Microgravity research activity in Japanese community

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Abstract

Japanese microgravity activities are reviewed; fluid physics, combustion, crystal growth, thermophysical properties and welding. For Marangoni flow study, the dynamic PAS (particle accumulation structure) was observed not only on earth but also under microgravity; this experiment was carried out using the MAXUS rocket under the ESA-JAXA collaboration. Electrolysis of KOH solution shows dependence of the number and size of O_2 and H_2 bubbles on gravitational acceleration. For bubble motion in the tube, the drift-flux model is of practical importance for two-phase flow analyses under microgravity. Mode selection of splashing or bouncing was observed as a function of gravitational acceleration for coronet formation. For droplet combustion, the Marangoni flow was found to play an important role for flame propagation. Ice crystal growth is carried out to investigate crystal growth mechanism. A Lyzozyme crystal 3mm in diameter was grown on board the FOTON mission. Solid solution single crystal growth of $In_{1-x}Ga_xAs$ is planned on board the International Space Station (ISS) Japanese Experimental Module (JEM)-Kibo. Diffusion constant measurements are planned to be carried out on board the ISS-Kibo. Thermal conductivity of molten silicon was measured using electromagnetic levitation superimposed with a static magnetic field. This is a spin-off technology of space utilization. Free fall capsule using a balloon is explained. Features of the Japanese parabolic flights are discussed.

1. Introduction

After the first human space activity was carried out, a concept of gravitational acceleration has been clearly recognized not only by people in space community but also by scientists in other fields, such as physical and life sciences. Space utilization opened a door for a new field of sciences; i.e. physics of gravity-dependent phenomena. Micro-gravity science is not only an ad-hoc activity of space development and exploration, but also should be recognized as one of cutting-edge and basic sciences which create new value for human activity. After microgravity environment was introduced as a tool for research, science and technology showed tremendous progresses; they are critical phenomena, crystal growth (semiconductor, protein), combustion, casting, heat/mass transport, boiling, thermophysical property measurement and so on. Microgravity also initiated and accelerated science even on earth. Typical examples are the science of undercooled high temperature melts, mechanisms of protein crystal growth, the physics of surface tension related phenomena, and so on.

Microgravity research activities in the Japanese community are carried out in several frameworks; they are 1) subjects targeted for the experiments on board the Japanese Experimental Module, Kibo, which means dream, of the International Space Station, 2) researches supported by Ground-based Research Program for Space Utilization supported by the Japan Space Forum, 3) activities carried out as Research Working Group Activity of Space Environment Science supported by the ISAS-JAXA, 4) application research program supported by JAXA, which supplies a unique opportunity to prepare materials in space, and 5) independent activities using other resources. International Topical Team Activities are also important to promote microgravity sciences; worldwide networks of the scientists are organized and experimental resources are shared. In this paper microgravity activities in Japanese community are reviewed.

2. JASMA activity

Almost all scientists, who are involved in microgravity science, are members of the JASMA (Japan Society of Microgravity Application), established in 1983 and now headed by Prof. Odawara of Tokyo Institute of Technology. The current policies of the society are as follows:

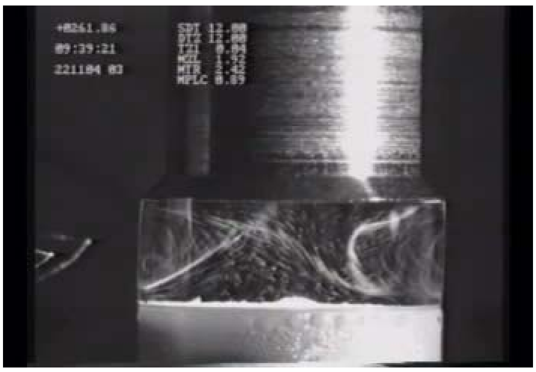

Fig. 1 (Movie) Particle accumulation structure in the liquid bridge of silicone oil [2]. Diameter of the liquid bridge is 6mm.

