*[10] and Yoda *et al.*[11] are measured in the microgravity.

liquid lead under the microgravity on the Apporo-Soyuz. Minster *et al.* [20] measured the impurity diffusion coefficient of copper in liquid lead under the microgravity condition. Frohberg *et al.* performed the pioneering work of diffusion research in space in the space shuttle missions of SL-1 [9], D-1 [21] and D-2 [22,23] and showed that the diffusion coefficient in liquids can be measured with high accuracy under microgravity. Malmejac *et al.* [24, 25] measured the thermomigration coefficient of cobalt in liquid tin with the use of shear cell in the SL-1 mission, which was the first shear cell experiment under microgravity. Diffusion experiments performed in the space shuttle and sounding rocket were summarized in the reviews [26, 27]. Matthiesen *et al.* [28] tried to measure the impurity diffusion in liquid germanium on the space shuttle in 1997. Smith *et al.* [29] measured the diffusion coefficient of many kinds of liquid metals on the Russian space station, MIR. Praizey and Frohberg [30, 31] measured the diffusion coefficient of metallic alloys by the use of shear cell on the retrievable capsule, FOTON in 1999.

In Japan, the diffusion experiments under microgravity were performed both in the space shuttle and in the sounding rocket. Especially, the sounding rockets have played an important role for Japanese diffusion experiments under microgravity. Uchida *et al.* [32] measured the mutual diffusion of PbTe-SnTe on the TEXUS26 in 1990, TEXUS29 in 1992 and TR-IA4 in 1995. Itami *et al.* measured the isotope diffusion of liquid germanium [33], isotope diffusion of liquid lithium [34]. The shear cell method coupled with the microgravity condition is the best way for measuring the diffusion coefficient in high temperature liquids. The shear cell experiment under microgravity was performed by Yoda *et al.* [35] on the TR-IA sounding rocket in 1996 for the measurement of isotope diffusion of liquid germanium. In Japan, the first diffusion experiment under long duration microgravity was performed on the SL-J mission by Dan *et al.* [36] in 1992. Nakata *et al.* [37] measured the diffusion coefficient of liquid InSb in the D-2 mission. The systematic investigation of diffusion phenomena under microgravity have been performed in the space shuttle in MSL-1 international mission by Japanese group. Itami *et al.* [10] measured the self diffusion coefficient of liquid tin with the use of the long capillary method at the temperatures higher than Frohberg's experiments. Uchida *et al.* [38] measured the mutual diffusion coefficient of PbTe-SnTe quasi binary semiconductor melts. Yoda *et al.* [11] have refined the shear cell technique and improved its reliability for the long duration microgravity experiments. The improved shear cell was tested to the experiment of self diffusion in liquid tin and mutual diffusion in PbTe-SnTe, for which the long capillary experiments were performed by Itami *et al.* [10] and Uchida *et al.* [38] respectively on the same microgravity mission (MSL-1). Yamamura *et al.* [39] measured the impurity diffusion of silver ion in molten salts with the use of the electro-chemical method.

The shear cell technique is powerful especially for the measurement of diffusion coefficient on sounding rocket experiments. The start and the end of diffusion can be controlled mechanically by the shear cell technique. Therefore, the short duration of microgravity, usually six minutes, on the sounding rocket can be fully used for the diffusion time without the problem of convection. The microgravity duration of sounding rocket is rather short for the precise measurements of the diffusion coefficient, but enough its the measurement with acceptable accuracy (10 % –20 %). In 1998, Itami *et al.* [40] and Kinoshita *et al.* [41] performed the measurement of diffusion in liquid alloys and molten semiconductors respectively with the use of refined shear cell. In these experiments, the glass seal technique [42] was developed for the prevention of the sample from evaporation.

The shear cell for the space experiment was made of sintered boron nitride. Boron nitride is easy to make a complicate shape but the finishing accuracy of machine work is limited by its fragility. Therefore the 2 millimeter diameter of sample must be accepted for the feasible connection of diffusion couple. This sample diameter of previous shear cell for the space experiments was somewhat large to prevent the convection under the normal gravity on ground. Recently, the many kinds of novel crucible materials have been developed. The precision of finishing of crucibles can be extremely improved enough to make the refined shear cell whose sample diameter is less than 1 millimeter; the considerably precise measurement of diffusion coefficient can be performed even on ground. In this paper, the feature of our shear cell is briefly introduced and the results of test experiment are described.

