

Ex-Situ Conversion of Physical Vapor Deposited YBCO Precursors on RABiTS

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Abstract: Physical Vapor Deposition (PVD) approach to ex-situ HTS precursor deposition does not suffer from thickness-related cracking problem, and meter-length coated conductors with high I_c 's have been reported on e-beam co-evaporated precursors. This deposition method, however, can be limited by a number of composition-control issues that can affect long-length uniformity. In addition, the high performance results have only been achieved in samples converted at slow rates of roughly 0.1 nm/sec. We have recently developed a PVD precursor method that utilizes Pulsed Electron-Beam Deposition (PED). This technique employs a single source, and has the potential of offering much simpler composition control and flexibility as well as cost reduction. Moreover, these as-deposited PED precursors are found to be capable of being converted at substantially higher rates, where a 1 mm film reacted at 0.8 nm/sec was determined to possess an I_c of 98 A/cm at 77 K. In addition to PED, a pre-anneal step and a modified deposition approach are being developed for e-beam co-evaporated BaF_2 precursors. By combining these steps, high I_c of 212 A/cm has been obtained on 1 mm YBCO converted at a rate of 1.15 nm/sec.

I. INTRODUCTION

The ex-situ approach of YBCO formation is a promising alternative to in-situ superconductor deposition, and is an active area of study in the coated conductor community. Ex-situ precursor deposition can in general be separated into solution and physical vapor deposition (PVD) routes. High I_c long-length samples converted at high reaction rates have been demonstrated using the solution route of precursor deposition [1], which requires no vacuum and appears to be very cost effective. These results, however, have typically been reported on YBCO of limited thickness; as precursor thickness increases, cracking may become an increasing issue. On the other hand, PVD precursor films do not suffer from this thickness issue, and meter-length coated conductors with high I_c 's have also been reported on e-beam co-evaporated BaF_2 precursors. [2]. While uniformly good results have been obtained, BaF_2

precursor suffers from a number of potential issues including:

- 1) Multiple guns to evaporate separate sources, which complicates the process and increases the capital cost.
- 2) Frequent discharges and cross-talk, which critically affect the composition control and therefore long-length uniformity.
- 3) Difficult to perform rare earth substitution and doping tasks, which limit the ability to introduce artificial pinning centers and enhance J_c .

In addition, the high performance results of BaF_2 precursor have only been achieved in samples converted at slow rates of roughly 0.1 nm/sec. Therefore, in order for PVD ex-situ precursors to be a viable manufacturing method, the deposition process needs to be simplified, and the reaction rate has to be increased without a concomitant reduction in performance.

II. EXPERIMENTAL RESULTS

A. Pulsed E-Beam Deposition

A new reel-to-reel (R2R) Pulsed Electron-Beam Deposition (PED) system has been developed and put into operation. This unit is consisted of a single pulsed-electron gun with associated controls. The 16 kV / 100 ns electron pulses are guided toward a single target through a ceramic tube (3 mm ID), which is situated inside a vacuum chamber. Ablation of the target results in a plasma that transfers the material onto the substrate that is held at a distance of ~5 cm from the target. During deposition, precursor thickness and tape movement are controlled by a R2R handler. Under a 9 mTorr nitrogen environment, typical deposition rate is found to be on the order of 0.1 nm/sec averaged over a 1 cm x 5 cm deposition zone. The stability of the configuration routinely allows for 10-hour deposition runs. After the corresponding ~350,000 pulses, target wear (materials consumption) requires a target change, which is achieved using a multi-target manipulator.

PED precursors of various thicknesses were deposited on lengths of RABiTS for conversion study. Initial conversion runs were performed in our R2R chamber that operates at a total pressure of ~ 1.5 atm at standard slow conversion rates of roughly 0.1 nm/sec. Utilization of these slow rates is previously found to be necessary to obtain high J_c 's for PVD BaF_2 precursors.. Individual 3 cm by 1 cm samples were spot-welded to Ni leaders, and were pulled through the pre-heated furnace at various speeds. Conversion parameters of the PED films were found to be similar to those of BaF_2 precursors. For example, samples converted at 740 C in $P(O_2)$ of 120 mTorr and nominal $P(H_2O)$ that increased from 3.5 Torr to 35 Torr resulted in YBCO films with $J_c > 1$ MA/cm² as listed in Table 1.

