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Determination of chemical composition and structure of $YBa_2Cu_3O_{7-x}$ – YBCO/Cu 2G HTS superconducting tape

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ABSTRACT

Purpose: The paper concerns the determination of the chemical composition and structure of high-temperature superconducting tapes $YBa_2Cu_3O_{7-x}$ – YBCO/Cu 2G HTS.

Design/methodology/approach: Studies were carried outusing a scanning electron microscope with a chemical composition analyser on prepared samples of a tape. Moreover, an abrasion resistance test which shown resistance to friction at 1, 2 and 3 hours by using ball-tester was carried out. The individual layers which are components of the test tape and depths of wipes which appeared after test on ball-tester were evaluated.

Findings: Studies showed a lot of information about abrasion resistance of tapes. Hourly friction, using ceramic ball did not result in breakthrough coating. The investigation are carried out for one, two and three hours. They also confirmed the chemical compositions provided by the manufacturer, as well as describe the individual layers of examined superconducting tapes.

Originality/value: Detailed studies in particular, on wear resistance of superconductors, which relate to the chemical composition of the tapes, and their construction carried out in the context of the article, may be a prelude to further research into the production of superconducting tapes that will show much greater resistance to abrasion. The essence of the problem is a construction base, in particular during the installation of such tapes, for example in the form of a transformer winding.

Keywords: High-temperature superconductor HTS; SEM EDX; Ball-tester

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MATERIALS

1. Introduction

Nowadays superconductors are used in many areas of e.g. transport, medicine, allow for lossless transmission of electricity and the production of huge magnetic fields. They possess properties unattainable with other materials, elements of different shapes – tape used as transformer windings are prepared from them. Superconducting tapes on the basis of $YBa_2Cu_3O_{7-x}$ have multilayer structure. They consist of a properly prepared metal base, buffer layers, superconducting material and the protective layer.

The variety of substrates or layers are used depending on the basic superconducting material. The main task of the base material is transfer mechanical load and create the right conditions for the application of successive layers [1-3].

To obtain the required adhesion of the other layers of the superconducting tape and the consistency of all the material, buffer layers are used to construct similar to the construction of superconducting material.

Silver is most commonly used in the protective layer. Such a layer is designed to protect superconducting layer against environmental influences and mechanical damage.

Successive layers are applied to the substrate by techniques of physical vapour deposition (PVD) and chemical (CVD), vacuum deposition or metal-organic deposition (MOD).

In Figure 1 the construction of superconducting tapes on REBCO base is presented.

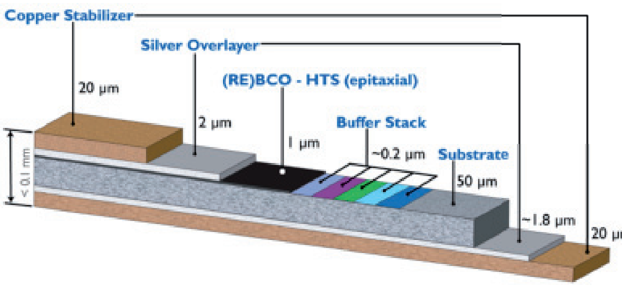

Fig. 1. Construction of superconducting REBCO tapes [4]

The REBCO assay, RE means rare earth elements, Y is replaced by the elements from the group as Eu, Dy, Gd, Sm [4-5].

The most common method of producing substrates for subsequent layers of superconducting tape is the method RABiTS (Rolling Assisted Biaxially Textured Substrates), which allows to obtain a suitable texture of the base, which facilitates the growth of successive layers. An alternative for the process may be the drag combined with a biaxial roll DABiTS (Drawing Assisted Biaxially Textured Substrates) [6-8].

Buffer layers and the layer of superconducting are further imposed by some several methods e.g. ion deposition IBAD (Ion Beam Assisted Deposition), pulsed laser deposition PLD (Pulsed Laser Deposition) deposition of organometallic MOD, and derivatives of the TFA-MOD method (metal TriFluoroAcetate-Organic Deposition) and flexible MOD (Excimer-Laser-Assisted-Metal-Organic Deposition) are used [9-18].