2. TECHNICAL DETAILS OF SHEAR CELL METHOD

The diffusion measurement due to the long capillary method is easily spoiled by the convective flow and the volume change on melting and solidifying the sample. The shear cell method has developed in order to overcome these problems. In the shear cell methods, the liquid diffusion sample is contained in the long and narrow space similarly to the case of long capillary method. The sample space is made of the pile of thin holes in the disks. Each disk has a hole for a center rod at the center and two or three sample holes around the center hole. Each disk can be rotated separately in order to form liquid columns of the sample for diffusion experiments at the start of diffusion and divides the liquid sample into small piece for the concentration analysis at the stop of it.

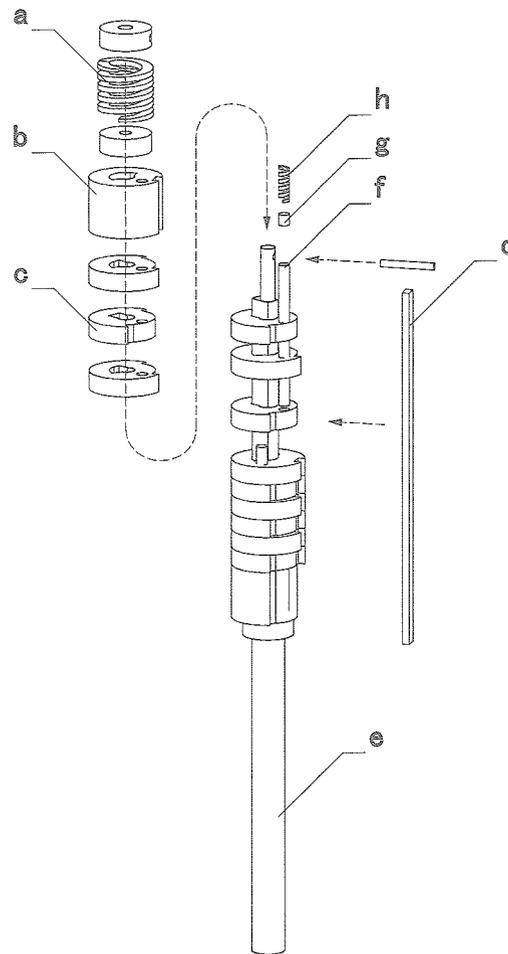


Fig. 2 Schematic figure of shear cell
 a: carbon spring; b: end part; c: disk crucible; d: fixed rod; e: center rod;
 f: diffusion sample; g: carbon rod; h: graphite spring.

The shear cell technique is now being developed in JAXA for the ISS experiments by using the $\text{AgAg}_{0.05}\text{-Ag}$ diffusion couple as a test sample. The shear cell assembly developed in JAXA was composed of more than twenty disks for crucibles, two end disks, a center rod and a crucible holder, as can be seen in figure 2. The same one millimeter was taken as the thickness of disk for the crucible and the diameter of sample hole respectively. The disk parts were made of glassy carbon for which the extremely fine machine work can be applied and other parts were made of sintered carbon. The center rod was made of mullite because of its low thermal conductivity. The samples, which was cast into the rod shape beforehand, were installed in the shear cell together with carbon springs and carbon rods whose diameters were same as those of sample. The typical length of the diffusion couple was 60 millimeters. The springs and rods were placed at the both ends of sample in order to compensate the volume change of sample on heating process particularly on melting and in order to avoid any void formation in the liquid diffusion sample. The experimental inserts were the shear cell, the heater and the ceramic tube which separates the shear cell from the air atmosphere. The heater of sample was made of pyrolytic carbon covered by pyrolytic boron nitride. The experimental inserts were introduced into the experimental chamber with X-ray image observation system. This facility is the ground test model of the Advanced Furnace for microgravity Experiment with X-ray radiography, AFEX, for the Japanese Experimental Module, JEM for the ISS (International Space Station). All of parts of experimental inserts are made of ceramics materials except for the diffusion sample. Therefore, the direct “*in situ*” observation of the connection and the division of liquid sample on the shear cell operation can be observed by the X-ray radiograph.

