WBP4-1

Enhancement of the Deposition Rate and Crystallinities for $SmBa_2Cu_3O_y$ Coated Conductors Using Vapor-Liquid-Solid Growth Technique

*Tomohiro Ito[1], Shuya Tajiri[1], Yusuke Ichino[1], Yuji Tsuchiya[1], Ataru Ichinose[2], Yutaka Yoshida[1]

Department of Electrical Engineering, Nagoya University, Japan[1]
Central Research Institute of Electric Power Industry, Japan[2]

In fabricating $REBa_2Cu_3O_y$ (REBCO) superconducting coated conductors (CCs), the CCs are required to increase deposition rate and crystallinities in order to reduce the cost of CCs fabrication. However, using the conventional pulsed laser deposition (PLD) method, the deposition rate is enhanced as the energy density of the pulsed laser is increased, while the crystallinities of the REBCO layer are deteriorated.
In this work, in order to improve both the deposition rate and superconducting properties, we fabricated $SmBa_2Cu_3O_y$ (Sm123) coated conductors using VLS growth technique. VLS growth technique is expected rapid growth rate and good crystallinity of REBCO films [1]. Furthermore, REBCO films fabricated using VLS growth technique by several group is reported that this films indicate high deposition rate and crystallinities [2,3].
The VLS growth technique consists of the following three steps by PLD method. The first step is to fabricate a solid Sm123 layer. The second step is to form a liquid layer on the solid layer. The last step is to supply Sm123 through the vapor phases on the liquid and solid films called upper layer. We changed the energy density of the pulsed laser ranging from 1.9 to 2.4 J/cm^2 in fabrication the upper layer.
Figs.1(a) and (b) show XRD intensity ratio of *a*-axis peak of 200 to *c*-axis peak of 005, critical temperature (T_c) and deposition rate of Sm123 thin films. Using the PLD method, intensity ratio of *a*-axis peak increased to 81% and T_c decreased to 88.9 K at 1.9 J/cm^2. On the other hand, using VLS growth technique, *a*-axis intensity ratio did not increase at all and T_c maintained a high value of 91.6 K even at 2.4 J/cm^2. Consequently, the deposition rate reached to 137.3 nm/min without deteriorations of crystallinity (*a*-axis mixing) and T_c. We will discuss superconducting properties of APC-doped VLS-SmBCO at various energy density.

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[1]Y. Yoshida *et al.*: Appl. Phys. Lett. **69** (1996) 845. 82 [2]Y. Yoshida *et al*: J. Cryst. Growth **229** (2001) 348. 81, 111 [3]K. S. Yun *et al*: Appl. Phys. Lett. **80** (2002) 61. 82, 107

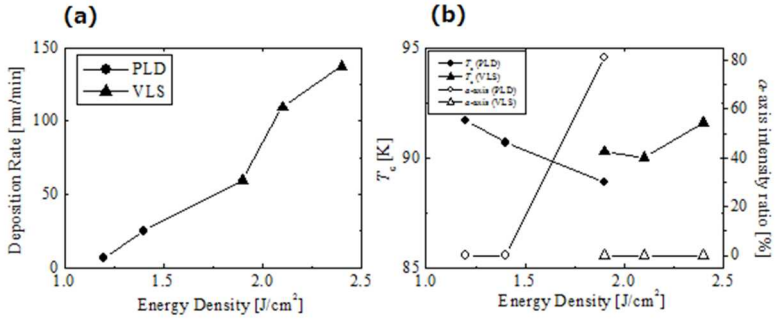


Fig.1 Laser energy density dependence of deposition rate(a), and Critical temperature (T_c) and *a*-axis intensity ratio(b).

