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Advanced development of TFA-MOD coated conductors

M.W. Rupich *, X. Li, S. Sathyamurthy, C. Thieme, S. Fleshler

American Superconductor Corporation, 64 Jackson Road, Devens, MA 01434, USA

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ABSTRACT

American Superconductor is manufacturing 2G wire for initial commercial applications. The 2G wire properties satisfy the requirements for these initial projects; however, improvements in the critical current, field performance and cost are required to address the broad range of potential commercial and military applications. In order to meet the anticipated the performance and cost requirements, AMSC's R&D effort is focused on two major areas: (1) higher critical current and (2) enhanced flux pinning.

AMSC's current 2G production wire, designed around a 0.8 μm thick YBCO layer deposited by a Metal Organic Deposition (MOD) process, carries a critical current in the range of 200–300 A/cm-w (77 K, sf). Achieving higher critical current requires increasing the thickness of the YBCO layer. This paper describes recent progress at AMSC on increasing the critical current of MOD-YBCO films using processes compatible with low-cost, high-rate manufacturing.

1. Introduction

Second generation (2G) high temperature superconducting (HTS) wire is now being manufactured at American Superconductor in long length with performance suitable for use in early commercial applications [1–5]. AMSC's current 2G production wire, based on an 0.8 μm thick YBCO layer deposited by a Metal Organic Deposition (MOD) process, carries a critical current in the range of 200–300 A/cm-w (77 K, sf). Although this performance is sufficient for initial applications, higher critical current will be required for broad-scale adoption in future cable and rotating machine applications. In addition, HTS applications, such as generators and motors, require the wire to operate at a high current in the presence of a magnetic field.

AMSC's approach to address these two needs is to increase the thickness of the YBCO layer while maintaining the pinning microstructure engineered for the specific operating conditions of targeted applications. The thickness of single-coat MOD-YBCO films has generally been limited by the formation of mechanical defects during the decomposition process. Thus MOD-YBCO films with thickness over 1 μm have been prepared by the deposition of multiple YBCO layers as illustrated schematically in Fig. 1 [6–8]. However, implementing the multi-coat approach into low-cost manufacturing has been hindered by two main factors. First, the deposition of multiple layers adds to the manufacturing cost of the 2G wire, and second, the presence of an interface between layers has a tendency to degrade the through thickness J_c of the multi-coat films at the high growth rates required for low-cost manufacturing.

In order to address these issues, AMSC's research effort has focused on developing a new technology for increasing the thickness of a single-coat film. The successful development of the single-coat, thick film technology provides a path to achieving high critical currents needed for broad-based commercial applications with a high-rate, low-cost manufacturing process.

2. AMSC's 2G wide-web manufacturing process and wire performance

AMSC's 2G wire is based on the Rolling Assisted Biaxially Textured Substrate (RABiTS™) technology for the template [6,9] and a Metal Organic Deposition (MOD) process for the HTS layer [6,10] The RABiTS template consists of a 75 μm thick, cube-textured Ni5 at.%W alloy tape coated with 75 nm thick layers of epitaxial Y_2O_3, YSZ and CeO_2. The cube textured NiW substrate is prepared by deformation-texturing and recrystallization and the oxide buffer layers are deposited by high-rate reactive sputtering. The rare earth doped, YBCO precursor film is slot-die coated onto the RABiTS template, pyrolyzed to remove the organics and reacted at 700–800 °C to form an epitaxial $(Y_{1-x}Dy_x)Ba_2Cu_3O_{7-\delta}$ film [11]. A thin Ag layer is sputtered onto the HTS film, which is then oxygenated to form the superconducting $(Y_{1-x}Dy_x)Ba_2Cu_3O_{7-\delta}$ phase.

This approach allows roll-to-roll processing of the 2G material in the form of a wide-web from the substrate rolling through the oxygenation stage. After the oxygenation step, the web is slit into individual strips (referred to as an "insert" wire), with the width optimized for the specific product application. This insert wire is

* Corresponding author. Tel.: +1 508 842 3217; fax: +1 508 842 3124.
E-mail address: mrupich@amsc.com (M.W. Rupich).

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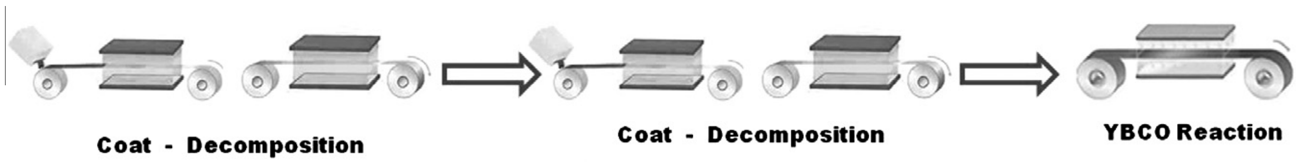

Fig. 1. Schematic illustration of the multi-coat used for preparation or thick MOD-YBCO films. The coating and decomposition steps are repeated multiple times to achieve the desired thickness. However, each repetition adds to overall manufacturing cost.