The resolution of X-ray radiograph is about 0.1 millimeter. A motor was fixed at the bottom of the experimental insert and was connected to the center rod of the shear cell assembly. The W-Re thermocouples were installed at the side of shear cell for the temperature measurement. The observation chamber and experimental inserts are evacuated and filled with high purity argon gas.

The sample in the shear cell was heated by the ceramic heater. The melting behavior was observed by the use of X-ray image. Following the melting of sample, the center rod was rotated by the motor at the bottom of the experimental insert and the each piece of the diffusion couple which had been separated at the initial configuration was joined into one liquid column, the liquid diffusion couple. The joining into the liquid diffusion couple was also observed by the X-ray image.

After the appropriate diffusion time was progressed, the center rod was rotated to the opposite direction and the liquid diffusion sample was divided into small pieces. Figure 3 shows the images of diffusion sample at each experimental stage due to the X-ray radiograph. Then, the shear cell assembly was cooled and the tracer concentration of each sample was analyzed. The dimension of divided diffusion sample was one millimeter diameter and one millimeter length. The shape of each divided sample was changed into thin plate of about 8mm diameter by the repetition of pressing and folding for the measurement of average concentration of overall piece by the X-ray fluorescence analysis.

Since the liquid diffusion sample is created only in the diffusion time by the mechanical operation for the shear cell method, the obtained diffusion coefficients become free from the experimental problem of long capillary method such as the proceed of the diffusion on heating and cooling process and segregation. However, the inherent problems to the shear cell method appear, for example, the miss alignment of diffusion sample and the additional flow induced by the rotation of disks. Our shear cell assembly was contrived in order to minimize the experimental error caused by these inherent problems.

For the solution of the first problem, the accuracy of machine work for the shear cell crucible was improved with the use of novel ceramic material. The X-ray radiography, which was installed to observe the condition of sample on the diffusion experiment, was also valid. If the misalignment of diffusion couple exceeds ten percent of sample diameter, the observed diffusion coefficients are three percent smaller than the exact value, which was evaluated from the numerical simulation [43]. Our shear cell was made of glassy carbon (Niss-

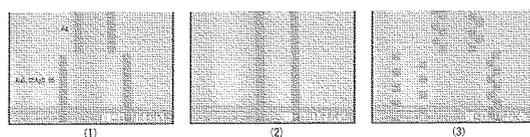


Fig. 3 The X-ray image of Diffusion sample in the shear cell
(1): Before joining; (2): Connected; (3): Divided.

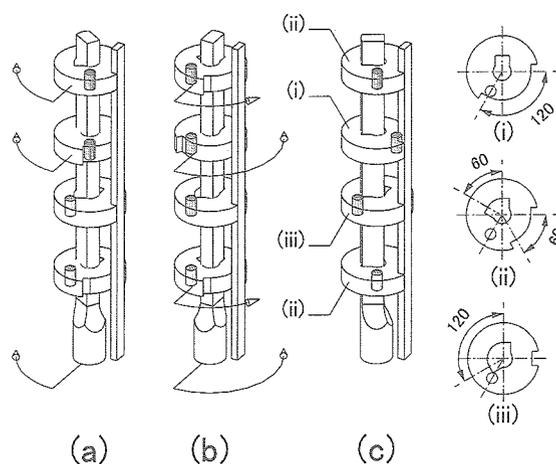


Fig. 4 The mechanism of shear cell.
(a) The rotation for the sample joining. (b) The rotation for the sample division.
(c) The divided state of sample. Arrows indicate the direction of rotation. The disks are separated for the visualization of the mechanism in the drawing. Each sample position is determined due to the rotation direction of center rod, inner arc at the center of disk, outer arc at the rim of disk, position of sample and fixed bar. The degrees of inner and outer arcs restrict the rotation angle of disks.

inbo Industrial Inc.), which is a very hard material. The glassy carbon provides the fine and accurate machinery products whose inaccuracy is less than 1 micrometer. It was confirmed that the misalignment of diffusion sample in our experiments was less than 0.1mm which was smaller than the resolution of X-ray radiography. The error derived from the misalignment was sufficiently negligible.

