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Measurement of Acoustic Properties for Liquid Metal Couplers with Low Melting Point and High Acoustic Impedance

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1. Introduction

Iridium (Ir) metal and Ir-containing alloys have been widely used in various fields of applications such as crucibles for crystal growth, spark plugs, and high temperature thermocouples, due to high melting point, high resistivity to an oxidation at high temperature, and high chemical stability. Most of Ir and Ir alloys products have been manufactured from ingots, which are produced by arc melting and casting. However, such hot working processes increase the manufacturing cost due to a yield loss especially for metals and alloys with difficult workability like Ir and Ir alloys. In order to solve the problem, we have developed a growth method of alloy wire materials named Alloy-micro-pulling-down (A-μ-PD) method [1]. Using this method, we succeeded in developing a flexible Ir/Ir-Rh wire for thermocouple application [2].

On the other hand, we have developed quantitative material characterization method using the ultrasonic micro-spectroscopy (UMS) technology [3-5]. In measurement by the UMS system, pure water usually uses as a coupler. However, when evaluating materials with high acoustic impedance such as Ir alloys, the acoustic mismatch is large and almost no acoustic waves penetrate the material. Therefore, the coupler with higher acoustic impedance is required.

In this paper, we synthesize a liquid alloy that has as high acoustic impedance as possible and is in a liquid state at room temperature so that we can evaluate materials with high acoustic impedance such as Ir alloy, and evaluate its acoustic properties.

2. Sample preparation

As a liquid alloy coupler, we prepared liquid Ga-Sn-Zn alloy. 3N-metal raw materials [Ga:90.15, Sn:6.64, Zn:3.21(at%)] were weighed using an electronic balance, and melted and alloyed by heating the carbon susceptor (500°C for 4 hours) using a high-frequency induction heating furnace. Melting point of the Ga-Sn-Zn sample is 10°C [6].

An Ir plate sample with dimensions of 25×25×0.5 mm^3 was also prepared.

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3. Measurement method

Longitudinal wave velocity of the Ga-Sn-Zn liquid sample was measured using the plane wave ultrasonic material characterization (PW-UMC) system [7]. Measurement principle of the bulk wave velocity by the PW-UMC system was described in [7]. However, in the case of a liquid sample, it is difficult to determine the sample thickness (propagation path length) with high accuracy. Therefore, the measurement was performed by the method shown in **Fig. 1**. After measuring at a certain distance d_1, the PW device is moved by a known distance Δd ($d_2=d_1+\Delta d$) and measured. Temporary measured velocities v_1 and v_2 are assumed at distances d_1 and d_2, respectively, the true velocity v_0 of the liquid sample can be obtained by the following equation.

$$v_0 = \frac{\Delta d}{\frac{d_1+\Delta d}{v_2} - \frac{d_1}{v_1}} \tag{1}$$

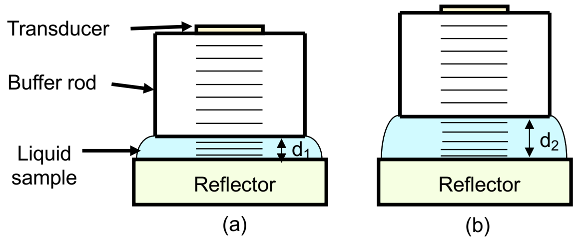

Fig. 1 Explanatory diagram of the method for measuring acoustic properties of liquid samples.

Density of the liquid sample was measured using dry automatic density meter (AccuPyc II 1345: SHIMADZU). Measurement conditions were as follows: container size 3.5 cc, purge gas 3G-Ar, purge fill pressure 134.45 kPaG.

4. Result and discussion

Measurement result of the liquid Ga-Sn-Zn sample was as follows: temporary distance d_1=1250

Table I Comparison of acoustic properties for each material.