2. Methodology and material

To determine the chemical composition and construction of high-temperature superconducting tapes multi-band superconducting $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS are selected. It had the following dimensions: width – 3.6 mm, thickness – 0.1 mm. In Figure 2 a cross section of the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS tape is presented with zoom 500x.

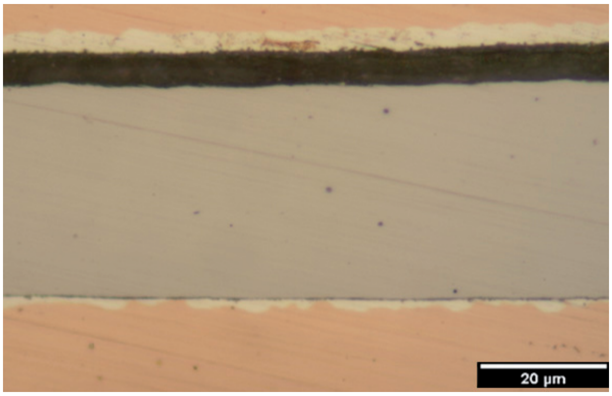

Fig. 2. $YBa_2Cu_3O_{7-x}$ coated with Cu High Temperature Superconducting Tape, zoom 500x

For the analysis of the chemical composition a scanning electron microscope JEOL JSM – 6610LV with micro analyser of chemical composition EDX was used. Moreover, the chemical composition of the superconducting layer YBCO after removing the other layers was measured. The next stage of the research was to determine the time after which the superconducting layer tore. A friction resistance test of surface was carried out using a ball-tester by using a ceramic ball with a diameter of 20 mm. Friction lasted 1, 2 and 3 hours. For worn areas, photographs at a magnification of 50x, determine diameters of wipe were prepared. Using the Pythagorean Theorem for right triangles the depth of created wipe was designated.

3. Results

The determination of chemical composition was carried out on the cross-section of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS tape. Measurements were made for the layers which are the components of superconducting tapes.

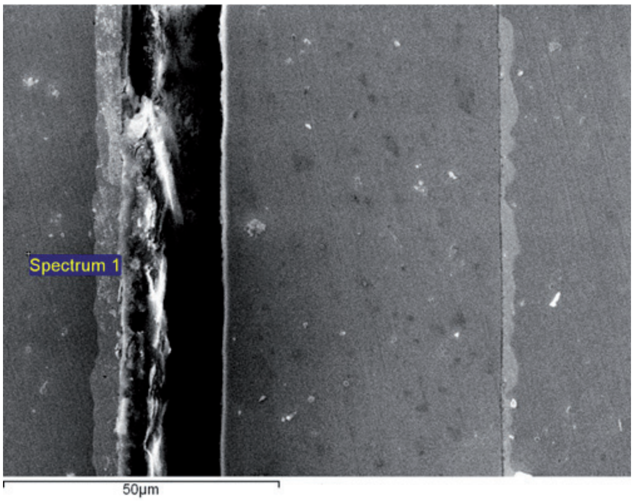

Fig. 3. Random selection of the place where the measurement of the point of the chemical composition on the cross section of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu was carried out

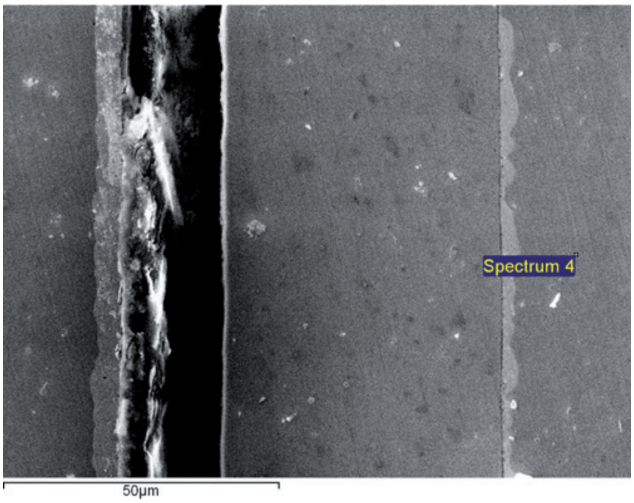

Fig. 4. Random selection of the place where the measurement of the point of the chemical composition on the cross section of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu was carried out