The second problem is unavoidable for the shear cell method. The rotation of cell added the drag force to the liquid at the contact with the moving disk and a pair of small vortex flow occurs on the joining of liquids. Therefore, the step function of tracer distribution as the initial tracer distribution is destroyed because the small amount of volume exchange occurs between each liquid piece of diffusion couple. This error of concentration in the initial stage provides additional contribution of errors to the evaluation of true diffusion coefficient. The contribution of this problem can be negligible if the diffusion time is sufficiently long. The same situation occurs on the division of liquid sample. The sample division are classified into two cases depending on the design of shear cell; one is a sequential division and the other is a simultaneous one. Each of these patterns has its merits and demerits. In the case of sequential division, the flow pattern in the sample is rather simple since the flow is limited only at the cutting part and this flow part moves sequentially; the finish times of diffusion are different between the first divided part and last one. In the case of simultaneous division, it is not necessary to be worried by the delay of cutting time. But we must be careful for the fact that the flow pattern in the sample is rather complicated. In our shear cell, the latter pattern is selected, i.e. the sample is divided simultaneously. The shear cell disk is constructed of three types of disk which possesses the cut part at the rim and the center hole which can be seen in figure 4. The angles of cut parts and position of sample holes correspond to the rotation angle of disk. The liquid diffusion sample can be joined or divided by the rotation of center rod in the direction of clockwise and counter clockwise respectively. Each disk is rotated simultaneously and is stopped at the appropriate position for the joining and the division due to the combination of cut angle of rim on disks and the fixed rod, which can be seen in figure 4.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The Ag-Au alloy was selected as the test material for the verification of the operation of our shear cell. It is well known that the silver and gold are inert materials and both are easy for handling. This system has another merit for the diffusion experiments judging from the analysis of concentration of diffusion sample. The phase diagram of Ag-Au system shows a typical solid solution system whose liquidus line and the solidus line are quite close. Therefore the segregation in the solidified diffusion sample is kept to be sufficiently small. This merit allows us that the concentration profile can be analyzed with the sufficient accuracy by the conventional X-ray fluorescence analysis for the solidified samples.

The diffusion couple was consisted of pure silver and silver-gold alloy in which five atomic percents of gold was contained. Each sample was cast into the narrow rod which was 1 millimeter diameter and 30 millimeter length. The end faces of samples were finished to be flat by the fine polisher for the optical fiber. The diffusion experiments were performed at the temperature of 1300K, which is 56 K higher than the liquidus temperature. The concentration profiles in the solidified samples were determined by the X-ray fluorescence analysis.

In the ideal case, the concentration profile of gold atom in the sample studied should obey the error function, which is the analytical solution of the diffusion equation for the diffusion couple and is given as follows:

$$\frac{2(c(x,t)-c_1)}{c_2 - c_1} = 1 - \text{Erf}(Y) \quad (2)$$

where c_1 and c_2 is the concentration of tracer in the diffusion couple at the start of diffusion. The error function, Erf , is defined as follows:

$$\text{Erf}(Y) = \frac{2}{\sqrt{\pi}} \int_0^Y \exp(-y^2) dy \quad (3)$$

The concentration profiles obtained from experiments are in good agreement with equation (2), which is shown in figure 5. The diffusion coefficient of gold atom in liquid silver was evaluated by the least square fitting of experimental data to this analytical solution (equation (2)).

The diffusion experiments were performed with the variation of the duration of diffusion in order to clarify the magnitude of error due to the joining the liquid. The duration of diffusion was varied from 240 seconds to 25200 seconds. From this variation of diffusion time, the diffusion coefficients obtained from shear cell experiments strongly depend on the duration of diffusion. The diffusion coefficient for the short duration was 50 % larger than for the sufficiently long duration. This is clearly derived from the initial disturbances due to the

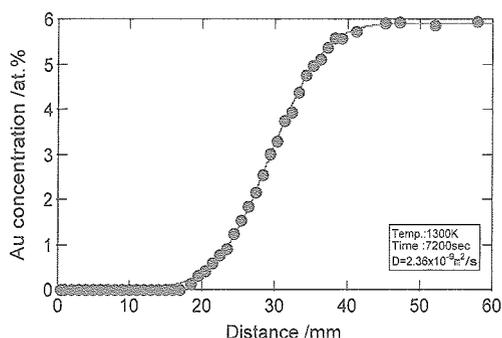


Fig. 5 Typical diffusion profile of Ag-Au_{0.05}Ag_{0.95} diffusion couple with the use of shear cell. The solid circle represents the experiment at 1300K with the diffusion time of 7200 s. The solid line shows the solution of Fick's second law with $D = 2.36 \times 10^{-9} \text{ m}^2/\text{s}$.

