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Superconducting characteristics of short MgB_2 wires of long level sensor for liquid hydrogen

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Abstract. To establish the worldwide storage and marine transport of hydrogen, it is important to develop a high-precision and long level sensor, such as a superconducting magnesium diboride (MgB_2) level sensor for large liquid hydrogen (LH_2) tanks on board ships. Three 1.7-m-long MgB_2 wires were fabricated by an in situ method, and the superconducting characteristics of twenty-four 20-mm-long MgB_2 wires on the 1.7-m-long wires were studied. In addition, the static level-detecting characteristics of five 500-mm-long MgB_2 level sensors were evaluated under atmospheric pressure.

1. Introduction

Hydrogen is a promising secondary energy for transforming a primary energy, such as a renewable energy, to resolve the problems of global warming and energy supply. For the storage and transport of a large amount of hydrogen originating from overseas renewable energies, a marine transport project for liquid hydrogen (LH_2: 20 K) has recently been attracting attention [1]. It is important for a high-precision and long level sensor to be installed in LH_2 tanks of about 10 m diameter on board ships. So far, Haberstroh [2] and Kajikawa [3] have developed self-heating-type magnesium diboride (MgB_2) level sensors for LH_2, on the other hand, we have studied an external-heating-type MgB_2 level sensor and its application to sloshing measurements of LH_2 [4-9]. A superconducting level sensor for LH_2, such as a MgB_2 level sensor, demonstrated high precision and high linearity in comparison with conventional level sensors/gauges: a differential pressure gauge, a capacitance-type level sensor, etc. In the case of enlarging/lengthening the MgB_2 level sensor, it is important to study, for example, the uniformity of the superconducting characteristics of long MgB_2 wires, the static and dynamic level-detecting characteristics of long MgB_2 level sensors, and the heater input and sensor length dependences of the level-detecting characteristics. The purpose of the present work is to perform an individual-difference performance evaluation of superconducting characteristics, taking twenty-four short MgB_2 wires (20 mm long) on three 1.7-m-long MgB_2 wires as the objects of study. In addition, the static level-detecting characteristics of five 500-mm-long MgB_2 level sensors are tested briefly.

2. MgB_2 wires for use as liquid hydrogen level sensor

The external-heating-type MgB_2 level sensor for LH_2 investigated in this study is composed of a MgB_2 wire of 0.32 mm diameter and a resistive heater (polyester-coated manganin wire of 0.2 mm diameter) wound around the entire MgB_2 wire with a pitch of 2 mm to prevent cooling by the hydrogen vapor around the liquid surface. Three 1.7-m-long MgB_2 wires (wires A, B and C) were fabricated by an in situ method with a heat treatment of 1 h at a temperature of 873 K in an argon gas atmosphere and reinforced by a CuNi (7:3) sheath. To suppress the superconducting transition temperature T_c to about 32 K below the critical temperature of LH_2, an impurity of 10% SiC was added to the MgB_2 core [4]. A photograph of the cross section of a MgB_2 wire is shown in Figure 1.

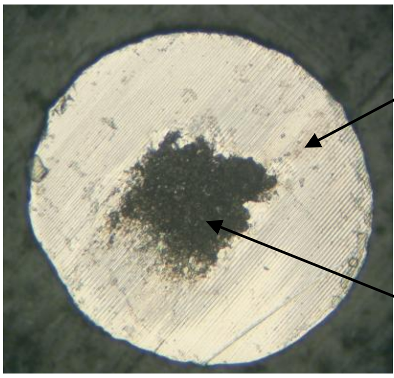

Figure 1. Photograph of cross section of MgB_2 wire of 0.32 mm diameter.

Figure 2 shows the positions of short MgB_2 sections on the 1.7-m-long MgB_2 wires. Nine 20-mm-long MgB_2 sections on wire A (denoted A-a1 to A-c3), nine 20-mm-long MgB_2 sections on wire B (denoted B-a1 to B-c3) and six 20-mm-long MgB_2 sections on wire C (denoted C-a1 to C-b3) were prepared as the short MgB_2 wires. A photograph of a short MgB_2 wire, which has current/voltage taps based on a four-wire technique, is shown in Figure 3.