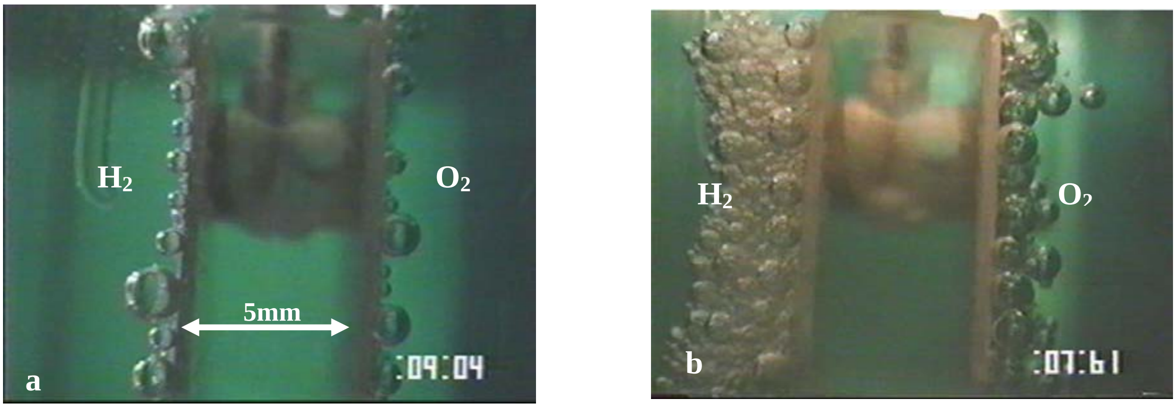

Fig. 2 (Movie) Bubble formation in KOH solution under 1G (a) and microgravity (b)conditions[4].

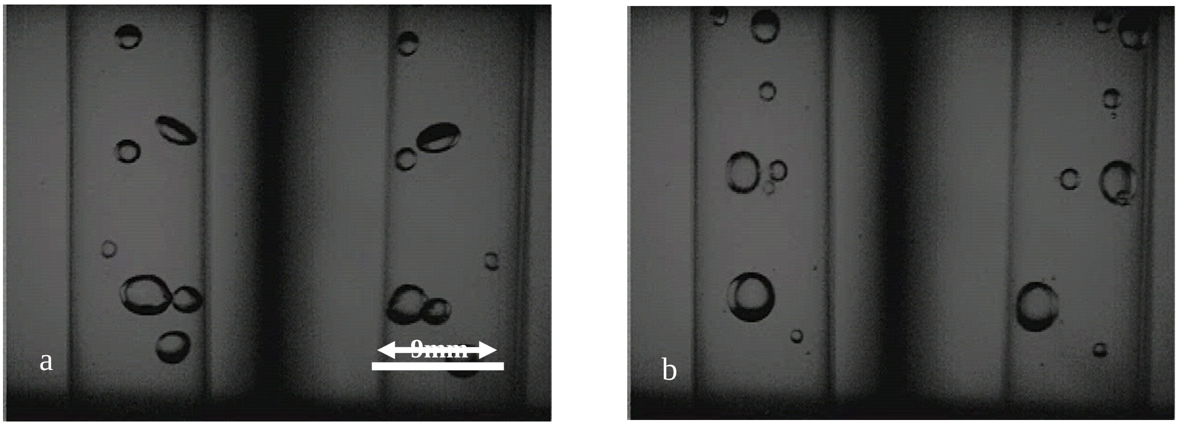

Fig. 3 (Movie) Bubble flow motion under 1G (a) and microgravity (b) conditions[5].

- Strengthening of JASMA community interactions
- Expanding space experiment opportunities
- Initiatives toward international globalizations
- Cooperation for future-incentive young researchers
- Promoting advantageous microgravity science and technology
- Linking with other space-related associations and organizations.

The JASMA organizes an annual meeting in autumn and stimulates young students through a Mohri poster session, where special awards are given by Dr. Mohri, the first Japanese astronaut. Journal of JASMA is issued four times per year, and it includes original scientific and technical papers. JASMA cooperated with ELGRA (European Low Gravity Research Association) to organize the Europe-Japan collaborative session for ELGRA biennial assembly in 2005.

3. Japanese progress in microgravity science

In this section, the recent progress in microgravity sciences is reviewed, particularly in the field of fluid physics, combustion science, materials science, crystal growth, thermophysical properties and welding.

3.1. Fluid Physics

The Marangoni flow experiments will be carried out on board the JEM-Kibo, in order to investigate dependence of the critical Marangoni number on the liquid bridge diameter and the lower mode of azimuthal oscillation of instability[1]. In the course of preparation of this experiment, a dynamic PAS (particle accumulation structure) observation experiment was performed using the ESA-MAXUS rocket under the ESA-JAXA collaboration with Schwabe[2,3]. Figure 1 (Movie) shows PAS observed under microgravity conditions.

