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Mechanical and electrical characteristics of silver stabilizer layer prepared by using nano silver paste for coated conductor

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ABSTRACT

Mechanical and electrical properties of silver stabilizer layer of coated conductor, which was prepared using nano silver paste as starting materials, have been investigated. Nano silver paste was coated on YBCO ($Y_1Ba_2Cu_3O_{7-\delta}$) film by a dip coating method with a speed of 25 mm/min. Coated film was dried in air and heat treated at 400–700 °C in a flowing oxygen atmosphere. Adhesion strength between YBCO and silver layer was measured by Tape test (ASTM D 3359). The hardness and electrical conductivity of the sample were measured by pencil hardness test (ASTM D 3363). Surface and volume resistance were measured by using LORESTA-GP (MITSUBISHI). The sample heat treated at 500 °C showed poor adhesiveness of 1B but it is clearly enhanced to 5B when samples were heat treated at higher than 600 °C. The silver layer heat treated at 700 °C showed a high hardness value of higher than 9H and a volume resistance of $1.417 \times 10^{-7}\ \Omega$ mm at room temperature. SEM observations showed that a dense silver layer was formed with a thickness of about 2 μm. Dip coated silver layer prepared by using nano silver paste showed superior electrical and mechanical characteristics which is comparable to those that sputter deposited Ag layer.

1. Introduction

Coated conductor is expected to be used widely as electric wire for the application in electric power devices due to its superior electric current carrying capacity even under magnetic field at a boiling temperature of liquid nitrogen. For the commercialization of coated conductor, there are three key elements to be solved; (1) fabrication of long-length wire with high critical current (I_c), (2) low ac loss, high I_c under high magnetic field and (3) high productivity and low cost. In order to achieve those issues, intensive research and development efforts have been made and long-length coated conductor with high performance has been realized by SuperPower Inc. [1]. The high I_c under high magnetic field and the anisotropy has been achieved by incorporation of second phase particles [2–4] and partial or complete substitution of yttrium by light rare earth elements [4–6]. Low ac loss of coated conductor has been decreased by reducing the width of superconducting layer using laser, photolithography and scalpel [7–9]. On the other hand, a wind-and-flip technique has been introduced for the fabrication of a persistent mode magnet which is essential for the application of MRI (Magnetic Resonance Imaging) and NMR (Nuclear Magnetic Resonance) [10].

Fabrication of coated conductor contains a various processing steps such as polishing of metallic substrate, texturization of metal substrate or ceramic buffer, epitaxial deposition of cap layer, epitaxial deposition of YBCO superconducting layer, silver deposition by sputtering, electrodeposition or soldering of copper layer. Therefore, it is not easy to achieve high productivities in all the above processing steps. However, on the long run, SuperPower Inc. has achieved high production speed of over 100 m/h in all important processes [1].

Even though there have been so big progresses in the development of production technologies, the efforts for the development of alternative processing techniques in order to reduce the production and capital cost are also very important for the fabrication of low cost coated conductor. For instance, silver stabilizer layer with a thickness of 1–3 μm is provided by using sputtering method in order to get low contact resistance and provide bottom layer for the electrodeposition of copper layer [11]. Coated conductor surrounded by copper electroplating is advantageous in being used at high voltage due to its round corner. For the electrodeposition of copper, double side deposition of silver layers is preferable. Nano silver paste is an important substance to give both of good electrical conductivity and adhesion for various devices [12].

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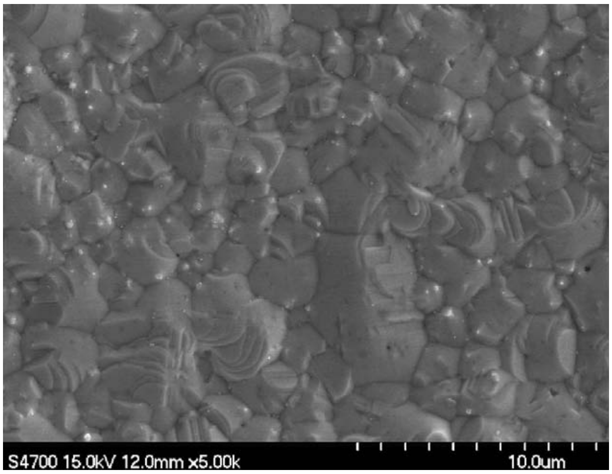

Fig. 1. Surface SEM micrographs of the silver layer for the coated conductor which was sintered at 600 °C.

Densification of silver layer is achievable at lower sintering temperature in case of nano-sized silver powder [12]. Double side coating is also able to be easily achievable if coating of silver paste is performed by a dip coating using diluted paste. Therefore, wet coating using silver paste is a candidate for the substitution of sputtering for the deposition of silver stabilizer layer.