3. Experimental apparatus and methods

Figures 4 and 5 show schematic diagrams of the system for measuring the superconducting characteristics of the short MgB_2 wires and the sample holder containing a vacuum space, respectively. The measuring system consists of the sample holder, which has a length of about 1 m, a liquid helium vessel, current generators, a power generator, voltmeters and a PC with a LabVIEW program. Two short MgB_2 wires, a Cernox thermometer and a resistive heater were mounted on the sample holder. The output voltages of the short MgB_2 wires with a 10 mA excitation current and the Cernox

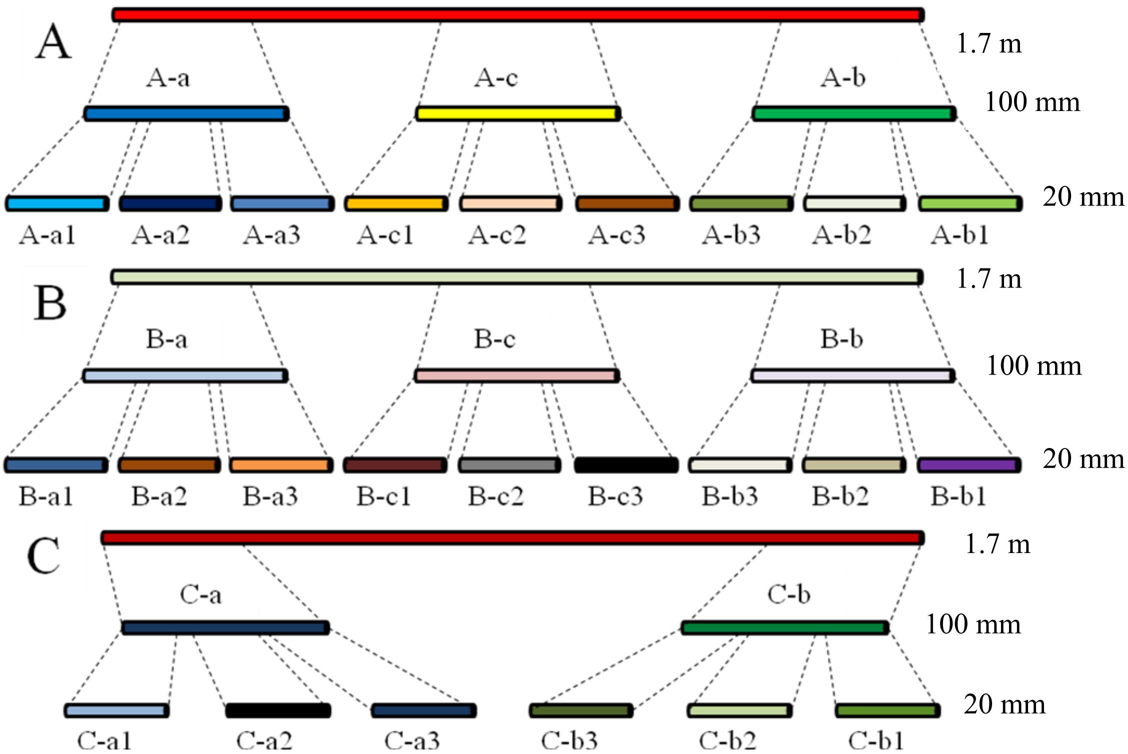

Figure 2. Positions of short MgB_2 sections on 1.7-m-long MgB_2 wires.

thermometer with a 10 μ A excitation current were measured by a DC four-wire technique utilizing Ohm's law. In the experiment on the superconducting characteristics, the onset temperature of the superconducting transition T_{c_on}, the offset temperature of the superconducting transition T_{c_off}, the electric resistance R_{on} at T_{c_on} and the temperature dependence of the electric resistance dR/dT were the measurements we focused on; a high-precision level sensor requires a narrow superconducting transition temperature difference ΔT_c, a relatively high R_{on} and low dR/dT.

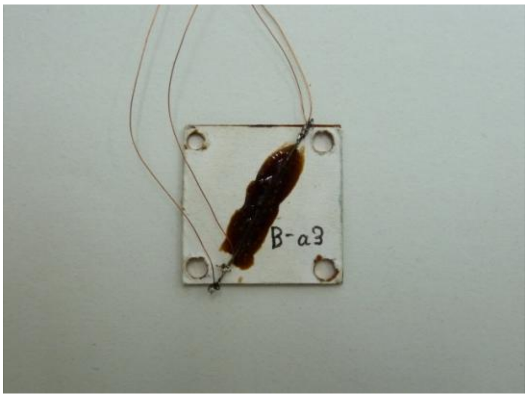

Figure 3. Photograph of a 20-mm-long MgB_2 wire.