The Fukunaka group observed the effect of gravitational acceleration on bubble formation during electrolysis of water with various pH values and found the gravitational acceleration affects the

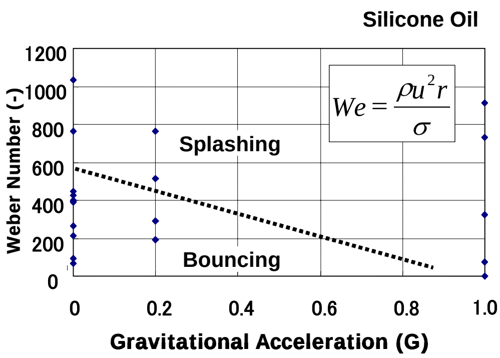

Fig. 4 Map for mode selection for splashing and bouncing[9].

Fig. 5 (Movie) Generation of fuel vapor jet at 3.0 MPa for n-decane[11]. Droplet diameter is 1mm.

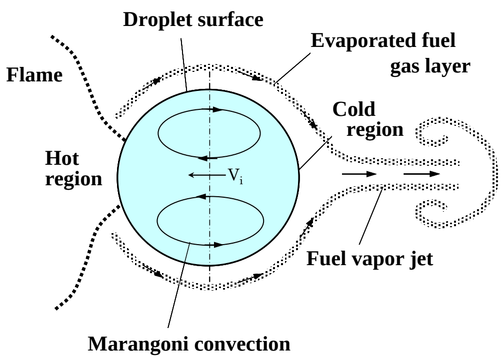

Fig. 6 Mechanism of fuel-vapor jet formation[11].

number and size of H_2 and O_2 bubble formed at the cathode and anode, respectively, as shown in Figs 2a and 2b (Movies)[4]. This is explained by the wettability, which is determined by the three-phase interaction among electrolyte, gas and electrode.

As shown in Figs. 3a and 3b (Movies), the Takamasa group studied bubble motion both in normal gravity and microgravity as a basic study of two-phase flow[5,6]. They reported that bubble rising velocity in microgravity is lower than that in normal gravity. Bubbles in a microgravity environment are almost spherical, which means that no vertical or lateral stress acts on the bubbles. Through this study, it has bee clarified that the drift-flux model is of practical importance for two-phase flow analyses in reduced gravity conditions. The constitutive equation of the distribution parameter for bubbly flow, which takes the effect of gravity into account, has been proposed.

Ohta et al. have proposed an experimental plan to investigate boiling and two-phase flow on board the International Space Station under the international collaboration[7]. Kawanami, Azuma and Ohta studied cryogenic heat transfer using liquid nitrogen during quenching, because management of cryogenic fluids will become common in orbit in the future[8]. They observed increase in heat transfer by 20% under microgravity compared with that in normal gravity, and reported that this is due to increase in quench front velocity.

The effect of gravitational acceleration on coronet formation was investigated using the parabolic flight of a jet plane. Coronet formation has been considered to be independent of gravitational acceleration for long time[9]. The condition for selection of splashing or bouncing modes was made clear; the condition was a function of Weber number, the ratio of inertial energy to surface energy, and gravitational acceleration, as shown in Fig. 4[10].

3.2. Combustion

Combustion is gravity-sensitive phenomenon and short-tem microgravity platforms are suitable for experimental study on combustion science; e.g. drop shafts, parabolic flight and sounding rockets. Kobayashi et al. found through microgravity experiments that a fuel gas jet driven by a strong Marangoni flow at the droplet surface due to intense temperature difference causes flame propagation, as shown in Fig. 5 (Movie) and 6[11]. It is noteworthy that the Marangoni flow contributes to combustion.

Combustion of wire insulation for fire safety in space was studied using the JAMIC drop faciity[12]. For polyethylene insulated wires, core material was found to affect flame shape and flame spread rate markedly. Thermal conductivity of core material, i.e., copper or Nichrome, plays an important role in the heat source and high conductivity material supplies more heat to the insulation.

3.3. Crystal Growth

As a basic study for understanding crystal growth mechanisms, pattern development of an ice crystal was observed using the Mach-Zhender interfereometer. The original shape of the disk

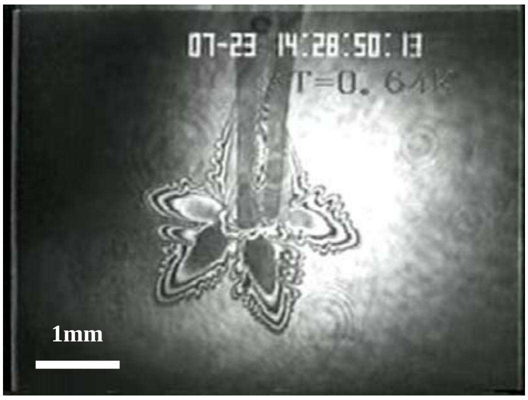

Fig. 7 (Movie) Morphological evolution of an ice crystal from a disk to dendrite with hexagonal symmetry[13].