Keywords: Vapor-Liquid-Solid growth technique, thin film, high deposition rate

WBP4-2

Measurement of magnetic properties of metal substrate for REBCO coated conductor at low temperature using a single sheet tester

*Shinya Ohara[1], Takuya Nakagawa[1], Kenya Fujimoto[1], SeokBeom Kim[1], Hiroshi Ueda[1]

Graduate School of Nature Science and Technology, Okayama University,Japan[1]

In recent years, from the viewpoint of energy conservation, electrical equipments are required to be designed for high efficiency, light weight, compactness, and high performance. In research and development of high-capacity generator, a high temperature superconducting (HTS) rotating machine is possibility of smaller volume and weight of the device, higher power density, improvement of economic efficiency. And, in the future, the application of HTS machine to a ship and land equipment is expected to cut in greenhouse gas and save the energy. Especially, REBCO tape has high strength and high critical current density in a magnetic field, therefore, the research and development of supplication of REBCO tape to the superconducting rotating machine are in progress. REBCO tape consists of an REBCO layer deposited on buffer layers on top of a substrate. Some substrate for REBCO tape has magnetism. In order to improve the electromagnetic field numerical analysis in the design of superconducting magnets for MRI and NMR, it is necessary to consider the magnetic characteristics of the metal substrate at low temperature. In this study, we measured the magnetic properties of REBCO tape with metal substrate (NiW) at low temperature by using a single sheet tester (SST), which is mainly used for precisely measuring the magnetic characteristics of the electromagnetic steel sheet. The magnetic properties of metal substrate were measured using SST in liquid nitrogen and these properties were compared with magnetic properties at room temperature.

Keywords: REBCO tape, metal substrate, measurement of magnetic properties

WBP4-3

Development of self-protected HTS coil for mechanical problems in non-insulated HTS coils

*Haruyoshi Okusa[1], Kentaro Tami[1], Takahiro Tatsuta[2], Hiroshi Ueda[1], SeokBeom Kim[1]

Graduate School of Natural Sciece and Technology, Okayama University, Japan[1]
Electrical and Communication Engineering, Okayama University, Japan[2]

In the case of motors and generators, the benefits of using high temperature superconducting (HTS) coils can be represented by the reduction of 50% in both losses and sizes compared to conventional machines. However, it is hard to establish quench detection and protection devices for the HTS coils applied to the rotors and generators. So, the stability of the HTS coils is lower than for the quiescent coils applied to NMR, MRI and so on. Therefore, it is important to improve the self-protection ability of HTS coils. We have studied the methods to improve the self-protection ability of HTS coils by removing the turn-to-turn insulation and inserting metal tape instead of the electrical insulation. However, the initial shape of the HTS coils will be changed by the thermal stress due to cooling down and warming up and the mechanical stress due to electromagnetic force, because the outermost turn of the HTS coils are fixed by epoxy resin or SUS tape even the non-insulated HTS coils. When the shape of the HTS coils are changed from initial condition, the contact resistance between the HTS tape wires in the non-insulated HTS coils is changed too. Therefore, the self-protection ability of non-insulated HTS coils should decrease because the current bypass characteristics is determined by contact resistance.

In this study, we developed a non-insulated HTS coil installed new protection device to prevent the shape deformation of the HTS coils. This protection device is composed of multiple metal rings which have different thermal and electrical properties, so we have to optimize the shape of the rings and determine the materials of it. It is assumed that the developed device will effective in not only the non-insulated HTS coil but also insulated HTS coils. The optimized shape of the metal rings to keep the shape of the HTS coil against the thermal and mechanical stresses obtained by FEM based numerical analysis will be presented.

Keywords: non-insulated HTS coil, self-protection, stress, ring

WBP4-4

Study on Electromagnetic Characteristics of Twisted Soldered-Stacked-Square (3S) HTS Wire with 1mm Width

*Yongkang Zhou[1], Zhuyong Li[1]

Department of Electrical Engineering, Shanghai Jiao Tong University, No.800 Dongchuan Road, Minhang District, Shanghai, 200240, China[1]

A novel soldered-stacked-square (3S) HTS wire is fabricated through narrowing, stacking and soldering process. Tapes with more than 4mm width are first incised into several 1mm narrow tapes and then immersed together into a solder bath and undergone stacking and soldering process simultaneously. A series of 3S HTS samples are prepared, and we evaluate the typical electromagnetic characteristics. Samples are twisted with different twist pitches and their critical currents and AC losses are measured at the same time. It is shown that the critical current of a twisted 3S HTS wire degrade no more than 10% of the original critical current with a twist pitch of 100mm. Measured AC losses are independent of frequency and are mostly sandwiched between theoretical values from the elliptical and thin strip equations of the Norris model except that they are a bit less than the theoretical value when peak transport current is reaching critical current.