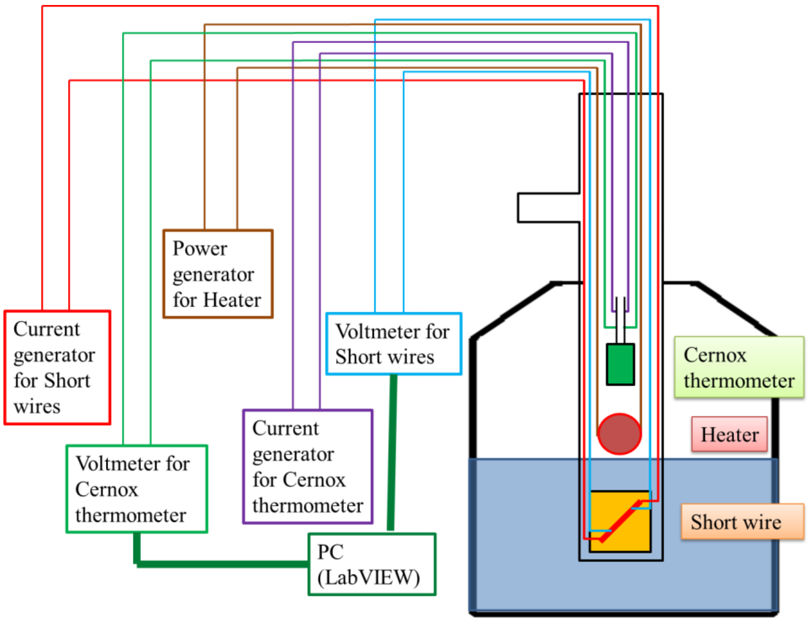

Figure 4. Schematic diagram of system for measuring superconducting characteristics of short MgB_2 wires.

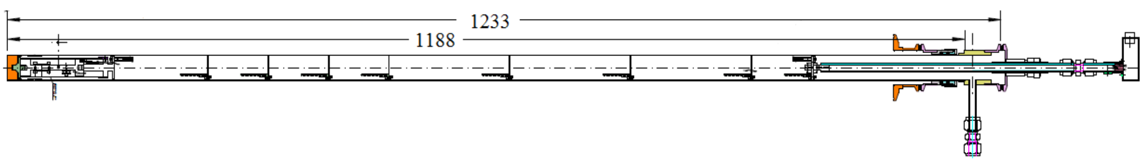

Figure 5. Schematic diagram of sample holder containing vacuum space (unit: mm).

4. Experimental results

4.1. Superconducting characteristics

Figures 6-8 show the experimental results of the relationship between the resistance per unit length and the temperature of the 20-mm-long MgB_2 wires on wires A, B and C, respectively. Table 1 shows the averages and standard deviations of the superconducting characteristics of all the short MgB_2 wires. The average values of T_{c_on} were 33.79 K for wire A, 33.81 K for wire B and 33.60 K for wire C with standard deviations of 0.4 K or less, indicating an almost uniform property. The average values of T_{c_off} were 30.98 K for wire A and 31.48 K for wire C with standard deviations of 0.5 K, whereas it was 30.52 K for wire B with a standard deviation of 2.6 K, indicating relatively large variations of 23.92 K for B-c3, 28.43 K for B-a1 and 30.45 K for B-a2 as seen at the offset of the resistance per unit length measurements shown in Figure 7. The average temperature difference ΔT_c between T_{c_on} and T_{c_off} was 3.3 K for wire B, which was relatively large.

The average values of R^*_{on}, where the asterisk denotes the resistance per unit length, were 5.053 Ω/m for wire A, 5.046 Ω/m for wire B and 5.013 Ω/m for wire C. The standard deviations were 0.16 Ω/m for wire B, and 0.18 Ω/m or more for wires A and C, which are relatively large values. The average values of dR^*/dT, where the asterisk denotes the resistance per unit length, were 0.004 Ω/m/K with standard deviations of 0.001 Ω/m/K for wires A-C.

To clarify the reason why T_{c_off} for wires B showed a relatively large variation, B-c3 was cut into four parts. Photographs of the six surfaces taken using a microscope are shown in Figure 9. A small region of MgB_2 on one of the surfaces showed some deformation, which is thought to be the main cause of the relatively large variation of T_{c_off}; some deformation may be related to weak coupling in superconducting transition.