Figures 3 and 4 show a cross section of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS tape coated with Cu, along with marked locations of performing measurement of the chemical composition. As it is apparent from the spectra of the radiation characteristics presented in Figures 5 and 6 the studied areas was copper coating by which the tape was coated on both sides.

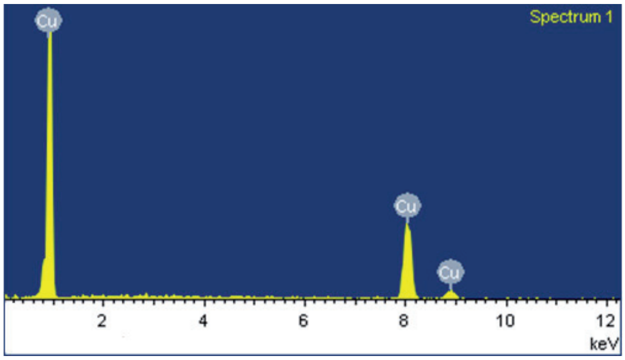

Fig. 5. Characteristic spectrum showing the chemical composition of the copper coating of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

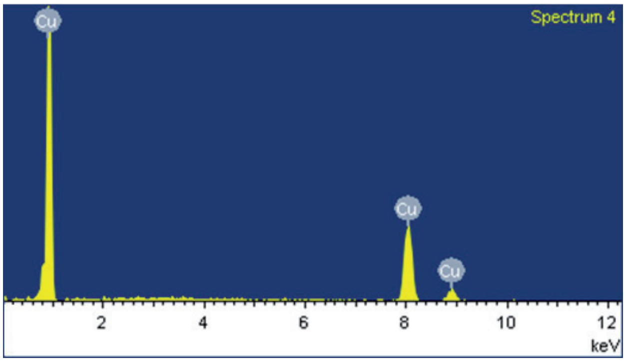

Fig. 6. Characteristic spectrum showing the chemical composition of the copper coating of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

In Figure 7 a cross section of the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS tape coated with Cu with a marked place, performing spot metering of chemical composition is presented. A layer located between the copper coating and the superconducting layer was chosen as a test area.

As it is apparent from the spectrum characteristic shown in Figure 8 the test area was a silver layer. The chemical composition of this layer was placed in the Table 1.

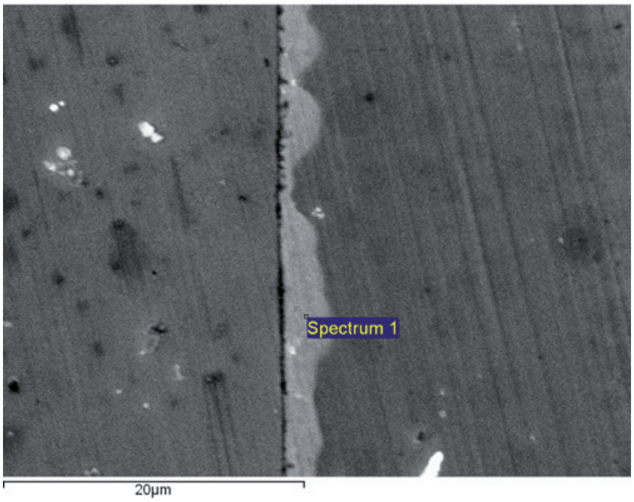

Fig. 7. Random selection of the place where the measurement for the chemical composition distribution of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu was carried out