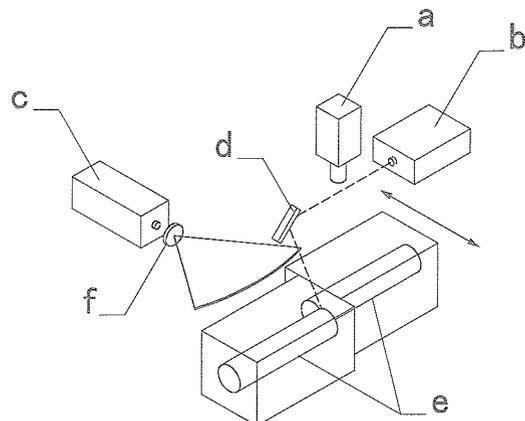


Fig. 6 Schematic figure of the apparatus for the observation of shear flow.

(a): video camera; (b) UV laser for the coloring the photochromic dye; (c): Argon laser; (e): observation cell(acryl resin); (f): cylindrical lens. The cylindrical vacancy of (e) is filled with the silicon oil together with particles and the dye.

joining of the liquid diffusion sample on the shear cell operation.

Concerning the initial disturbance of the shear cell technique, direct observation experiments were carried out with the use of silicon oil as a model fluid. The properties of fluid mechanics, for example, kinetic viscosity, the scale of model cell and the velocity of cell movement, were determined by simulating the hot liquid sample in the shear cell. The flow pattern observed were classified by the non-dimensional fluid parameter i.e. Reynolds number, $Re = ud/v$, where u , d and v are the shearing speed of cell, the diameter of sample and the kinematic viscosity respectively. In the diffusion experiments of liquid silver alloys, the Re is equal to 1.8 where $u = 0.554 \text{ mm/s}$, $d = 1.0 \text{ mm}$ and $v = 0.396 \text{ mm}^2/\text{s}$. The Re was varied from 0.2 to 110 due to the change of shearing speed and the viscosity of silicon oil. The motion of model fluid was observed by the photochromic dye [44, 45] in addition to the tracking of the particle tracer. The observation system is shown in figure 6. The same kinds of experiments are reported by several authors, though most of them used particles as a marker of flow. This experiment is the first to use the photochromic dye as a marker of shear flow for the shear cell. The density of colored fluid and others are not different in the case of photochromic dye method. It is not necessary to worry about the sedimentation or the buoyancy of tracer particles. Furthermore, it is available to mark only the fluid at the contact of diffusion couple. The flow pattern of each time step is shown in figures 7 and 8. It can be seen that the small vortex flow was induced by the drag force given by the movement of the cell. The photochromic dye clearly indicated the trajectory of fluid motion at the contact of liquid diffusion couple.

This trajectory was regarded as the ridge of area of liquid exchange between the samples of diffusion couple. Figure 9 shows the dependence of penetration length, L on Re .

Under the condition of the Re of diffusion experiments of liquid silver alloys, which is about 10, the influenced area of flow was estimated to be within the adjacent part to the interface of the joining part. The influenced length was less than 20 % of the sample diameter.

The time dependence of observed diffusion coefficients can be explained by the result of this model fluid experiment qualitatively, as shown in figure 10. The enlarged diffusion coefficients due to the initial flow on joining are evaluated by the numerical simulation with the change of the penetration length, L . The initial concentration of disturbed area would be evaluated as the interpolation of linear function of each concentration of diffusion couple. The exact diffusion coefficient of gold in silver was assumed to be $2.24 \times 10^{-9} \text{ m}^2/\text{s}$. This value was obtained from the average value of experiments whose duration of diffusion was sufficiently long. Figure 10 shows the comparison of experimental data with results of numerical simulation. In the case of L equal to the sample diameter, the result of simulation is in good agreement with the experimental result. The L evaluated from this numerical simulation is five times larger than that of model fluid experiments. The quantitative difference of L between the actual diffusion experiment and model fluid experiment may be derived from the wetting of sample to the shear cell. The additional experiments should be performed for the quantitative estimation of L from model fluid experiments which simulate also the wetting condition. Nevertheless, the observed diffusion coefficients became constant when the diffu-

