4MP4-08

International Round Robin Test for Critical Current Measurement of RE-Ba-Cu-O Superconducting Tapes

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Introduction

Versailles Project on Advanced Materials and Standards (VAMAS) Technical Working Area (TWA) 16 (Superconducting materials) has contributed pre-standardization activities, i.e., research and development activities aiming standardization, of superconducting materials. Most of the activities resulted international standards (IS) issued by International Electrotechnical Commission (IEC).

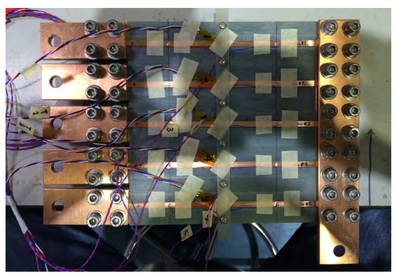
VAMAS TWA 16 had promoted an international round robin test (RRT) on critical current (I_c) measurement of RE-Ba-Cu-O (REBCO; RE=rare earth) superconductors in 2014. The international RRT aimed to establish the transport I_c measurement method in liquid nitrogen (LN_2) bath in self field, i.e., without an external magnetic field. Five industries, three institutes, and two universities were participated in the RRT. The present paper describes the international RRT results. The measurement uncertainties derived from the RRT results are discussed.

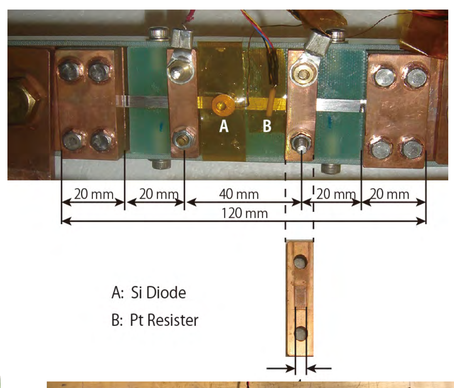
Distributed REBCO Tapes

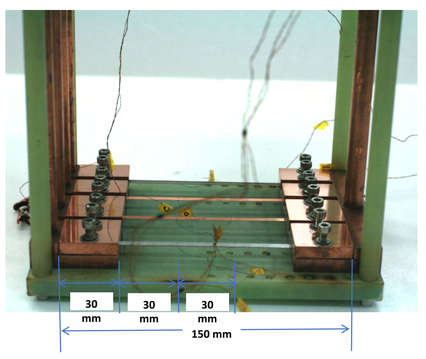
Manufacturer	A	B	C	D
Rare earth	Y	Gd	Y and Gd	Gd
Deposition process	RABiTS/MOD	IBAD/RCE-DR	IBAD/MOCVD	IBAD/PLD
Conductor width [mm]	4.4	4.1	4	5
Conductor thickness [mm]	0.4	0.1	0.095	0.16
Substrate	Ni-5W	Hastelloy C-276	Hastelloy C-276	Hastelloy C-276
Substrate thickness [μm]	50-75	60	50	75
Lamination	Brass	-	-	-
Lamination thickness [μm]	150	-	-	-
Copper stabilizer	-	Both sides	Both sides	SC side
Copper thickness [μm]	-	No information	20×2	75
Inspection report I_c [A]	102	198	89	>250

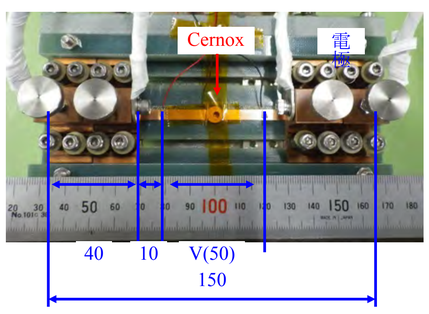
- Tapes were cut in ~1.2 m pieces, coiled, and sent to participants.
- Each participant cut tape in ~20 cm specimens. I_c was measured at 77 K, self-field, for 5 specimens.
- I_c, n values, temperatures, etc. were reported.

