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Chemical solution deposition of $YBa_2Cu_3O_{7-x}$ coated conductors

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Abstract

At present, the development of superconducting $YBa_2Cu_3O_{7-x}$ coated conductors attracts much attention due to their enormous application potential in electric power systems. Worldwide research is focused on the investigation and improvement of buffer materials and $YBa_2Cu_3O_{7-x}$ superconducting properties as well as low-cost manufacturing processes in cooperation with industrial companies. Accordingly, chemical solution deposition has emerged as a highly competitive, versatile, and cost-effective technique for fabricating coated conductors of high performance. New chemical solution approaches are under development for buffer layer deposition. In order to achieve high critical current carrying $YBa_2Cu_3O_{7-x}$ layers, the established trifluoroacetate route is favored. This paper reviews the most recent work on chemical solution deposition within the IFW Dresden while also considering achievements on this specific research topic worldwide.

Keywords: Chemical solution deposition; Coated conductors; $YBa_2Cu_3O_{7-x}$ superconductor; Trifluoroacetate route; Buffer layers

1. Introduction to YBCO coated conductors and CSD

During the last few years, efforts have been strongly focused on the development of high temperature superconducting (HTS) coated conductors (CC) based on $YBa_2Cu_3O_{7-x}$ (YBCO) as Second-Generation HTS tapes for electric power applications such as motors, generators, transformers, and cables. The advantage of HTS is that, at low temperatures, electrical current is conducted with no resistivity, offering a great potential for energy saving applications and higher engineering current densities, which enable much higher power densities and therefore, a compact system design [1–4,*5,*6,*7,*8]. Such conductors generally consist of a YBCO film grown on a flexible metallic substrate with intermediate buffer layers and, if needed, a protection cap layer as shown in Fig. 1. Buffer layers act as chemical barriers between the YBCO layer and the substrate in order to prevent metal-ion diffusion from the substrate into YBCO as well as to avoid oxidation of the metallic surface during YBCO film deposition. Due to the percolative nature of the superconducting current, a sharp texture exhibiting only low-angle grain boundaries is essential to obtain high critical current densities (J_c) [9]. Therefore, buffer layers must act as either textured

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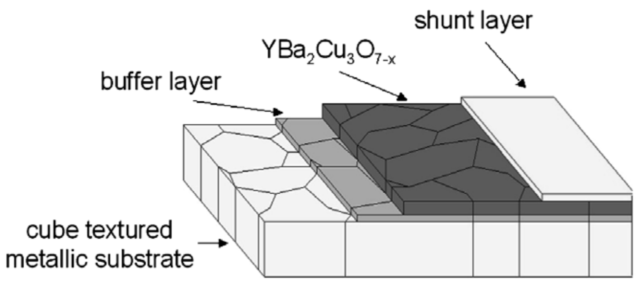

Fig. 1. Design of a typical YBCO coated conductor based on a RABiTS textured metallic substrate.

templates or texture transfer layers between substrate and YBCO. Further important parameters to consider for buffer material choice are lattice matching, structural and chemical compatibility, similar thermal expansion coefficients, and a low surface roughness of the deposited layers to enable undisturbed epitaxial growth of subsequent layers. The three state-of-the-art technologies capable of producing highly-textured substrates for YBCO coated conductor fabrication are the ion beam assisted deposition (IBAD) [10–12], inclined substrate deposition (ISD) [13,14], and the Rolling-Assisted Biaxially Textured Substrates (RABiTS) technique [15,*16,17]. The RABiTS process is one of the most potentially economic approaches to fabricate HTS wires. Generally, buffer and YBCO layers can be prepared using several deposition methods including physical deposition techniques (pulsed laser deposition (PLD), sputtering, thermal and e-beam evaporation) and chemical deposition techniques like chemical vapor deposition and chemical solution deposition (CSD). CSD is widely considered the most promising route to the low-cost commercial production of HTS wires due to its advantages, including inexpensive non-vacuum equipment, precise control of metal–oxide precursor stoichiometry, ease of compositional modification on a molecular level, high deposition rates on large areas, and potentially near 100% utilization of the precursor material. Furthermore, deposition techniques such as dip coating, spray coating, and printing methods allow scalability. CSD processes have proven to be a viable low-cost high-volume manufacturing technology for high-performance long-length practical wires competitive with established physical deposition methods [*5,3,18]. The combination of the RABiTS approach with CSD is a particularly attractive approach for low-cost manufacturing of HTS wire in that it can enable the realization of all chemically derived YBCO coated conductors [*5]. Nickel-based alloys have become the substrates of choice for the RABiTS approach due to the sharp cube texture achievable as well as chemical compatibility and lattice and thermal expansion match with many diffusion barriers [15,*16,17,19]. Among a variety of chemical solution derived potential buffer materials on RABiTS investigated recently such as RE_2O_3 (RE = rare-earth and Y), $RE_2Zr_2O_7$, and RE_2NbO_7 [20–30,*31,32], $La_2Zr_2O_7$ and CeO_2 are the most promising candidates for all CSD processed YBCO coated conductors at present [20,21]. Several solution routes are currently under investigation. For the deposition of YBCO films using the CSD method, the trifluoroacetate (TFA) process has attracted the most attention due to the suppression of $BaCO_3$ formation, which strongly reduces the critical current density [**33]. Recent efforts are focused on a further development and improvement of the TFA–YBCO process and are making progress towards scaling-up of low-cost high-J_c YBCO coated conductor manufacturing.

This paper presents a detailed review of the recent activities regarding YBCO coated conductor development based on the chemical solution deposition processes within the IFW Dresden, particularly the buffer layer development. Additionally, background knowledge of the CSD process and an overview of worldwide achievements in this specific research field are presented.

2. Chemical solution deposition – a brief overview

The chemical solution deposition method for the preparation of thin layers can be subdivided into three main stages: 1. *The precursor solution synthesis* from educts according to the designated layer composition and the chemical process to be used. 2. *The coating procedure* to obtain homogeneous precursor layers of controlled thickness. 3. *The thermal treatment* of the precursor layer converting the as-deposited layer into a crystallized final oxide layer via an amorphous state as summarized in Fig. 2. The desired layer thickness can be achieved through multiple coating and/or heat treatment steps. Since the precursor solution and chemical process used directly influences the properties of the final oxide layer, the choice of the educts and the chemical route should be carefully made, enabling the controlled design of solutions and, consequently, oxide layer properties. To form oxide layers, it is advantageous to introduce educts consisting of metal–oxygen (M–O) bonds. Moreover, properties such as solubility, reactivity, yield of the desired metal cations, and a low content of organic species to reduce shrinkage are crucial. A low toxicity of the solution is also preferred (*green solution routes*). The control of the precursor solution properties and the deposition parameters provides control over the microstructural properties of the oxide layer. However, most of the processes that occur during the transformation of the as-deposited layer into the intermediate amorphous state are not well understood due to the difficulty of investigating both the amorphous layers and the solutions.

2.1. Chemical solution routes – aspects of chemistry

The wide range of chemical routes available for the synthesis of appropriate precursor solutions can be divided mainly into classical sol–gel processes and metal organic decomposition (MOD) processes [**34,35,36]. Sol–gel processes commonly start from metal alkoxides undergoing hydrolysis and condensation reactions, leading to a