Keywords: Soldered-Stacked-Square (3S) HTS Wire, twist pitch, electromagnetic property, 1mm width

WBP4-6

CORC modeling and bending experiments with variation of cable manufacturing parameters

A. Nijhuis[1], V.A. Anvar[1,2], M. Binet[3], K.A. Yagotintsev[1], D.C. van der Laan[4], J. Weiss[4], T.J. Haugan[5]

University of Twente, Faculty of Science & Technology, 7522 NB Enschede, The Netherlands[1]
University of Wollongong, Wollongong, Australia[2]
TKM College of Engineering, Department of Mechanical Engineering, Kollam, Kerala, India[3]
Advanced Conductor Technologies and University of Colorado, Boulder CO 80301, USA[4]
US Air Force Research Laboratory, Wright Patterson AFB, OH 45433, USA[5]

A CORC cable is composed of several layers of helically wound HTS tapes on a round core with the winding direction reversed in each successive layer. The cable is flexible but the flexibility is limited by the critical strain value when causing breakage of the HTS layer.

Depending on the application, the cables can experience substantial thermal, mechanical and electromagnetic loads arising from cabled conductor and coil manufacturing to cooling and operation of the magnet. In order to optimize the manufacture and operating conditions, the mechanical behavior of CORC cable must be understood for the relevant loading conditions. The complex configuration with many contact interactions between tapes and the non-linear behavior of the materials from the production to operation conditions requires the use of finite element (FE) modeling. The FE modeling will allow an accurate calculation of the stress-strain state of the cable components under various loads and importantly; avoiding large-scale and expensive experimental optimization studies.

This work presents the results of a series of small scale experimental bending tests at 77 K and detailed FE modeling of the 3D stress-strain state in a CORC cable under bending load, taking the temperature dependence and the elastic-plastic properties of the individual tape materials into account, starting from the initial tape processing conditions during its manufacture up to magnet operating conditions. Furthermore a comparison of the simulations with experiments is presented with special attention for the critical force, the threshold where the individual tape performance becomes irreversibly degraded. Different cable manufacturing parameters as core diameter, tape width, winding angle and lubrication are varied and investigated.

WBP4-7

AC Loss Properties of Stacked REBCO Superconducting Multifilamentary Tapes under Perpendicular Magnetic Field

*Hiromasa Sasa[1], Tetsuya Ito[1], Shun Miura[1], Masataka Iwakuma[1], Teruo Izumi[2], Takato Machi[2], Akira Ibi[2]

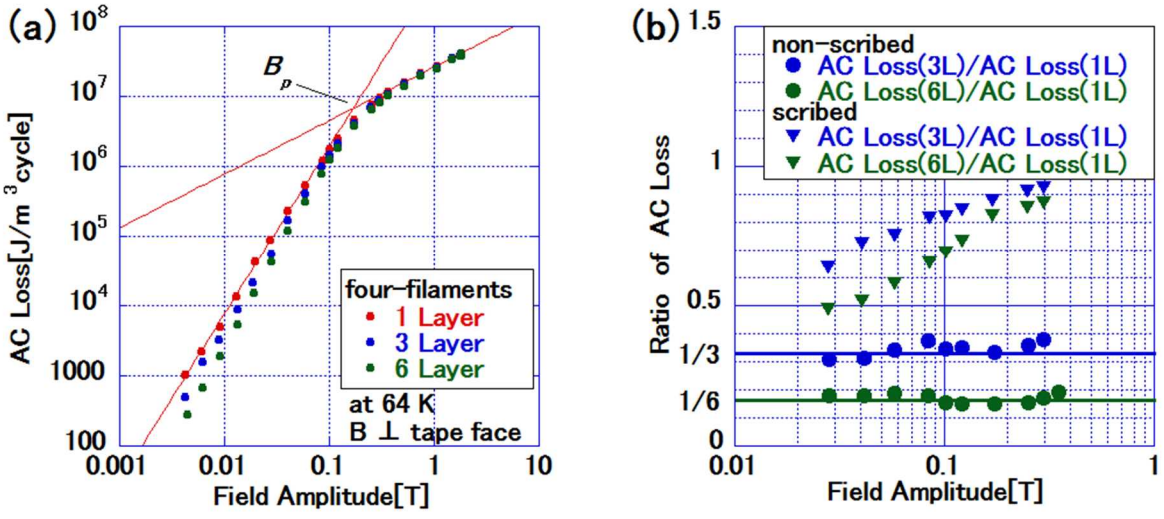
Institute of Superconductors Science and Systems, Kyushu University, Japan[1]
National Institute of Advanced Industrial Science and Technology, Japan[2]

