Multi-chamber deposition system for continuous production of YBCO coated conductors by thermal co-evaporation

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Abstract. We recently reported on a simple thermal co-evaporation route based on a reel-to-reel system, that enables the production of 2 m-long superconducting tapes with Ic values up to 120 A/cm-width (Jc = 2 MA/cm²) and Tc = 88 K. This work describes the development of a new multi-chamber system designed for the continuous production of these tapes suitable for an industrial process. The system consists in three distinct vacuum chambers connected one with another by two specially designed 50 cm long slits. The length and cross-section of these slits have been calibrated in order to achieve a pressure difference up to 5 orders on magnitude across adjacent chamber. The system is originally conceived for the continuous production of CeO2 buffered RABiTS Ni-based tapes that require a pre-treatment of the bare metallic tapes in forming gas, followed by CeO2 deposition and a post-treatment in oxygen. To improve the robustness of the whole tape production process, we have designed and built a novel device based on a supersonic oxygen gas expansion for the continuous in situ oxygenation of YBCO during deposition. Here, we present preliminary results demonstrating the effectiveness of this device. Specifically, thanks to the enhancement of the number of collisions of the O2 molecules with the substrate due to the focused supersonic beam, we find that the oxygen pressure in the vicinity of the substrate can be up to 3 orders of magnitude higher than the background pressure in the chamber. The main advantage of this supersonic device is the insensitivity of the effective pressure to the substrate-nozzle distance, in the 2-5 mm range, which can be easily controlled during a continuous production process.

1. Introduction

The challenge for the industrial YBCO Coated Conductors (CC) production is the development of a low-cost process enabling the continuous deposition of long length tapes with high performances. A number of film deposition routes are currently under development and it is not yet clear whether chemical or vacuum techniques would be more convenient. Among the various vacuum techniques, thermal co-evaporation is attractive for the low cost and simplicity. Further, it was established that state-of-the-art YBCO films can be routinely deposited large areas (>over 20x20 cm²) with high deposition rates up to 1 nm/s [1,2]. Both features are prerequisites for the scaling-up of the production process.

In a recent publication [3], we reported on a simple thermal co-evaporation route based on a reel-to-reel system, that enables the production of 2 m-long superconducting tapes with Ic values up to 120
A/cm-width ($J_r = 2 \text{ MA/cm}^2$) and $T_r = 88 \text{ K}$. This route is attractive for the simple multilayer architecture with a single CeO$_2$ buffer layer deposited onto cube-textured Ni tapes. These results were obtained using a prototype film deposition system consisting of a single vacuum chamber that allowed us to fabricate up to 2 m long tapes [4]. Our next objective is the scaling-up of the above CC deposition route for the industrial production. Here we describe a novel 3-chamber system enabling to scale up the production of CeO$_2$ buffered tapes. Typically, the production route requires a pre-treatment of the bare metallic tapes in Ar/H$_2$(5%) gas mixture (forming gas) in the 1$^{\text{st}}$ chamber, followed by the CeO$_2$ deposition in the 2$^{\text{nd}}$ chamber and a post-treatment in oxygen in the 3$^{\text{rd}}$ chamber.

To improve the reliability and robustness of the overall deposition process, we describe a novel YBCO oxygenation device based on a supersonic nozzle. Indeed, the in situ oxygenation of the growing film is necessary to avoid phase decomposition. In the case of thermal evaporation, this requires a minimum background pressure $P_{O_2} \approx 10^{-2}$ mbar at 700 $^\circ$C during deposition. On the other hand, thermal evaporation requires background pressures $<10^{-4}$–$10^{-5}$ mbar. Previous reports have shown that both requirements are met by enhancing locally the oxygen pressure in the vicinity of the growing film using an appropriate device. One successful solution is the so-called “oxygen pocket” that confines the oxygen molecules within a box moving over the entire deposition area. The weakness of this technique consists in that the confinement is effective only if the pocket-substrate distance is very short ($\approx$0.2-0.4 mm). In the case of a continuous production of coated conductors (CC), it is critical to control such a small distance for long times. The present device based on a supersonic nozzle overcomes this difficulty thanks to the focusing effect of the supersonic gas expansion. Indeed, model calculations show that the enhancement of effective O$_2$ pressure caused by the nozzle is not sensitive to the substrate-nozzle distance (in 2-4 mm range). Here we present preliminary results that confirm this expectation thus demonstrating the effectiveness of this device.