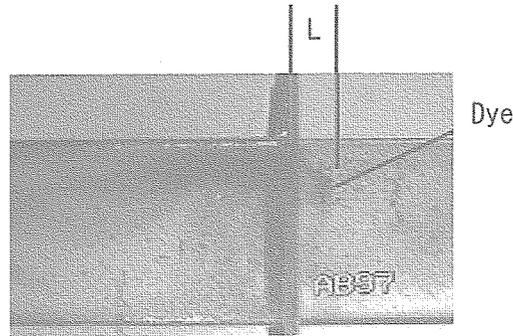


Fig. 7 Video image of induced flow on joining two liquid columns by using the photochromic dye

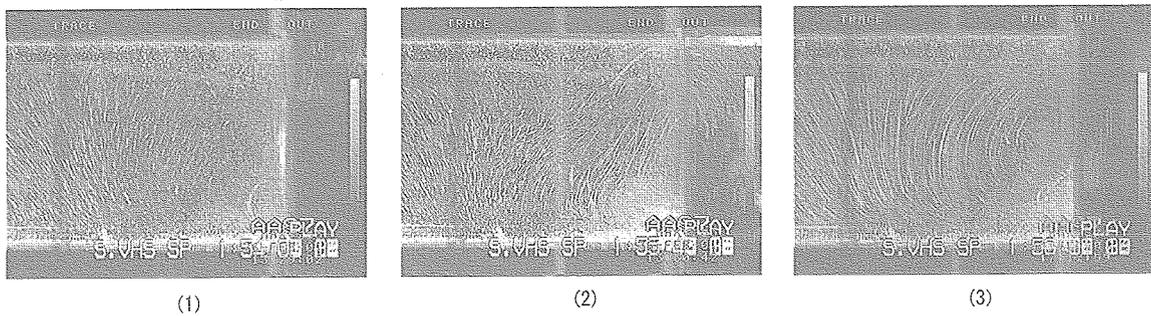


Fig. 8 Video Image of flow pattern
(1): Beginning of joining; (2): Intermediate state; (3): End of joining

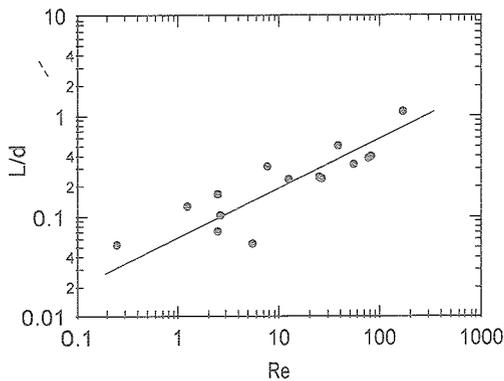


Fig. 9 Relation between L/d and Re for the model fluid simulation; L : penetration depth; d : diameter of hole in the shear cell disk; Re : Reynolds number.

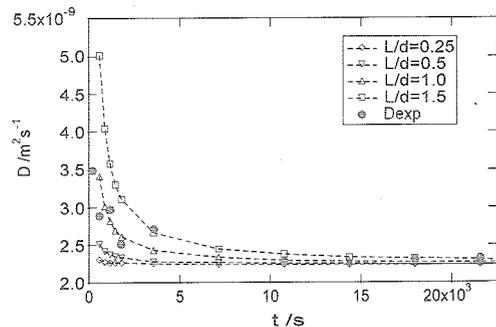


Fig. 10 The time dependence of the observed diffusion coefficient. Closed circle: experimental data; open marks: numerical simulation.

sion time longer than 10800 sec, as shown in figure 10. Hence, the disturbance of initial disturbance of flow on joining can be negligible if the diffusion time is sufficiently long.

The same kind of flow is also induced by the cutting process and the stream of flow is much more complicated. Nevertheless, the effect on diffusion coefficient can be regarded to be much smaller than the former case because of following two reasons. The first one is that the concentration differences between the divided samples are small at this stage and, therefore, the concentration change due to the liquid exchange may be small. The second one is that the small vortex flows induced by the cutting process is limited just in the neighborhood of interfaces of divided samples. Therefore, the influence of cutting process dose not exceed the length of divided sample and the error due to this cause may be negligible.

