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ISD process development for coated conductors

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Abstract

The fabrication of coated conductors involves a multitude of processing steps. We present an economic route to produce second generation HTS tape from the initial substrate preparation to the final metal coating. The most important and technically challenging steps are the deposition of an oriented buffer layer and the superconductor film in a reel-to-reel configuration. New evaporation techniques have been developed to enable reliable, high rate tape coating. Highly oriented MgO-buffer layers are realized by inclined substrate deposition (ISD) yielding an in-plane orientation $< 10°$ FWHM and critical current densities up to 2.5 MA/cm^2. Buffered tape is fabricated up to 40 m length. The subsequent HTS deposition has been performed on several meter long pieces and reaches current levels in excess of 400 A/cm.

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1. Introduction

Coated conductors require excellent alignment of the superconductor coating to ensure maximum critical currents. Inclined substrate deposition (ISD) is one of the competing techniques to effect such alignment [1]. Neglected for quite a while against the more commonly used RABiTS and IBAD-techniques [2,3] latest progress render it a serious and economic alternative for coated conductor alignment. Regarding the high temperature superconductor (HTS) coating, chemical metal organic deposition (MOD) and physical vapor deposition (PVD) techniques are under intense development. Among the PVD methods evaporation offers high uniformity over large area and high volume deposition rates, which are necessary ingredients for a future low cost production. In this

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article we present a consistent, scalable reel-to-reel tape fabrication process based on a new evaporation scheme. This latest electron gun based deposition process has been designed for long-term operation and has improved the efficiency and reliability of coated conductor fabrication considerably.

Another crucial point in coated conductor manufacturing is a proper quality assessment. Monitoring the various manufacturing steps is often very complicated. In collecting data during processing a compromise has to be made between resolution and speed. Inline quality control—such as X-ray diffraction—can usually monitor only average properties of the layers or confirm proper process operation. Consequently, a lot of faults or problems can be detected unambiguously only in the performance of the superconductor. Variations in the film quality can be tiny and local, extended, or even periodic. For this reason it is crucial to employ a characterization tool that allows a precise evaluation of the superconductor and collects all available information to assign certain defect types to critical processing steps or deposition parameters. The reel-to-reel evaluation of the critical current by a Hall probe array is a very fast and high-resolution technique, which even yields 2-dimensional information about the defect structure. Guided by various examples we will demonstrate how such defect signatures can be used to reveal the origin of problems and to relate them to certain processing steps or critical hardware components.

2. Tape fabrication process

As flexible metal substrate we use commercially available, non-magnetic Hastelloy® C276 cut in 10 mm wide tape of 100 μm thickness. The as-received tape is degreased and passed through a mechanical grinding stage for surface conditioning. Subsequently, the tape is electro-polished, cleaned with de-ionized water, and dried in airflow at a processing speed of 6 m/h. The resulting substrate tape has a residual thickness of 90 μm. Maximum surface slopes, which could affect the buffer alignment, are less than 0.8° so that the inclination angle of the ISD process is well preserved even on a microscopic scale. To protect the sensitive surface from damage a 20 μm thin polyimide tape is wound in the tape coil after the polishing and in all subsequent processing steps.

A well-aligned MgO-buffer layer is deposited by ISD. MgO is electron beam evaporated from a turntable feeding stage. To remove water from the tape surface and to facilitate adhesion of the buffer the tape is passed through a short heating stage at 300 °C before entering the deposition area. The vacuum deposition process is performed at ambient temperature without additional heating. Details of the ISD texturing technique have been published previously [4]. Essentially, the substrate is inclined at an angle of 25–30° towards the MgO vapor. Due to the high deposition rate > 4 nm/s and growth selection by shadowing, only those MgO grains with good in-plane alignment and a surface tilt of about 20° prevail. In general, the alignment improves with increasing deposition rate and film thickness. A reasonable optimum for the MgO film thickness is 2.5–3 μm which yields an in-plane alignment $< 10°$ FWHM. In the current prototype phase, the processing speed is about 6 m/h. However, deposition rates of 28 nm/s have been successfully realized already. This offers the perspective of speeding up by more than a factor of five.

On top of the thick ISD-MgO layer a 200 nm thin MgO cap layer is grown homo-epitaxially at 720 °C and at perpendicular incidence. This layer serves to close gaps between the large MgO columns and to establish an appropriate surface quality for the subsequent HTS coating. For efficiency reasons the tape is wound in 16 loops to utilize a large deposition area (e.g. 400 cm^2 in case of the MgO cap and the HTS layer). This arrangement also guarantees better uniformity in film thickness and performance than a single, wide web. Integrated into the tape winder there are a heater and an oscillating oxygen shuttle for the epitaxial coatings [5]. Since the MgO cap layer is thin, the transfer speed is already 8 m/h. The buffered tape is manufactured with a standard length of 30–40 m.

DyBCO is deposited by an electron gun. A water-cooled copper turntable is extracting the granular DyBCO material from a funnel and conveying the evaporation material in form of a track