2. Continuous multi-chamber system

The multi-chamber production system consists of three distinct chambers. In each chamber one of the 3 different steps of the CeO$_2$ deposition process takes place (see Figure 1).

![Figure 1. The multi-chamber system designed to perform the 3-step CeO$_2$ deposition route.](image-url)

To enable a continuous deposition process, a reel-to-reel system is installed in the system. The unwinding and the winding of the tape take place in the pre- and post-treatment chambers respectively. The main technological challenge for the realisation of the above vacuum system is the back and forth motion of the tape across the 3 chambers by controlling very large differences of gas pressures and by avoiding the gas flow from one chamber to the other. A further difficulty is that, during motion, any contact between the coated side of the tape and the rail must be prevented.

To solve these problems, special slits have been designed and manufactured. The lower part of the slits is shaped in such a manner to avoid any contact with the coated side of the tape. The inner part of the channel has been designed to minimise the gas flow caused by the pressure difference across the
slits. To determine the values of cross-section and length of the slits a mathematical model of gas flow has been used. The conductance depends on the gas characteristics and on the slit geometry as follows:

\[ C(v, H, A, L) \approx \frac{4}{3} v \int_{0}^{L} \left( \frac{H}{A^2} \right) dl \]  

where:
- \( C \) is the conductance
- \( v \) is the average molecular speed
- \( H \) is the slit perimeter
- \( A \) is the slit cross-section
- \( L \) is the slit length

The results of our calculations based upon the above formula show that the conductance, \( C \), decreases with the slit length as \( 1/L \) and increases with the cross-section, \( A \). This is shown in figure 2.

Based on these results, the slits were manufactured. The body and cover were made of stainless steel and aluminium respectively (figure 3).

![Figure 3. Detail of the slit and of the slit-chamber connection.](image)

The modelling of the gas flow has enabled us to design the complete pumping system enabling to achieve the desired values of pressure in the 3 chambers. The test of the whole system is in progress.

3. Supersonic nozzle for the in situ oxygenation during YBCO film deposition (SNEO)

A platinum sheet that has been laser drilled to achieve the typical conical profile of a supersonic nozzle. To obtain the enhancement of the effective \( O_2 \) pressure over an area of about 1 cm\(^2\), an array of such nozzles has been made, as illustrated in the photograph of figure 4. To ensure the oxygenation over the entire deposition area 20x20 cm\(^2\), during deposition, the nozzle is moved forth and back along the tape.

![Figure 4. The array of laser drilled platinum sheet (left) and a detail of one nozzle (right).](image)

The nozzle device has already been tested for the deposition of HTS tapes. The typical substrate temperature and total pressure in the vacuum chamber were \( \sim 690 \, ^{\circ}\text{C} \) and \( 6 \times 10^{-5} \) mbar respectively.
According to our numerical calculation describing the supersonic expansion in the nozzle, the effective pressure in the vicinity of the growing film is enhanced up to 3 orders of magnitude with respect to the background pressure. A further positive feature of the nozzle device is that the YBCO oxygenation is independent on the nozzle-substrate distance within the 2-5 mm range.

The first series of YBCO/CeO2/Ni-5 at. % W films grown using our first prototype of nozzle device confirm the above expectations and also the reproducibility of the deposition process. Figure 5 (a,b) shows the XRD diffraction pattern and the resistivity curve respectively of one of those films. One notes the full c-axis orientation of the YBCO film and the absence of any impurity phases, thus confirming that the effective pressure produced by the nozzle prevents YBCO phase decomposition. The films are characterised by \( T_c=88 \) K and transition width 1 K.

4. Conclusions and perspectives

We have described a novel multi-chamber deposition system designed for the continuous production of HTS coated conductors. The system features the independent control of the parameters for a 3-step deposition route consisting of a pre-treatment of the tapes, the film deposition and a post-treatment in oxygen. Special slits allow to maintain pressure differences of up to 5 orders of magnitude between adjacent chambers. Also, to enhance the robustness of the whole deposition route, we have designed, built and successfully tested a new device for the in situ oxygenation of YBCO during deposition based on a supersonic nozzle. This device is suitable for an industrial process, for it enhances the effective O2 pressure near the substrate by 3 orders of magnitude independently of the substrate-nozzle distance within 2-5 mm. The first films grown using this device exhibit state-of-the-art properties with full c-axis orientation and sharp superconducting transitions \( T_c=88 \) K.

References

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