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Physica C 426–431 (2005) 849–857

PHYSICA C

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Progress in scale-up of second-generation high-temperature superconductors at SuperPower Inc

Y.-Y. Xie [a,*], A. Knoll [a], Y. Chen [a], Y. Li [a], X. Xiong [a], Y. Qiao [a], P. Hou [a], J. Reeves [a], T. Salagaj [a], K. Lenseth [a], L. Civale [b], B. Maiorov [b], Y. Iwasa [c], V. Solovyov [d], M. Suenaga [d], N. Cheggour [e], C. Clickner [e], J.W. Ekin [e], C. Weber [a], V. Selvamanickam [a]

[a] *SuperPower Inc., 450 Duane Ave., Schenectady, NY 12304, USA*
[b] *Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[c] *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[d] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[e] *National Institute of Standards and Technology, Boulder, CO 80305, USA*

Received 23 November 2004; accepted 9 March 2005
Available online 8 August 2005

Abstract

SuperPower is focused on scaling up second-generation (2-G) high-temperature superconductor (HTS) technology to pilot-scale manufacturing. The emphasis of this program is to develop R&D solutions for scale-up issues in pilot-scale operations to lay the foundation for a framework for large-scale manufacturing. Throughput continues to be increased in all process steps including substrate polishing, buffer and HTS deposition. 2-G HTS conductors have been produced in lengths up to 100 m. Process optimization with valuable information provided by several unique process control and quality-control tools has yielded performances of 6000–7000 A m (77 K, 0 T) in 50–100 m lengths using two HTS fabrication processes: metal organic chemical vapor deposition (MOCVD) and pulsed laser deposition (PLD). Major progress has been made towards the development of practical conductor configurations. Modifications to the HTS fabrication process have resulted in enhanced performance in magnetic fields. Industrial slitting and electroplating processes have been successfully adopted to fabricate tapes in width of 4 mm and with copper stabilizer for cable and coil applications. SuperPower's conductor configuration has yielded excellent mechanical properties and overcurrent carrying capability. Over 60 m of such practical conductors with critical current over 100 A/cm-width have been delivered to Sumitomo Electric Industries, Ltd. for prototype cable construction.

* Corresponding author. Tel./fax: +1 518 346 1414x3041.
E-mail address: yxie@igc.com (Y.-Y. Xie).

0921-4534/$ - see front matter
doi:10.1016/j.physc.2005.03.071

Keywords: Second-generation HTS wire; Coated conductors; Electropolishing; Magnetic field; Ac losses; Narrow conductor; Cable; Stress; Strain; Mechanical properties

1. Introduction

Second-generation (2-G) high-temperature superconductor (HTS) wires are referred as the $YBa_2Cu_3O_x$ (YBCO)-type superconducting films coated conductors while first-generation (1-G) HTS wires as Bi(Pb)SrCaCuO superconductor made in a powder-in-tube process. 2-G HTS wires have several important advantages over 1-G HTS wires including potentially high engineering current density, better in-field performance at higher temperatures, potentially low processing costs, lower ac loss, and significantly improved mechanical properties. Research institutes and industries worldwide have shifted efforts towards the commercialization of 2-G HTS wires. To obtain high critical current density in YBCO superconductors, an outstanding problem is that its grains are difficult to align. Therefore, biaxially textured buffer films or layers are necessary for successful deposition of textured YBCO films on metallic substrates. So far, a few techniques have been developed for textured buffer layers, among which ion beam assisted deposition (IBAD) [1,2], rolling assisted biaxially textured substrates (RABiTS) [3,4], and inclined-substrate deposition (ISD) [5,6] have shown the potential in commercialization. At SuperPower, the development of long-length coated conductors is based on IBAD for textured buffer layers and metal organic chemical vapor deposition (MOCVD) for HTS growth including $YBa_2Cu_3O_x$ (YBCO), whereas PLD is employed mainly to confirm the quality of layers underlying HTS. In order to meet the milestone of scaling up coated conductor processes to produce tape in piece-lengths greater than 1 km with performance greater than 100,000 A m by mid-decade, our research and development activities have been directed towards the following key objectives:

(a) High throughput at every step of the process to demonstrate a route for low cost production.
(b) Equipment and processes suitable for long production runs.
(c) Continuous, reel-to-reel on-line and off-line quality-control and analytical tools to ensure high-quality production in fast and long runs.
(d) Robust manufacturing process for a practical conductor for prototype device demonstration.

A high throughput is essential to a large-volume production at a given equipment base, and thus to low cost fabrication, since capital equipment for manufacturing coated conductors is expensive [7]. With several equipment and process advancements, high linear tape speeds from 10 to 60 m/h have been achieved in three major steps: metal substrate polishing, IBAD-buffer and HTS deposition, while maintaining HTS performance at a level above 100 A/cm. These tape speeds were obtained in prototype, pilot-scale and preproduction manufacturing facilities that can handle tape lengths from 50 to 100 m in continuous runs. Feedback from several improved and newly added on-line and off-line quality-control and quality-analysis tools has led us to a better understanding of the relationship between microstructure and performance. This feedback has enabled optimization and stabilization of process conditions to achieve 6000–7000 A m performances over those tape lengths. Major progress has been also made towards the development of a practical conductor configuration. Improved in-field performance has been achieved by chemical modification of the HTS layer; practical useful tape width has been enabled by slitting; and excellent mechanical properties and electrical stability have been achieved by electroplating surround Cu. These processes result in a product of an application-ready conductor.

2. Pre-HTS processes: high throughput and long tape handling capability in metal tape polishing and IBAD

Hastelloy®-C is used as the metal tape substrate. The smoothness of Hastelloy®-C surface is