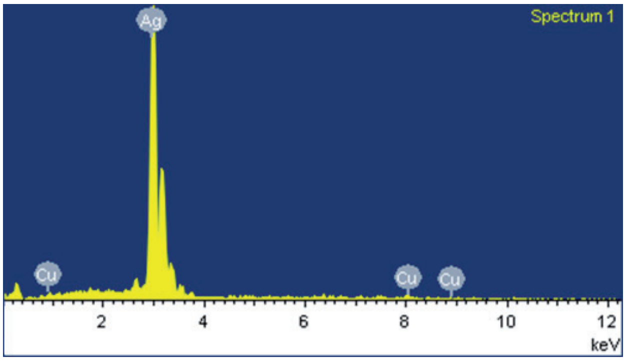

Fig. 8. Characteristic spectrum showing the chemical composition of the layers between the substrate and the coating copper of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

Table 1.
The chemical composition of the layers between the substrate and the coating copper of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

Element	Type of study	weight%	atomic%
Cu K	EDS	2.51	4.19
Ag K	EDS	97.49	95.81

The next stage of the research was to determine the chemical composition of a base of superconducting tapes. Figure 9. shows a cross-section of the tape $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS coated with Cu, along with the selected place of performance, point measurement of chemical composition.

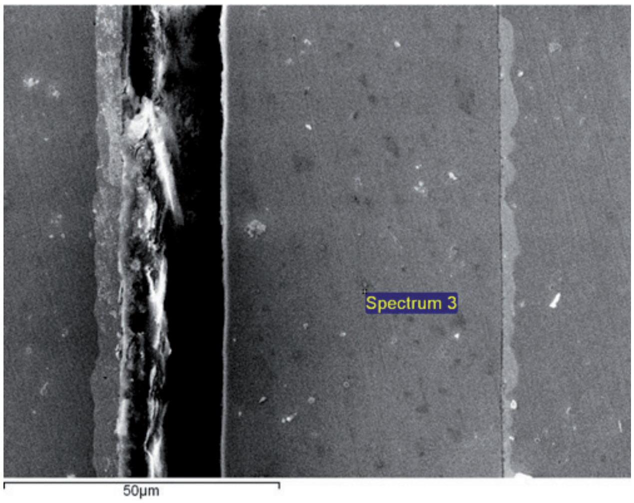

Fig. 9. Random selection of the place where the measurement of the chemical composition distribution of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu was carried

As it is apparent from the spectrum characteristics shown in Figure 10, the substrate has been made of stainless steel. The chemical composition base was placed in Table 2.

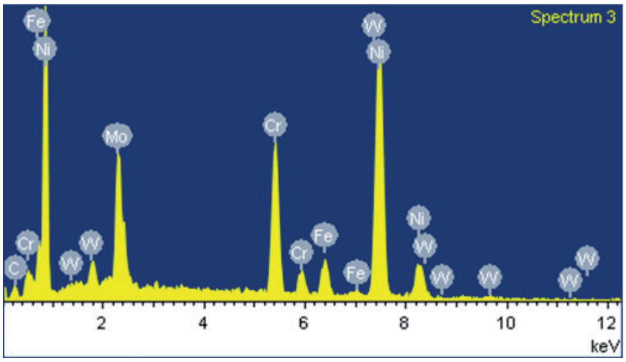

Fig. 10. Characteristic spectrum showing the chemical composition of a base of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

Table 2.
Chemical composition of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducitng tape base coated with Cu

Element	Type of study	weight%	atomic%
C K	EDS	5.21	22.40
Cr K	EDS	15.46	15.36
Fe K	EDS	4.61	4.26
Ni K	EDS	54.84	48.24
Mo L	EDS	16.18	8.71
W M	EDS	3.71	1.04

In order to investigate the chemical composition of the layers beneath the copper and silver layers it was necessary to remove them. Below them there was the structure which is shown in Figure 11 and had strong texture.

