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# Al doping influence on crystal growth, structure and superconducting properties of $Y(Ca)Ba_2Cu_3O_{7-y}$ whiskers

L. Calore [a], M.M. Rahman Khan [a,b], S. Cagliero [a,*], A. Agostino [a], M. Truccato [c], L. Operti [a]

[a] NIS-Centre of Excellence, Department of Chemistry, University of Torino, Via P. Giuria 7, I-10125 Torino, Italy
[b] Department of Chemistry, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh
[c] CNISM and NIS Center of Excellence, Department of Physics, University of Torino, Via P. Giuria 1, I-10125 Torino, Italy

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ABSTRACT

We synthesized Al doped $Y(Ca)Ba_2Cu_3O_{7-y}$ (YBCO) whiskers via the solid state reaction method. Al doping was systematically varied in the nominal cationic stoichiometry of $YBa_2Cu_3CaTe_{0.5}Al_xO_{7-y}$, with $0 \leqslant x \leqslant 0.5$. The amount of the grown whiskers increases for nominal Al addition up to $x = 0.05$, decreasing for larger concentrations. The concentration of Al incorporated in the crystals ($x'$) is always higher with respect to the starting stoichiometry and shows a gradient along its length, with a higher amount at the tip regions. The single crystal diffraction analyses show an increasing tetragonal character with increasing $x'$, with a transition from the orthorhombic to the tetragonal system for $x' = 0.13$, which is in agreement with the worsening of electrical transport properties and disappearing of superconductivity for $x' = 0.19$.



## 1. Introduction

Stacks of Intrinsic Josephson Junctions (IJJs) with atomic size are naturally formed in layered high-$T_c$ superconductors (HTS) such as $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212), $La_{2-x}Sr_xCuO_4$ (LSCO) and RE-123 (Rare Earth = Y, Eu, Gd, Dy, Ho, Er, Tm, and Lu) [1–4]. IJJs have been proposed as modular elements in the realization of various cryogenic devices, such as THz emitters/sensors [5], micro-SQUIDs' [6], and quantum bit-computing based on Macroscopic Quantum Tunneling phenomena [7].

Among the possible IJJs applications, high frequency devices can take advantage from the large Josephson plasma frequency found in some HTS. For instance, Y-123 has a Josephson plasma frequency close to a few THz because of its low anisotropy and high critical current densities [8], which makes it a suitable candidate for the fabrication of these devices. Furthermore, such properties could be modulated by cationic substitutions as already noticed for Pb doped Bi-2212 [9].

In a future context of IJJs exploitation, HTS whiskers, like the ones belonging to the YBCO system, are suitable for studies and devices based on IJJs, which require high homogeneity of IJJs properties on the micrometric scale. Their highly crystalline nature, low defect concentration and excellent superconducting features provide this aspect. Moreover, starting from a micrometric cross section, they are easily scalable by etching techniques down to submicrometric sizes and are also very suitable for 3D machining, resulting in solid-state devices with a high degree of miniaturization [3,4,10].

One of the main concerns about YBCO whiskers employment for these kinds of investigation is their synthesis in useful quantities, with respect to the BSCCO counterpart. As a matter of fact, much information is given in the literature about BSCCO whiskers and what is favoring or allowing their growth [11]. In this case, alumina addition as a precursor dopant has been found to drastically enhance the formation of such whiskers [12–15]. Moreover, Al together with Te represents the most efficient combination to favor the growth of Bi-2212 whiskers [12].

About YBCO whiskers the present situation is quite different. Although the growth of pure Y-123 whiskers has already been shown [16], the fact that Ca-doping of Y-123 can increase the carrier density in underdoped material [17] and also enhance both the values and the isotropy of the critical current density, $J_c$ [18,19] makes Ca-doped YBCO whiskers interesting. Indeed, also this kind of whiskers has been synthesized by Nagao et al. making combined use of Ca- and Te-based precursors [20]. However, in spite of the dramatic effect that alumina has on the growth of BSCCO whiskers, no corresponding investigation has been carried out so far about its influence in promoting the Y-123 whisker growth, neither in the pure nor in the Ca-doped form.

Concerning the influence of Al doping on the structure and superconducting properties of Y-123, this topic has been studied

* Corresponding author.
*E-mail address:* stefano.cagliero@unito.it (S. Cagliero).

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