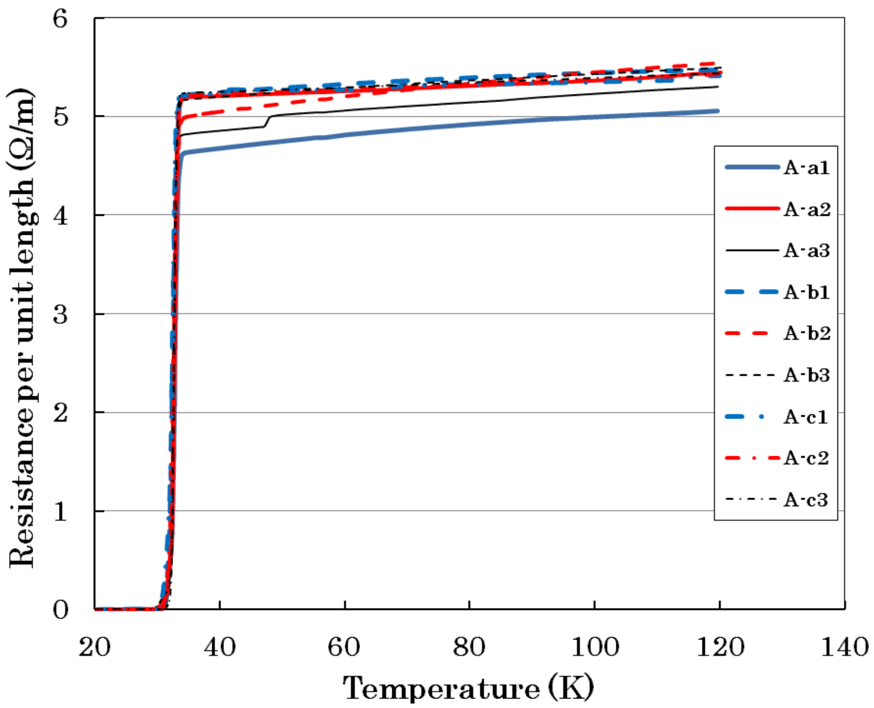

Figure 6. Relationship between resistance per unit length and temperature of 20-mm-long MgB_2 wires on wire A.

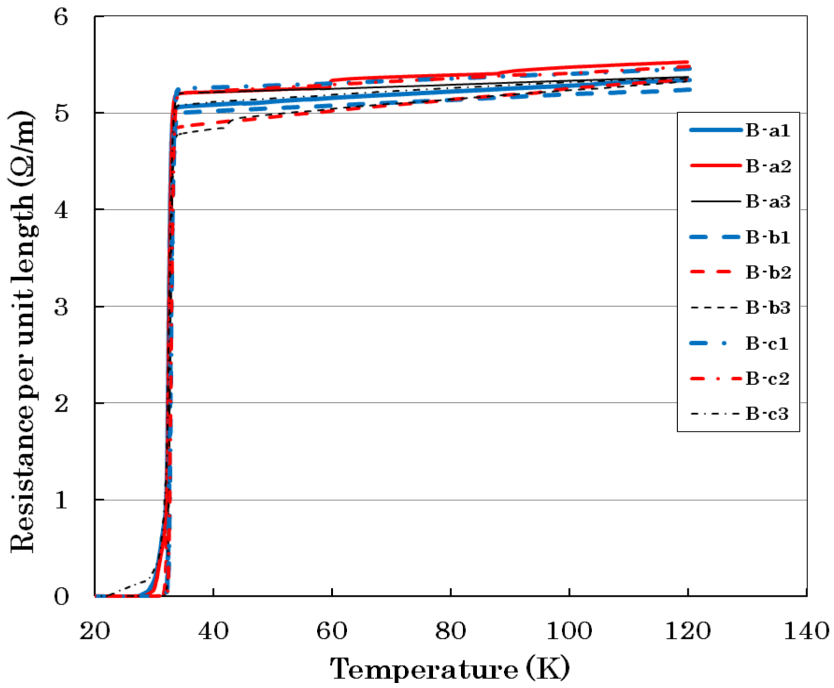

Figure 7. Relationship between resistance per unit length and temperature of 20-mm-long MgB_2 wires on wire B.