Attempts in increasing the conversion rate of PED precursors revealed that these precursors can tolerate more aggressive conversion conditions without significant development of random YBCO or reduction in c-axis YBCO crystallinity. Fig. 1 shows the normalized XRD peak intensities of YBCO(200) and $BaF_2(111)$ for a PED film converted at 0.8 nm/sec. It can be seen from the figure that YBCO(200) intensity increases to a high value and levels off, signifying the completion of conversion. High YBCO(00L) intensity has previously been related to high J_c 's [3], and transport measurement revealed that this YBCO film possesses an I_c of 98 A/cm ($J_c = 1$ MA/cm²).

TABLE 1. Conversion rates and superconducting properties of ex-situ PED precursors on RABiTS.

YBCO thickness (μ m)	Conversion rate (nm/sec)	I_c (A)	J_c (MA/cm ²)
0.72	0.06	117	1.6
0.86	0.08	92	1.1
0.94	0.07	100	1.1
1.30	0.07	159	1.2

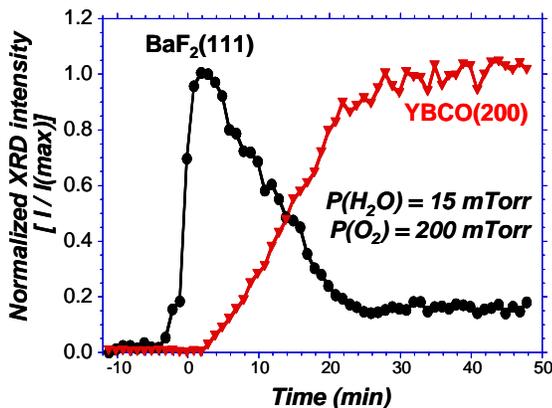


Figure 1. Changes in normalized in-situ XRD $BaF_2(111)$ and YBCO(200) peak intensities for PED precursor converted at 0.8 nm/sec.

B. Modified e-beam BaF_2 precursor with pre-anneal

Significant progress has also been made in the conversion of e-beam BaF_2 precursor. Previously, we have found that under aggressive conditions, as-deposited BaF_2 precursors could not be readily converted into high J_c films. One such sample converted in our low-pressure system is shown in Fig. 2 (Standard w/o pre-anneal) having an I_c of only 0.1 A/cm under the imposed reaction rate of 0.9nm/sec. Recently, we have developed a pre-anneal step that drastically improves the convertibility of BaF_2 precursors. It can be seen from Fig. 2 that when a standard precursor is subjected to pre-anneal, YBCO conversion is improved significantly under identical reaction conditions, resulting in an I_c of 129 A/cm ($J_c = 1.3$ MA/cm²) at a conversion rate of 0.9 nm/sec. Further modification of deposition conditions in combination with pre-anneal led to an even higher I_c of 188 A/cm ($J_c = 1.9$ MA/cm²). To date, the highest I_c obtained on 1 cm-wide RABiTS with modified e-beam precursor plus pre-anneal is 212 A/cm ($J_c = 2$ MA/cm² for this 1 μ m YBCO film) at a conversion rate of 1.15 nm/sec.

III. SUMMARY

A PED technique has been developed to simplify the composition control of PVD precursors. Short samples processed at standard slow conversion rates of ~ 0.1 nm/sec resulted in high quality YBCO films with J_c 's as high as 1.6 MA/cm². More importantly, high J_c films have been obtained, for the first time, on PVD precursors that were converted at an order of magnitude higher rates,

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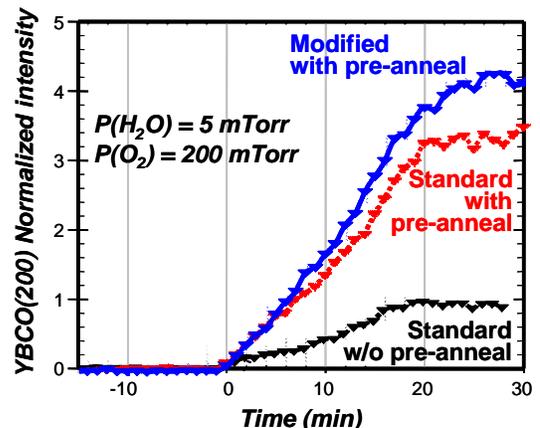


Figure 2. Changes in normalized in-situ XRD YBCO(200) peak intensities for e-beam BaF_2 precursors converted at 0.9 nm/sec.