The Latest Trends of MOD REBCO Superconducting Coated Conductors in SWCC

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The REBCO (RE: Rare-earth, REBCO: REBa₂Cu₃O₇) high-Tc superconducting coated conductors are well known as one of the candidates of superconducting conductors for practical use. SWCC Showa Cable Systems developed low-cost REBCO coated conductors which are consisted of several layers (see Figure 1). REBCO coated conductors have developed using the metal-organic deposition (MOD) process including trifluoroacetates (TFA) collaborating since 1999. In 2008, we successfully developed 500 m-class YBCO coated conductors which had the critical current ($I_c$) values of 310 A/cm-width at 77 K in self field. Moreover, we successfully developed a way for introducing artificial pinning centers (APC) to control the degradation of superconducting properties in magnetic fields. The way was substitutions of Gd for a part of Y elements and introduction of nano-particle BaZrO₃, which was a compound of Ba, O and Zr added in the raw material, in the superconducting layer using a large batch type furnace [¹]. We successfully fabricated 100m-class REBCO with APC coated conductors which had $I_c$ values of over 50 A/cm-width at 77 K in 3 T [²]. We will improve performance of REBCO coated conductors and develop products of superconducting applications, from now on. We have named the MOD REBCO coated conductors with APC “nPAD-YBCO®” (nPAD-YBCO®: nano particle artificial pinning center distributed YBCO).

Recently, we successfully developed the low heat leakage superconducting current leads using “nPAD-YBCO®” for the superconducting equipment (see Figure 2). Moreover, the nPAD-YBCO® superconducting current leads have been commercialized since 2013.

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Performance and Improvements in 2G HTS Wires at SuperPower

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Second generation (2G) high temperature superconducting (HTS) wire is now widely available for various applications. In SuperPower, the 2G HTS wires are being produced by applying MOCVD growth of Zr-doped REBCO thin superconducting film on an IBAD textured buffer stack with enhanced pinning effect resulting in large in-field current capability. SuperPower continues to address 2G HTS wire development and production methods to enhance performance of the wire. In this presentation, we report recent progress on in-field performance, mechanical strength and other wire properties that are important to the coil applications.
DEVELOPMENT OF REBCO COATED CONDUCTORS
BY IBAD/PLD PROCESS FOR MAGNET APPLICATIONS

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Abstract
We developed high-throughput production technique for REBCO coated conductors using ion-beam-assisted-deposition (IBAD) and pulsed-laser-deposition (PLD), which enabled us manufacture with length up to 1km and \( I_c \) over 600 A/cm-width at 77 K, self field. This paper reports; 1) reproducibility improvement, and 2) \( I_c \)-B-T property enhancement, achieved by PLD process amendment, and 3) new folding type Cu stabilizing layer for magnet applications. Several tens km long wires were delivered worldwide in a fiscal year. But so far manufacture yield depends on the length, width, and minimum end-to-end \( I_c \), mainly limited by reproducibility of REBCO deposition process by hot-wall type PLD on10mm wide substrate tapes, and also succeeding process for products whose final width below 5mm. We reformed furnace structure of hat-wall PLD system for better reproducibility over 500m long run, and also achieved \( I_c \)-B-T property enhancement. \( I_c \) of 809A/cm was obtained at 4.2K, 17T, which corresponds Je of 623 A/mm2 for 130mm thick wire. Furthermore, new folding type structure of Cu stabilizing layer was developed for magnet applications. 20mm thick Cu foil was wrapped around all the circumference of coated conductors and pasted by solder in order to improve mechanical strength especially of delaminating properties.
Manufacturing of 2G-HTS Tapes and Current Status of Research and Development at SuperOx Japan LLC

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SuperOx Japan LLC was established in August 2011 to develop cost-effective technology for the manufacturing of second generation (2G) HTS tapes by set of physical vapor deposition methods, and to deliver affordable and customized 2G tapes to the market. During the first year of company operation the R&D and production facilities were established in Sagamihara (Japan), and the equipment for RF and DC magnetron sputtering, ion-beam assisted deposition (IBAD), and pulsed laser deposition (PLD) methods was installed and fully tested. The activities of the second year were focused on the research and development of the technological process and optimal wire architecture. This work was done in collaboration with SuperOx (Moscow, Russia), which possesses a unique expertise in chemical vapor deposition and solution based methods. The combined efforts of the two companies allowed SuperOx Japan LLC to develop the technological path, which relies on the use of Hastelloy substrate tape and IBAD-MgO texturing.