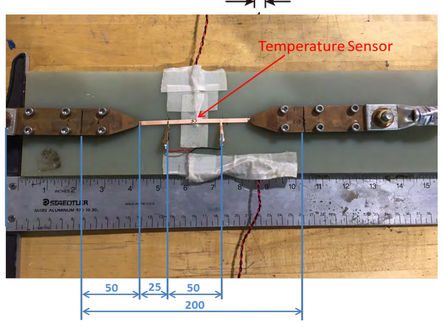
Measurement Setups

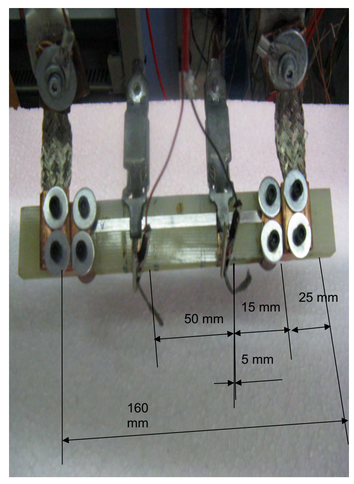


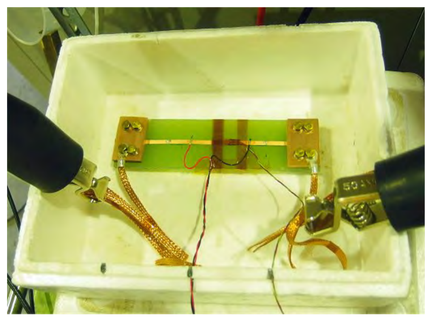












Results

Type-A (experimental) Uncertainty Analysis for tape C

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	89.626	90.674	87.649	86.160	89.600	88.790	91.200	88.960	92.650	91.490
2	90.814	93.314	90.775	86.040	89.800	94.080	93.400	91.300	92.650	92.960
3	92.230	88.783	88.390	88.360	88.600	87.960	93.100	91.460	93.700	91.670
4	89.545	90.176	86.317	88.330	89.600	90.910	90.500	91.790	92.760	92.170
5	89.231	89.539	85.786	86.340	87.400	88.670	90.800	92.630	91.110	89.790
Average	90.289	90.497	87.783	87.046	89.000	90.082	91.800	91.228	92.574	91.616
SD [A]	1.240	1.727	1.967	1.191	1.010	2.492	1.351	1.368	0.930	1.169
SU [A]	0.555	0.772	0.880	0.532	0.452	1.114	0.604	0.612	0.416	0.523
RSU [%]	0.614	0.853	1.002	0.612	0.507	1.237	0.658	0.671	0.449	0.571

	Tape A	Tape B	Tape C	Tape D
N	50	45	50	45
$I_{c,avg}$ [A]	103.417	192.404	90.192	300.080
SD [A]	3.176	4.447	2.189	5.746
RSD [%]	3.071	2.311	2.427	1.915

	Tape A	Tape B	Tape C	Tape D
N	50	45	50	45
s_a^2 inter-lab	34.730	588.496	15.886	111.738
s_b^2 intra-lab	4.544	156.153	2.296	12.421
F-value	7.644	3.769	6.918	8.996
$F_{0.95}(f_a, f_b)$	2.124	2.209	2.124	2.209

Type-B Uncertainty Analysis

$$I_c = \left(\frac{LE_c}{U}\right)^{\frac{1}{n}} I + g_{\mathrm{Temp}}(T) + \varepsilon_{\mathrm{NU}}$$

$$u_c^2 = \left(\frac{\partial I_c}{\partial L_1}\right)^2 u_1^2 + \left(\frac{\partial I_c}{\partial U}\right)^2 u_2^2 + \left(\frac{\partial I_c}{\partial I}\right)^2 u_3^2 + \left(\frac{\partial I_c}{\partial n}\right)^2 u_4^2 + c_{\mathrm{Temp}}^2 u_{\mathrm{Temp}}^2 + c_{\mathrm{NU}}^2 u_{\mathrm{NU}}^2$$

Budget table of SUs of tape C I_c measurements

Component	Source	ij	c_{ij}	u_{ij}	$c_{ij}u_{ij}$ [A]
L_1	Length	11	0.0375 [A/mm]	0.289 [mm]	0.01445
U	DC Noise	21	0.375 [A/μV]	0.0202 [μV]	0.0101
	Voltage	22	0.375 [A/μV]	0.4621 [μV]	0.2311
I	DC Noise	31	1	0.004619 [A]	0.0009236
	Voltage	32	1	0.1733 [A]	0.3002
T	Temperature	4	-10.49 [A/K]	0.05196 [K]	-0.5449
I_c	Non-uniformity	5	1	1.96 [A]	1.96

Intrinsic I_c non-uniformity evaluated by RTR-SHPM

	RTR-SHPM (1-3×10^{-8} V/m criterion, 0.43 mm resolution)			Converted to 4-probe method (10^{-4} V/m criterion, 90 mm resolution)		
	$I_{c,avg}$ [A]	RSD [%]	SD [A]	$I_{c,avg}$ [A]	RSD [%]	SD [A]
A	88.4	2.96	2.62	116	2.1	2.44
B	155.7	3.58	5.57	201	2.5	5.03
C	67.2	3.14	2.11	89	2.2	1.96
D	211.6	3.99	8.44	271	2.8	7.59

Comparison of RSU for tapes B, C, and D

		Tape B (N=45)	Tape C (N=50)	Tape D (N=45)
Type A	$I_{c,avg}$ [A]	192.40	90.19	300.1
	x_{SU} [A]	4.447	2.189	5.476
	x_{RSU} [%]	2.31	2.43	1.91
Type B	x_{SU} [A]	5.112	2.047	7.739
	x_{RSU} [%]	2.69	2.27	2.58