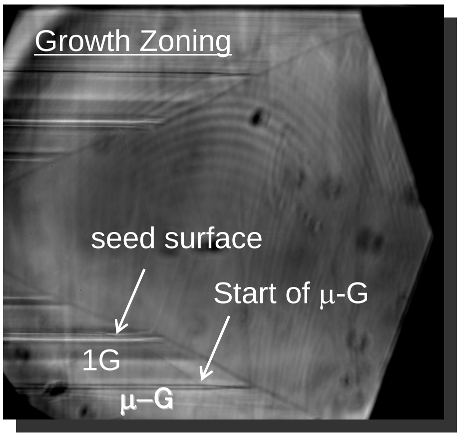

Fig.8 Lyzozyme crystal grown on board the FOTON satellite[14]. Crystal is 3mm in diameter.

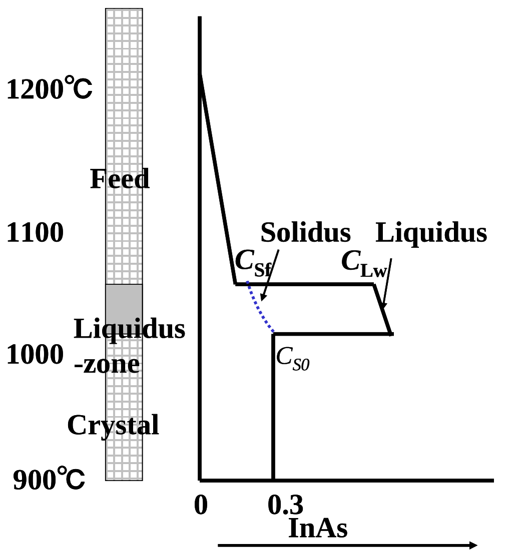

Fig. 9 The principle of TLZ (travelling-liquidus-zone) method for growth of solid solution single crystal of $In_{1-x}Ga_xAs$ with homogeneous somposition[15].

changes into a dendrite with hexagonal symmetry: see Fig. 7 (Movie). This is attributed to morphological instability at the edge surface of a disk plate. Furukawa et al. will study this morphological evolution in more detail in the ISS-Kibo[13].

Tsukamoto et al. successfully performed protein crystal growth on board the Russian FOTON-M3 satellite in September 2007 for 12 days, in order to study the effect of microgravity on the perfection of lysozyme crystals, as shown in Fig. 8[14]. Using seed crystals, lysozyme crystals grew as large as 3mm in diameter; the size was suitable to get a high resolution X-ray topograph for the first time at the High Energy Research Center in Tsukuba. The microdefects and defects in the space grown crystals were investigated by high resolution optical microscopy, to show reduction of impurity effects in space. Growth rate under the given supersaturation condition was measured using the thickness of the overgrown part of a space grown part on the seed crystals.

Kinoshita et al. plan to grow a solid solution single crystal of III-V compound semiconductor $In_{1-x}Ga_xAs$ with high homogeneity on board the ISS-Kibo by the TLZ (travelling-liquidus-zone) method[15]. The principle of this idea is to give a compositional gradient both in feed and liquidus zone as shown in Fig. 9. This idea can be surely realized in the microgravity condition, because mass transport can be controlled by diffusion.

3.4. Thermophysical property measurements

Microgravity is an ideal condition for the measurement of thermophysical properties of high temperature melts; particularly transport properties, such as thermal conductivity and the diffusion constant because of no convective flow.

Masaki et al. have a plan to continue to measure diffusion constants of high temperature melts using a shear cell technique, as shown in Fig.10[16]. The shear cell technique assures suppression of mass transport during the melting and solidification processes.

The SEMITHERM project will be carried out on board the ISS-Columbus; Japanese scientists are members of this program for measurement of thermophysical properties of molten semiconductors.