Currently SuperOx-Japan LLC operates in the pilot production mode. We proposed and refined a group of 2G-HTS tapes architectures, which allow fabrication of tapes with $I_c$ values of 300-500A/cm-width and typical piece length of 300-500 m at the industrially acceptable process rate, tuned the manufacturing technology and produced several kilometers of 12 mm wide equivalent 2G-HTS tapes.

At present, we focus our efforts on further improvement of manufacturing process towards the production of 12 mm tapes with $I_c x L$ of 300,000A*m by the end of 2014. Simultaneously, our highest priority is the development of highly customized 2G-HTS tapes that can be produced “on demand” in response to the needs of the customers. By now SuperOx Japan LLC has reached world competitive level in terms of performance and reproducibility of the 2G HTS tapes, and it is improving rapidly.
We have fabricated a high performance GdBa$_2$Cu$_3$O$_{7-\delta}$ (GdBCO) coated conductor (CC) by reactive co-evaporation deposition & reaction (RCE-DR), which showed great potential as the highest throughput fabrication process compared with other methods developed previously for second generation (2G) high temperature superconducting (HTS) wires, meeting the current and future need of industry in terms of price and production speed. GdBCO CCs fabricated by RCE-DR showed outstanding transport properties such as a critical current of 794 A/12 mm-width at 77 K in self-field.

Earlier this year, we combined system for Al$_2$O$_3$ barrier & Y$_2$O$_3$ seed layer and system for IBAD, homo-epi & buffer layers. It enabled the buffer and seed layers to be stably grown, having excellent texture without becoming polluted from particles in the air. As the result, the occurrence of delamination between superconducting layer and buffers layer became infrequent and current transport property of our product was quite improved. We have also introduced vision inspection system (VIS) for in-line monitoring and feedback control of layer deposition. This allows us to fine-tune the composition of GdBCO and thus to maintain the excellent critical current uniformity along length. Eventually, SuNAM’s efforts for technical development led to achievement of 566,214 A·m (579 A × 978 m) as shown in Figure 1.

GdBCO CCs fabricated by SuNAM can be utilized in various application areas. As a practical example, we fabricated superconducting magnet generating 4 T and developed I$_c$ (B,T,θ) measurement facility applying the magnet. In succession, we are also trying to develop high field superconducting magnet of 20 T and have been proving GdBCO CCs by SuNAM to be enough qualified for application.

Figure 1. Critical current variation along length of SuNAM’s 2G wire.
Processing for high performance REBCO coated conductors via RCE-DR

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Long-length GdBCO coated conductors (CCs) possessing high critical current at 77 K in self field up to ~800 A/cm-width are being produced via a reactive co-evaporation deposition and reaction (RCE-DR) process by SuNAM. Recently, we have reported details on this high throughput process [J. H. Lee et al., Supercond. Sci. Technol. 27 (2014) 044018]. While this technology has been continuously improved by SuNAM for GdBCO CCs, there have been some challenging problems, including relatively weak pinning properties as reported by S.M. Choi et al. [IEEE Trans. Appl. Supercond. 23 (2013) 8001004]. Since accurate information on the stability diagrams of the REBCO phases in low oxygen pressures is critical for the optimization of the RCE-DR process, we have investigated those for RE = Gd, Sm, and Y. Among these REBCO phases, we have already reported the stability phase diagram of GdBCO [J.W. Lee et al., J. Alloys Compd. 602 (2014) 78]. Interestingly, the stability phase diagrams of REBCO (RE= Gd, Sm, Y) are quite different from each other, particularly in their decomposition products, suggesting that the growth conditions should be properly modified for each REBCO. In this talk, the key factors for the fabrication of high performance REBCO CCs will be discussed on the basis of their stability diagrams, and some of our meaningful efforts to overcome the weak pinning properties will be presented for a discussion.

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