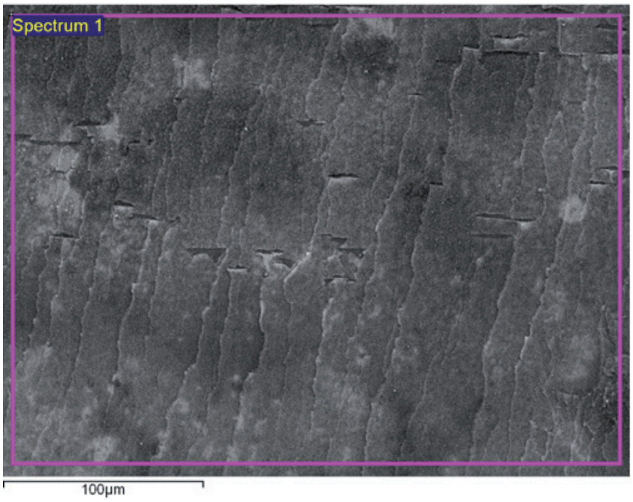

Fig. 11. Randomly selected area in which measurement of the chemical composition distribution layer for super-conducting tapes $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS coated with Cu was carried out

The spectrum characteristics shown in Figure 12 shows that the area of study was the layer of superconducting because signals were received from Y, Ba, Cu, and O. A peak from Mg comes from the buffer layer and the peaks from Fe, Ni, Cr, Al, Mo, and C informed about signals coming from the ground of superconducting tapes. The chemical composition of a superconducting layer is shown in Table 3.

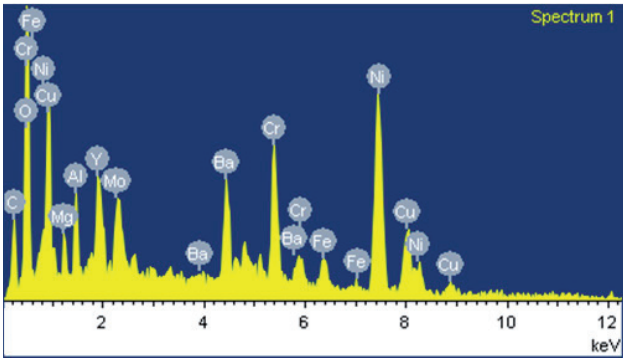

Fig. 12. Characteristic spectrum showing the chemical composition of the layers of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tapes coated with Cu

Table 3.
Chemical composition of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting layer coated with Cu

Element	Type of study	weight%	atomic%
C K	EDS	13.34	34.64
O K	EDS	15.49	30.20
Mg K	EDS	1.41	1.81
Al K	EDS	2.33	2.69
Cr K	EDS	8.33	5.00
Fe K	EDS	2.06	1.15
Ni K	EDS	24.66	13.10
Cu K	EDS	10.30	5.06
Y L	EDS	6.81	2.39
Mo L	EDS	5.02	1.63
Ba L	EDS	10.25	2.33

The analyses of the chemical composition shows that the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tape has a layered structure. The components of the tape are: the substrate, the buffer layer, a layer of superconducting and protective coating. The coating is applied on both sides. Corrosion-resistant steels where the main components are Fe, Cr, Ni and Mo are used as a base. The alloying additives such as Co, W, Mn, Al and Si were also detected. As buffer layers MgO is used and as a coating to protect the superconductor from influence of the environment Cu is used. It was also the existence of the silver layer between the superconducting phase and a copper coating. The purpose of the layer is to increase the electrical conductivity of the system.

The next stage of the research was to determine the resistance to friction. In Figure 13 the surface of the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS tape after one hour of friction is shown. Then, there was no breakdown of the protective coating. The diameter of the wipe was 1020 microns and 13 microns of its depth.

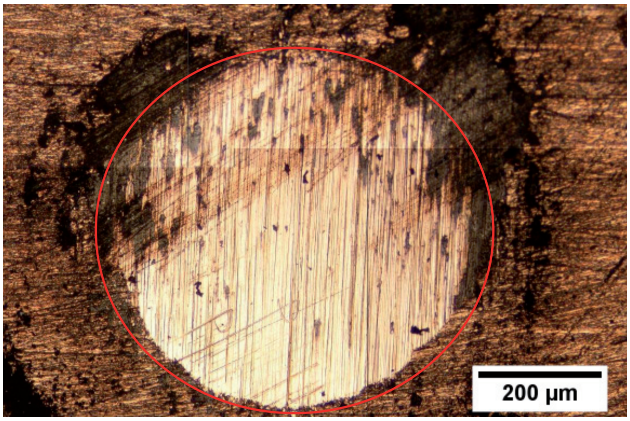

Fig. 13. A wipe made on the surface of the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS high temperature superconducting tape coated with Cu, after 1 hour