For AC applications of superconductors, an AC loss leads to the temperature rise of superconducting systems and it is a great part of total heat load. Therefore, it is very important to estimate the AC loss in superconucting windings.

In this study, the AC loss properties of multi-filamentary $EuBa2Cu_3O_y$ (EuBCO) superconducting tapes were investigated by using a saddle-shaped pick-up coil. The tapes were fabricated by the pulsed laser deposition (PLD) process, and then divided into a four-filament structure by the laser-scribing technique. The thickness of a EuBCO superconducting layer is 3.6 μm. The length and width of sample tapes are 60 mm and 5 mm, respectively.

Fig. 1(a) shows magnetic field amplitude, B_m, dependence of AC loss of the four-filament tapes which stacked into 1, 3 and 6 layers at 64 K in external magnetic field. The external field was applied perpendicularly to the tape face. The breaking point, B_p, of the AC loss curve corresponds to the penetration field where the magnetic flux penetrates to the center of the tape or filaments. The AC losses for $B_m > B_p$ roughly coincide regardless of the number of stacked tapes. However, for $Bm < Bp$, the AC losses of the stacked tapes (3- and 6-layer) do not coincide with those of the one-layer. The AC loss properties of the non-scribed EuBCO tapes which stacked into 1 to 6 layers at 64 K were also investigated. Fig. 1(b) shows field amplitude dependence of the ratio of AC losses in the non-scribed and four-filament tapes to those in the one-layer tape for $Bm < Bp$. Here, n is the number of stacked tapes. In the case of the non-scribed tapes, the ratios roughly correspond to approximately $1/n$. However, in the case of the scribed tapes, the ratios are higher than $1/n$. Moreover, the ratios increase with increasing B_m. The reason for the difference between non-scribed and scribed cases is not cleared yet and the objective of this study is to reveal that. The AC losses of 2-, 12- and 16-layer multifilamentary tapes with 2 and 8 filaments will be further investigated and then discussed from the viewpoint of demagnetizing effect.

Fig. 1(a) Magnetic field amplitude dependences of AC losses of 4-filament REBCO superconducting tapes and (b) the ratios of AC losses of 3- and 6-layer tapes which are non-scribed and scribed into a four-filament structure to those of 1-layer tape for $Bm < Bp$.



Keywords: AC loss, laser-scribing, superconductor, REBCO

WBP4-8

Experimental investigation and analysis on critical current of HTS tapes in current-rise-rate by Wavelet Analysis Algorithm

*Jie Chen[1], Jin Fang[1], Xinyu Fang[2]

The School of Electrical Engineering, Beijing Jiao-Tong University, Beijing[1]
The Department of Electrical and Computer Engineering, University of Victoria, Victoria[2]

The application of HTS technology in power system will greatly improve the efficiency of the power grid and bring remarkable economic and social benefits: the transmission loss of power will greatly be reduced; the low-priced electricity for costumers will be achievable. The development of HTS power devices give rise to higher requirements for superconducting materials. In HTS power applications, the superconducting tape is often used to transmit the ac current. At present, the research has focused on the HTS transmission characteristics and the stability of HTS materials. Now the critical current of HTS in DC circumstance is defined and at the meantime AC current-carrying capability of HTS is involved, however, the critical current after filtering by the method of wavelet analysis is affected by current-rise-rate. A new critical current criterion of the condition should be established for further studies.

In this paper, the E–I curves were obtained by the four-probe method and the current-rise-rate ranges from 1 A/s to 50A/s. The ac current carrying capacity of the superconductors is discussed and analyzed by the RMS method, virtual n value method, and the loss concept method. Therefore, DC&AC critical current calculation method is obtained and the calculative equation at different rise rate is established.