In this study, we introduce a successful preparation and characterization of silver stabilizer layer of coated conductor prepared by dip coating method using nano silver paste.

2. Experimental

Two kinds of silver pastes with different size of silver particle were used for the preparation of silver stabilizer layer. Nano silver paste (40 wt% Ag, average particle size = 10 nm) and micron silver paste (NP-4731A, 70 wt% Ag, average particle size = 7–10 μm) were purchased from CMS TECHNOLOGY and NORITAKE, respectively. Screen printing was conducted on the YBCO film of coated conductor using nano and micron silver paste. The viscosity of the pastes was 140,000 cps, and 400,000 cps, respectively. Screen printed film was fired at 500 °C for 5 h in air. SEM (Scanning Electron Microscope) observation showed that porous silver film was formed for the sample prepared from micron silver paste whereas dense structure was formed for the sample prepared using nano silver particle. For a dip coating, nano silver paste was diluted by adding gelling agent as viscosity to be low as 45000 cps. Dip coating was conducted with a pulling speed of 20 mm/min and coated film was dried by blowing a hot air directly onto the specimen. A sample that silver film was prepared by DC sputtering was prepared for comparison. Dried silver film was sintered at 400–700 °C for 5 h in flowing oxygen atmosphere and oxygenation heat treatment was conducted at 500 °C for 5 h and furnace cooled in oxygen atmosphere.

Adhesion strength of silver layer was assessed by a peel-off test using 3 M Scotch™ tape in accordance with ASTM D 3359 (standard test methods for measuring adhesion by tape test method A: the X-cut test). Hardness of silver layer was measured by ASTM D 3363(standard test method for film hardness by Pencil test). Volume resistance and surface resistance were measured by using LORESTA-GP (MITSUBISHI), respectively.

Microstructure of silver layer was characterized using Field Emission Electron Scanning Microscopy (FESEM) and Focused Ion Beam (FIB) etching. The critical current (I_c) was measured by a four probe method at 77 K and self-field.

3. Results and discussion

As a preliminary experiment, silver layer was prepared by screen printing using two kinds of silver pastes with micron-sized and nano-sized silver particles, respectively. Coated film was

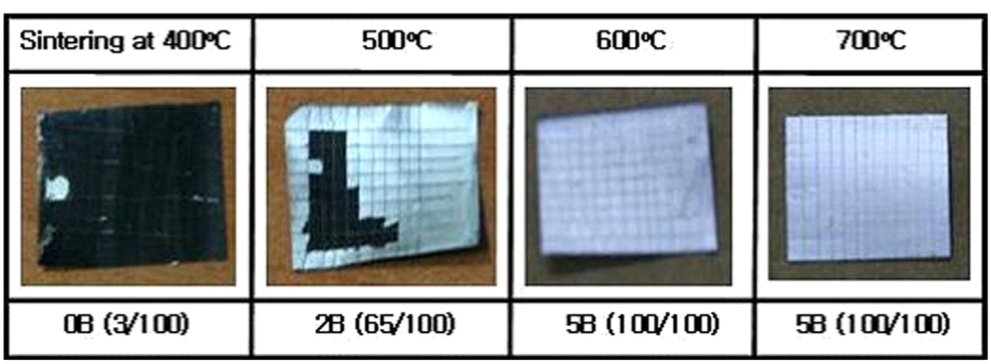

Fig. 2. Results of 3 M tape test for the sample sintered at various temperatures of 400–700 °C. 0B, 2B and 5B in figure represents that more than 65%, 15–35% and 0% of layer was peeled out, respectively.

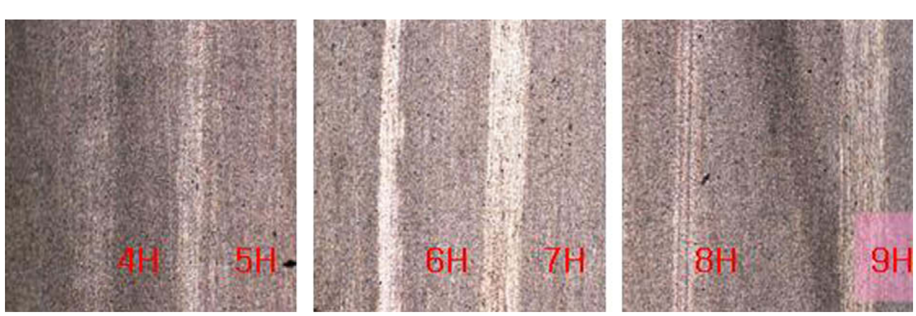

Fig. 3. Results of a pencil harness test for the sample which sintering was performed at 700 °C.