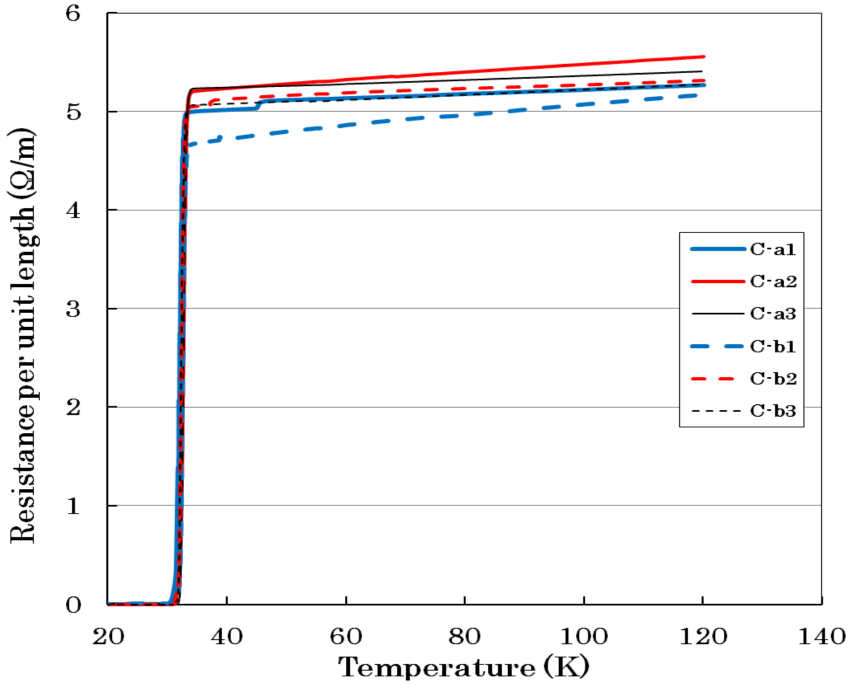

Figure 8. Relationship between resistance per unit length and temperature of 20-mm-long MgB_2 wires on wire C.

Table 1. Averages and standard deviations of superconducting characteristics of short MgB_2 wires.

	Wire A Ave.	Wire A σ	Wire B Ave.	Wire B σ	Wire C Ave.	Wire C σ
T_{c_on} [K]	33.79	0.23	33.81	0.41	33.60	0.44
T_{c_off} [K]	30.98	0.42	30.52	2.60	31.48	0.54
R^{*}_{on} [Ω/m]	5.053	0.208	5.046	0.164	5.013	0.185
dR^{*}/dT [Ω/m/K]	0.004	0.001	0.004	0.001	0.004	0.001

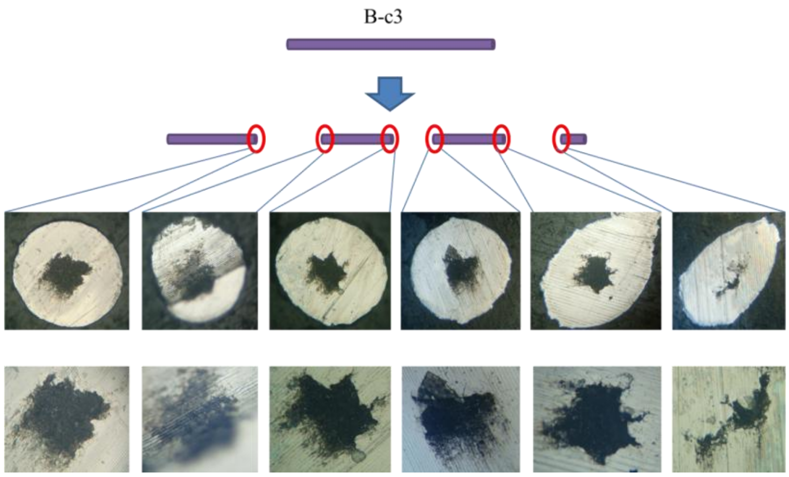

Figure 9. Photographs of cross sections of B-c3 showing six cutting surfaces.

4.2. Level-detecting characteristics
Five 500-mm-long MgB_2 level sensors (A1, A2, B1, B2 and C) were fabricated from three 1.7-m-long MgB_2 wires. Static level-detecting characteristics were evaluated under atmospheric pressure by a four-wire technique with a current of 10 mA using an LH_2 glass Dewar during a spontaneous decrease in the LH_2 level. Figure 10 shows the experimental results of the relationship between the level read from the scale and the output voltage of the 500-mm-long MgB_2 sensors at a heater input of 6 W. As can be seen in this figure, the output voltage of A1 was 0.7 mV higher than those of the other sensors at a liquid level of zero; the main cause can be explained as a difference of length between voltage taps of A1. In contrast, the five 500-mm-long MgB_2 level sensors, including B1 and B2 with the relatively large variation of T_{c_off}, showed a correlation coefficient of 0.999 or more with high linearity and a gap of the maximum level-detecting length between A1 and A2 of 4 mm (about 1%) for heater inputs in the range from 3 W to 9 W.