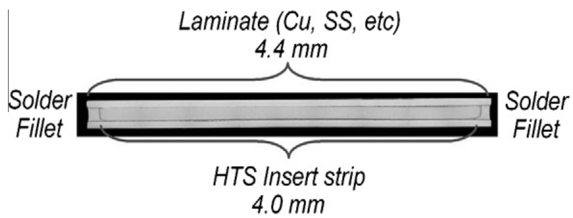

Fig. 2. Cross-section micrograph of AMSC's standard 2G HTS wire, called Amperium™ wire.

then laminated between two metallic stabilizer strips to form the superconducting wire, called Amperium™ wire, shown in Fig. 2. The specific composition and thickness of the stabilizer strips are selected to customize the electrical, thermal and mechanical properties of the wire for specific application requirements.

The roll-to-roll "wide-web" process is designed to be low-cost and have the flexibility to produce wire with varying dimensions and properties which can be tailored for specific applications [2]. The current production process at AMSC is based on a 40 mm wide web; however, the width is being increased to 100 mm to meet commercial demand for Amperium™ wire.

AMSC's current 4 mm wide 2G wire, with an 0.8 μm thick YBCO layer, has a critical current (77 K, self-field) ranging from ~80 to 120 A/cm-w as shown in Fig. 3. The I_c at the high end of the range is equivalent to the best achieved in short length R&D samples prepared with the same HTS thickness. Fig. 4, which shows the I_c along the length of four wires produced from individual 40 mm strips, illustrates the consistency and uniformity that can be achieved with the MOD/RABiTS process.

For commercial applications, it is critical that the pinning microstructure of 2G wire is easily controlled and uniform over length. The pinning in AMSC's MOD-YBCO, at 77 K, is engineered by the addition of rare earth based nanoparticles and the controlled formation of planar stacking faults. Fig. 5 shows the critical current as a function of length for AMSC's 2G production wire in self-field and in an applied magnetic field of 0.52 T oriented parallel and perpendicular to the tape surface.

3. Routes to high I_c in MOD-YBCO

Although this performance level is acceptable for initial commercial applications, higher critical currents will be needed for broad-based commercial applications. The first approach, which has already been done for the MOD-YBCO, is to increase the critical current density, J_c, of the YBCO. Thus the next route to higher critical current is to increase the thickness of the YBCO layer. If the through thickness microstructure and texture remains constant, this approach should increase I_c proportionally at all temperatures and fields.

In the past, the thickness of a single-coat MOD-YBCO film had been limited to <1 μm due to the formation of mechanical defects arising from the pyrolysis process. Thus, the general approach to increasing the thickness has focused on multi-coat processes. However, the major drawback to the multi-coat process (in addition to the increased processing steps) was a progressive decrease in through thickness J_c with each additional layer. Detailed analysis of the multi-coat films prepared at AMSC found the decomposition process resulted in the formation of a copper rich layer at the interfaces between the individual layers [6]. Studies of the through thickness growth of the MOD-YBCO films found that as the YBCO growth front passed each interface there was a disruption of the epitaxial growth, resulting in a decrease in the texture above the interface as seen in the cross-sectional micrograph in Fig. 6. In contrast, the YBCO growth in single-coat films proceeds unimpeded through thickness with no loss of texture. This is shown in Fig. 7, which plots the in-plane and out-of-plane texture and J_c of YBCO films, with various thickness, prepared by both single-coat and multi-coat processes.

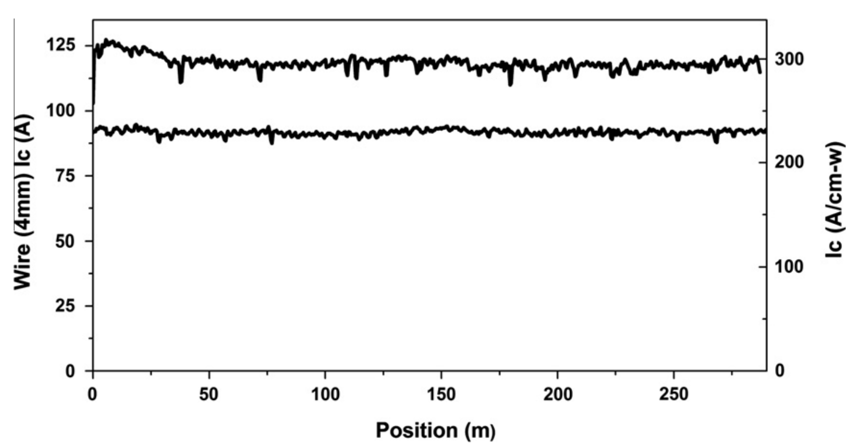

Fig. 3. Range of critical current for 2G wire produced in AMSC's 40 mm wide web production line using a 0.8 μm thick rare earth doped YBCO layer. Transport critical current (77 K, self-field) was measured every 0.5 meter over a 1 meter length using a voltage criterion of 1 μV/cm.