After two hours of study, the diameter of the resulting wipe reaches 1717 microns, and the depth of 36.9 mm. As it is apparent from Figure 14, there was a breakthrough of the copper coating and the silver layer and the superconducting layer can be seen.

Fig. 14. A wipe made on the surface of the high temperature $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS superconducting tape coated with Cu, after 2 hours

After three hours the diameter of the resulting wipe reaches 1919 microns, and its depth - 46.1 mm. as it is apparent from Figure 15, there was breakthrough to the substrate.

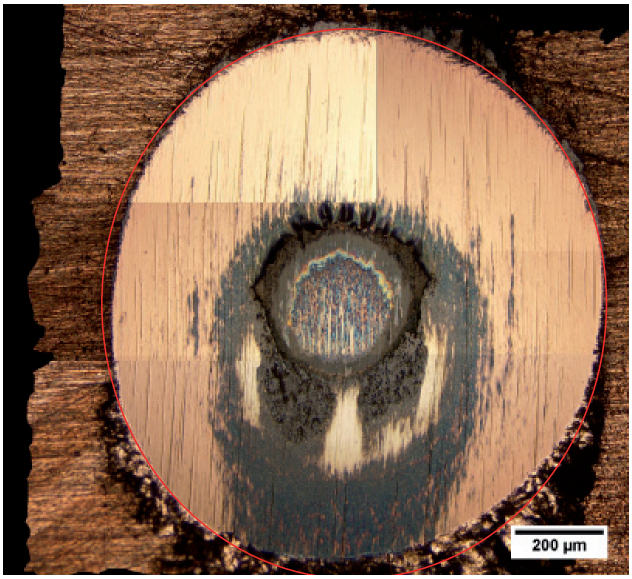

Fig. 15. A wipe made on the surface of the $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS high temperature superconducting tape coated with Cu, after 3 hours

Analysing the photograph wipe, presented in Figure 15 all the layers making up the test tape namely: copper coating, a layer of silver, superconducting layer and buffer, and the substrate may be observed.

4. Conclusions

- The tested $YBa_2Cu_3O_{7-x}$ – 2G YBCO HTS superconducting tape has layered structure.
- The components of the tape are: copper coating applied to both sides, a silver layer, a layer of superconducting and buffer and the substrate.
- Silver layer between the copper layer and the superconducting layer is applied in order to increase the electrical conductivity of the system.
- Hourly friction, using ceramic ball did not result in breakthrough coating.
- After two hours of friction, a puncture of the protective layer appeared.
- After three hours of friction, piercing appeared, to the substrate of $YBa_2Cu_3O_{7-x}$ – YBCO 2G HTS high temperature superconducting tape.

- Wipe diameter after three hours of friction was 1919 microns and its depth 46.1 mm.

References

[1] J.J. Sunol, J. Saurina, P. Bruna, Structural and thermal changes induced by mechanical alloying in a Fe-Ni based amorphous melt-spun alloy, Materials Chemistry and Physics 114/2-3 (2009) 996-999.

[2] A. Urata, N. Nishiyama, K. Amiya, A. Inoue, Continuous casting of thick Fe-base glassy plates by twin-roller melt-spinning, Materials Science and Engineering A 449-451 (2007) 269-272.

[3] C.C. Clickner, J.W. Ekin, N. Cheggour, C.L.H. Thieme, Y. Qiao, Y.Y. Xie, A. Goyal, Mechanical properties of pure Ni and Ni-alloy substrate materials for Y-Ba-Cu-O coated superconductors, Cryogenics 46 (2006) 432-438.