5. Summary
The superconducting characteristics of twenty-four 20-mm-long MgB_2 wires on three 1.7-m-long MgB_2 wires were evaluated. It was found that several short wires showed different characteristics, for example, T_{c_off} for wire B and R^{*}_{on} for wires A and C regardless of the position on the 1.7-m-long MgB_2 wires. Static level-detecting characteristics were evaluated under atmospheric pressure for five 500-mm-long MgB_2 level sensors made from three 1.7-m-long MgB_2 wires. It was found that all the 500-mm-long MgB_2 level sensors exhibited good level-detecting characteristics for LH_2 and little variation among their individual performances. The mass production of long MgB_2 level sensors for LH_2 is thus believed to be feasible.

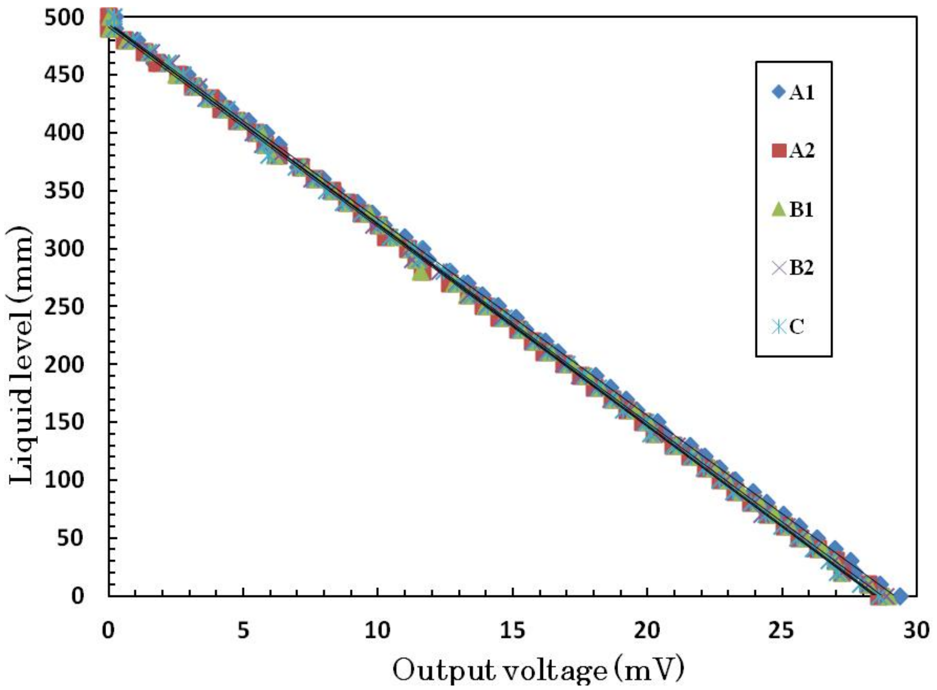

Figure 10. Relationship between level read from scale and output voltage of 500-mm-long MgB_2 sensors at a heater input of 6 W under atmospheric pressure.

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References

[1] Kamiya S 2015 *Physics Procedia* **67** 11
[2] Haberstroh C, Dehn G and Kirsten G 2007 *Proc. ICEC21-ICMC2006* 357
[3] Kajikawa K, Tomachi K, Tanaka K, Funaki K, Kamiya T, Okada M and Kumakura H 2009 *Proc. ICEC22-ICMC2008* 425
[4] Takeda M, Matsuno Y, Kodama I, Kumakura H and Kazama C 2009 *IEEE Trans. Appl. Supercond.* **19** 764
[5] Takeda M, Yagi S, Kodama I, Fujikawa S, Kumakura H and Kuroda T 2010 *Adv. Cryo. Eng.* **55** 311
[6] Maekawa K, Takeda M, Matsuno Y, Fujikawa S, Kuroda T and Kumakura H 2013 *Proc. ICEC24-ICMC2012* 59
[7] Takeda M, Fujikawa S, Matsuno Y, Maekawa K, Kuroda T and Kumakura H 2013 *Proc. ICEC24-ICMC2012* 311
[8] Maekawa K, Takeda M, Matsuno Y, Fujikawa S, Kuroda T and Kumakura H 2015 *Physics Procedia* **67** 1164
[9] Takeda M, Nara H, Maekawa K, Fujikawa S, Matsuno Y, Kuroda T and Kumakura H 2015 *Physics Procedia* **67** 208