A. Principle and Procedure of Experiment

In our cases, firstly, we attempted to obtain the *E–I* curves of HTS tapes by utilizing the method of measuring DC&AC critical current by current-rise-rate. Second, the *E–I* curves signal is filtered by using wavelet analysis algorithm. So as to foundation for accurate judgment. In our measurement, all measurements of two samples were carried out at the temperature of 77 K.

B. Samples of the Experiment

Two kinds of YBCO tape which were called sample A-Shanghai Superconductor and sample B-Super Power were selected as the test sample.

C. The AC Measurement Results

To find the current-rise-rate dependence of critical current, the samples A and samples B were measured under DC&AC condition. The measured data is plotted as the E–I curves from 1A/s to 50A/s,. The experimental results show that the voltage increases with the increasing of current-rise-rate.

Keywords: DC&AC critical current, current-rise-rate, YBCO tape, wavelet analysis method

WBP4-9

I_c –Bending Strain Characteristics of REBCO Coated Conductor Tapes at 77 K using a Bending Beam Spring Test Rig

*Mark Angelo E. Diaz[1], Hyung-Seop Shin[1]

Andong National University, Korea[1]

Recently, REBCO coated conductor (CC) tapes have been applied to magnets and coils due to their outstanding electrical and mechanical properties. In such applications, the CC tapes are subjecting to stresses/strains during manufacturing, cool-down and operation. It is known that the mechanical stress/strain degrades significantly the critical current, I_c of the CC tapes. Understanding of the I_c characteristics of REBCO CC tapes in a full strain range from tension to compression at cryogenic temperature is important to expand the application field of the CC tapes. In this study, the I_c characteristics were examined using bending beam spring test rig which can apply continuous bending strain from compressive to tensile to the CC tape attached to the beam holder at 77 K. In addition, a Goldacker-type bending test rig, which does not use a bending beam holder, was used to examine the I_c-bending strain characteristics of the CC tapes. Comparison of the I_c - bending strain characteristic obtained using two bending test rig was performed. As a result, both test methods verified that when the applied strain exceeded beyond a critical strain value, I_c decreased due to the onset of cracks on the superconducting film. The irreversible strain limit of the CC samples in bending mode was tried to determine, however, it was still reversible in the tested strain range. The I_c was completely recovered to the original critical current, I_{c0}, when the bending strain applied was removed.

Keywords: bending beam spring, Goldacker-type bending test rig, compressive/tensile bending strain, cryogenic temperature

WBP4-10

Enhancement of Delamination Strength in Cu-stabilized GdBCO CC Tapes under Transverse Tension

*Zhierwinjay M. Bautista[1], Mark Angelo E. Diaz[1], Hyung-Seop Shin[1]

Andong National University, Korea[1]

The improvements of the critical current under magnetic field and the electromechanical properties in second generation high temperature superconductor (2G HTS) coated conductor (CC) tapes have widened its potential to device applications such as magnets and coils. In the aspect of mechanical and electromechanical properties, the structure of CC tapes has significantly affected its performance for the practical applications in various loading modes. Recently, a long CC tape with high current carrying capacity could be achieved. On the other hand, with these achievements, the transport properties of CC tapes should be coupled with high uniformity and reliability under various loading conditions. During fabrication, cool-down and operations of the HTS coils, the CC tape may experience a large force or deformation that affects its current carrying capacity. Especially, the excessive transverse tensile stress induced to the CC tapes may cause the delamination phenomenon on the multi-layer structured CC tapes and the ballooning during cool-down of coils. Therefore, the building some improvement measures based on the delamination mechanism observed in the CC tapes is important, especially for the design of delamination resistance in devices including impregnated coils. **In this study, the delamination resistances of Cu-stabilized CC tape with additional treatments such as laser cleaning, Ag heat treatment and hole drilling/soldering process were examined under transverse tensile loading at RT and 77 K.** In order to understand the delamination mechanism, fractographic morphologies of delaminated specimens are also examined.

Keywords: Delamination, Coated conductor, additional treatment, transverse tension