3.5. Welding

GFTA (Gas hollow tungsten arc) welding using a filler wire is proposed, so that maintenance of the ISS structure can be carried out in space[17]. In order to see the possibility of use of welding in space,

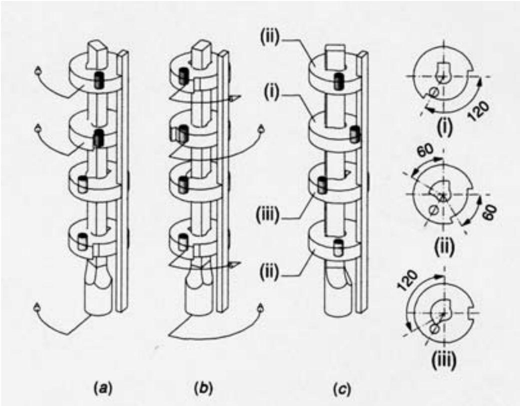

Fig. 10 Shear cell strucuture[16]. The mechanism of the shear cell. (a) The rotation for the sample joining. (b) The rotation for the sample separation. (c) The separated state of samples. Arrows indicate the direction of rotation. The discs are separated for the visualization of the mechanism in the drawing.

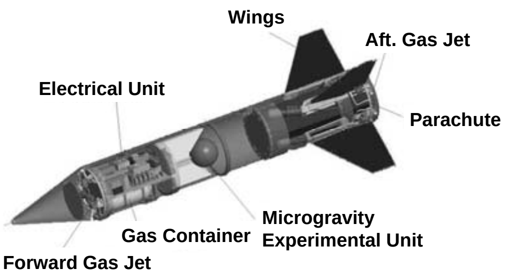

Fig. 11 Free fall capsule using a balloon. It is 4m long and named BOV(Balloon-based Operation Vehicle)[18].

GHTA welding was carried out in the microgravity conditions during the parabolic flight of a jet aircraft. Mechanical strength was observed to be sufficient, when compared with that done on earth. The shape of a weld pool appears to be affected by microgravity; the shape was round due to non-existence of hydrostatic pressure.

4. Japanese Platforms for microgravity

The Japanese new microgravity platform, i.e., a free fall capsule using a balloon has been introduced. Also several features of the Japanese parabolic flights are shown. Drop shaft of MGLAB supplies 5sec microgravity. These short-term microgravity platforms can supply not only precursor experiment opportunities but also necessary and sufficient amount of data to study the gravitational effect on high-speed phenomena, such as combustion, fluid physics, heat transfer, thermophysical property measurement, and so on.

Fig. 12 Discussion with DAS pilots after flight experiments.

4. 1. Free fall capsule using a balloon

Microgravity experiment systems using a free fall capsule from a high altitude balloon were examined in May 2006 and in May 2007 by Inatomi et al[18].Using a drag free control, around 10^{-4}G gravity conditions were obtained for 30 sec. A combustion experiment with Japanese sparker was conducted inside the microgravity experimental unit. Figure 11 shows a 4m long capsule, which is called BOV (Balloon-based operation vehicle).

4. 2. Parabolic flight

Diamond Air Service (DAS) is operating parabolic flights using Mitsubishi MU-300 and Grumman Gulf Stream II. Parabolic flight can prepare not only 10^{-2}G acceleration level but also other magnitude of gravitational acceleration: continuously from 10^{-2} to 1G. Using a parabolic flight, gravitational acceleration can really be a parameter for materials processing.

Since they are small aircrafts, there are several merits for researchers. Japanese parabolic flights are featured with the following advantages;[19]

- Two or three teams perform experiments simultaneously; i.e., flexible operation can be assured. Detailed flight conditions can be discussed and determined among people concerned.
- Meetings are held between scientists and DAS pilots and support staff before and after flight experiments: see Fig. 12.
- DAS assists scientists, so that experiments can be successfully completed.
- Pilots shall start parabolic flight after confirming that experimental preparation has been completed.

Depending on the scientists' requirement, the following flight modes are available:

- 1.5G or 1.2G entry for microgravity,

- 0.5G parabola for 40sec,
- 0.1G, 0.2G or any small G Parabola
- Shallow entry from 2G to 0G
- High gravity, such as 2.0 - 2.5 G through a steep urn.

5. Ground base research: spin-off from space utilization

Triggered by new and attractive findings in microgravity research, many people made efforts to simulate microgravity conditions on earth; this is called microgravity simulation laboratory. A typical example of this movement is "containerless levitation". AC calorimetry using electromagnetic levitation had been proposed by Wunderlich et al.[20)], so that specific heat and thermal conductivity can be measured under microgravity conditions. By superimposing a static magnetic field with this technique, Fukuyama group measured successfully thermal conductivity of molten silicon[21)]. Because flow within a droplet can be suppressed under a strong magnetic filed, a droplet behaves as if it were solid even on earth, as long as heat transfer is concerned. This method is one of the spin-off technologies of space utilization. Also research in combustion science, synthesis of metastable phase materials, protein crystal growth and Marangoni convection has been stimulated on earth to a great extent by microgravity utilization.

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