Sample	Velocity [m/s]	Density [kg/m^3]	Acoustic impedance [10^6 Pa·s/m^3]
Ga-Sn-Zn (liquid)	2828.7	6206.4	17.556
Pure water	1483.0	998.2	1.480
Ir plate	13231	22562	298.52
SiO_2 glass	5942.4	2200.5	13.076

µm, known moving distance Δd=560µm. In the experiment, SiO_2 glass plate was employed as a reflector. The tentative longitudinal wave velocity obtained at this time is v_1=2827.1 m/s and v_2=2827.6 m/s. Using Eq. (1), true value of longitudinal wave velocity v_0=2828.7 m/s. Density was determined as 6206.4 kg/m^3.

Longitudinal wave velocity for the Ir plate sample was obtained by usual measurement method using pure water by the PW-UMC system. Since the sample surface is not completely mirror-polished, the reflection from the sample surface is small, and since the acoustic mismatch is large, the reflected wave from the back surface of the sample is also quite small, so the S/N is poor and the measurement accuracy is not sufficient. **Table I** shows the results.

From the result of Table I, acoustic impedance of Ga-Sn-Zn sample was 12 times higher than that of pure water. The acoustic impedance of Ga-Sn-Zn sample was also higher than that of solid sample of typical SiO_2 glass.

The reflection coefficient of the incident wave on the Ir sample for the water coupler is obtained as 99.01% from the results in Table I. On the other hand, the reflection coefficient of the incident wave on the Ir sample for the Ga-Sn-Zn coupler is obtained as 88.89%.

The ratio of waves that pass from water to the inside of the Ir sample and return to the water is 1.96%. On the other hand, The ratio of waves that pass from Ga-Sn-Zn coupler to the inside of the Ir sample and return to the Ga-Sn-Zn coupler is 20.98%. The liquid metal coupler can increase the S/N ratio of the reflected wave from the back surface of the Ir sample about 10 times more than the water coupler.

5. Summary

Acoustic properties of liquid alloy couplers with high acoustic impedance were investigated in order to evaluate materials with high acoustic impedance. A Ga-Sn-Zn liquid alloy was prepared and its acoustic properties were measured. We prepared an Ir plate with high acoustic impedance as a sample, and examined how much the reflected signal from the sample is improved in the case of a liquid alloy coupler. As a result, the liquid metal coupler can increase the S/N ratio of the reflected wave from the back surface of the Ir sample about 10 times more than the water coupler. In the future, we plan to search for liquid alloy materials with even higher acoustic impedance.

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References

1. Y. Yokota, T. Nihei, K. Tanaka, K. Sakairi, V. Chani, Y. Ohashi, S. Kurosawa, K. Kamada, A. Yoshikawa: Adv. Eng. Mater. **20** (2018) 1700506.
2. R. Murakami, K. Kamada, Y. Shoji, Y. Yokota, M. Yoshino, S. Kurosawa, Y. Ohashi, A. Yamaji, A. Yoshikawa: J. Cryst. Growth **487** (2018) 72.
3. J. Kushibiki, Y. Ono, Y. Ohashi, M. Arakawa: IEEE Trans. Ultrason. Ferroelectr. Freq. Control **49** (2002) 99.
4. Y. Ohashi, M. Arakawa, T. Kudo, Y. Yokota, Y. Shoji, S. Kurosawa, K. Kamada, J. Kushibiki, A. Yoshikawa: Jpn. J. Appl. Phys. **55** (2016) 07KB06.
5. Y. Ohashi, Y. Yokota, A. Yamaji, M. Yoshino, S. Kurosawa, K. Kamada, H. Sato, S. Toyoda, T. Hanada, A. Yoshikawa: Jpn. J. Appl. Phys. **60** (2021) 078002.
6. A. Dobosz, Y. Plevachk, V. Sklyarchuk, B. Sokoliuk, T. Gancarz: Fluid Phase Equil. **465** (2018) 1.
7. J. Kushibiki and M. Arakawa, J. Acoust. Soc. Am. **108** (2000) 564.