[4] http://www.superpower-inc.com

[5] http://www.amsc.com

[6] D.Q. Shi, M.J. Qin, J.H. Kim, M.Y. Zhu, S.X. Dou, Superconducting properties of coated conductor grown by RABiTS on Ni-Mn tape, Physica C 460-462 (2007) 1392-1393.

[7] Y. Zhang, R.C. Duckworth, T.T. Ha, M.J. Gouge, Solder ability study of RABiTS-based YBCO coated conductors, Physica C 471/15-16 (2011) 437-443.

[8] J. Eickemeyer, D. Selbmann, R. Opitz, V. Subramanya Sarma, B. Holzapfel, L. Schulz, Nickel DABiTS-tapes as a promising alternative to RABiTS-tapes, Physica C 408-410 (2004) 906-907.

[9] Y. Yamada, S. Miyata, M. Yoshizumi, H. Fukushima, A. Ibi, T. Izumi, Y. Shiohara, T. Kato, T. Hirayama, Long IBAD-MgO and PLD coated conductor, Physica C 469 (2009) 1298-1302.

[10] Y. Sutoh, K. Kakimoto, N. Kaneko, Y. Iijima, T. Saitoh, Mechanical bending property of YBCO coated conductor by IBAD/PLD, Physica C 426-431 (2005) 933-937.

[11] P.N. Arendt, S.R. Foltyn, L. Civale, R.F. DePaula, P.C. Dowden, J.R. Groves, T.G. Holesinger, Q.X. Jia, S. Kreiskott, L. Stan, I. Usov, H. Wang, J.Y. Coulter, High critical current YBCO coated conductors based on IBAD MgO, Physica C 412-414 (2004) 795-800.

[12] S. Hanyu, C. Tashita, Y. Hanada, T. Hayashida, H. Kutami, M. Igarashi, H. Fuji, K. Kakimoto, Y. Iijima, T. Saitoh, IBAD-MgO buffer layers for coated conductors in the large-scale system, Physica C 469 (2009) 1364-1366.

[13] T. Manabe, W. Kondo, I. Yamaguchi, M. Sohma, T. Tsuchiya, K. Tsukada, S. Mizuta, T. Kumagai, Critical current density and microwave surface resistance of 5-cm-diameter YBCO films on $LaAlO_3$ substrates prepared by MOD using an infrared image furnace, Physica C 417 (2005) 98-102.

[14] K.C. Chung, Y.K. Kim, X.L. Wang, S.X. Dou, Texture analysis of RF-sputtered CeO_2 buffer layers and superconducting MOD-YBCO films, Physica C 470 (2010) 225-227.

[15] T. Izumi, Y. Tokunaga, H. Fuji, R. Teranishi, J. Matsuda, S. Asada, T. Honjo, Y. Shiohara, T. Muroga, S. Miyata, T. Watanabe, Y. Yamada, Y. Iijima, T. Saitoh, T. Goto, A. Yoshinaka, A. Yajima, Progress in development of coated conductors by TFA–MOD processing, Physica C 412-414 (2004) 885-889.

[16] M. Sohma, T. Tsuchiya, K. Tsukada, I. Yamaguchi, T. Manabe, T. Kumagai, K. Koyanagi, T. Ebisawa, H. Ohts, Preparation of YBCO films by an excimer-laser-assisted MOD by scanning irradiation, Physica C 463-465 (2007) 891-894.

[17] T. Taneda, K. Muranaka, K. Fujino, K. Ohmatsu, H. Takei, Y. Sato, S. Honjo, Y. Takahashi, Enhancement of Jc and crystal alignment by reverse ISD method, Physica C 378-381 (2002) 944-949.

[18] M. Li, B. Ma, R.E. Koritala, B.L. Fisher, K. Venkataraman, V.A. Maroni, V. Vlasko-Vlasov, P. Berghuis, U. Welp, K.E. Gray, U. Balachandran, Pulsed laser deposition of c-axis untilted YBCO films on c-axis tilted ISD MgO-buffered metallic substrates, Physica C 387 (2003) 373-381.