Finally the discussion is focused on the influence of the convective flow on the diffusion coefficient measured by the shear cell. If the convection occurs in the sample, the mixing of diffusion couple is enhanced. Therefore, the observed diffusion coefficient increases

depending on the diffusion time. Nevertheless, the experimental results show that the diffusion coefficient becomes independent on the diffusion time in the case of the long diffusion time. The diffusion coefficient obtained, $2.24 \times 10^{-9} \text{ m}^2/\text{s}$, for liquid $\text{AgAu}_{0.05}\text{-Ag}$, is slightly lower than the experimental value by Gupta, which is $2.46 \times 10^{-9} \text{ m}^2/\text{s}$ [46]. The experimental errors of long capillary method, i.e. the undesirable diffusion on heating and cooling process and the segregation on solidification, tend to increase the measured diffusion coefficient. The shear cell method adopted here is advantageous for the removal of these errors. In the present experimental configuration, the density of liquid silver in the upper position is lighter than that of silver-gold alloy in the lower one. Additionally, the temperature of upper part was kept to be about five degrees higher than that of lower part in order to prevent the convection. The present configuration might suppress the occurrence of convection in the liquid sample.

4. THE CURRENT STATUS OF THE SHEAR CELL FOR THE MICROGRAVITY EXPERIMENTS ON ISS

The shear cell, which is now being developed in JAXA, is applicable to the microgravity experiment without any change of basic design. The shear cell with the similar design has been successfully applied to the microgravity experiments [11, 35]. Currently, the experimental insert of shear cell is being developed for the measurement of self and impurity diffusion in liquid germanium, which is to be performed as microgravity experiments in JEM. The furnace, which is named as the gradient heating furnace, GHF, has three heaters in the evacuated chamber and the available maximum temperature is around 1870 K. The GHF is developed for the high temperature experiment with temperature gradient such as the crystal growth of semiconductors. The GHF is also applicable to the isothermal experiment for the optimization of furnace configuration. The design of experimental insert for the shear cell experiment in JEM is same as that of the grand base experiment, which is consisted of shear cell covered with a tube and a fitting part to the furnace, thermocouple and motor for cell rotation. The test experiment will be performed in the GHF by using the test model of experimental insert in the near future.

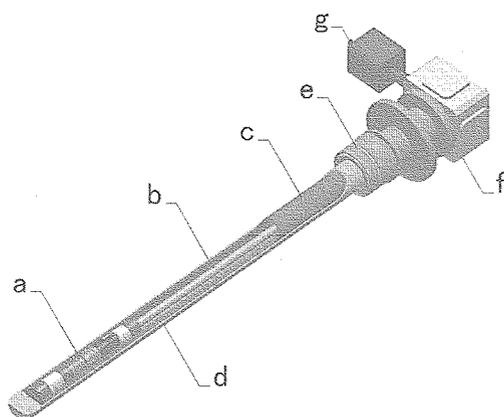


Fig. 11 Experimental insert for the GHF.
a: shear cell assembly; b: center rod; c: shear cell support; d: metal tube;
e: fitting part of GHF; f: interface box; g: motor.

5. CONCLUSION

The experimental results of simulation of fluid motion for the shear cell are in good agreement with the numerical simulation whose initial mixing length is equal to the capillary diameter. The diffusion coefficient can be measured by the use of present shear cell if the diffusion time is sufficiently long; in the case of liquid metals, longer than 2 hours (10800 sec). In the case of this experiment, the convective flow can be regarded to be negligible since the density difference between the upper part and the lower one properly established to suppress the convection. The shear cell technique is satisfactory for the measurement of the diffusion coefficient with high precision. Nevertheless, the convection in the diffusion sample cannot be avoided completely on the ground for some interesting cases, for example, the measurements of the self-diffusion coefficient just above the melting temperature and the diffusion with the strong temperature depen-

dence. It should be noted that it is the next best method to add the temperature gradient to measure the exact diffusion coefficient. The diffusion coefficient itself should be determined on the isothermal condition. In such cases, the microgravity condition coupled with the shear cell will be the last resort for the measurement of diffusion.

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