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# 17 keV photon induced damage of Bi-2212 whiskers by synchrotron $\mu$-beam exposure

**G Aldica[1,2], S Cagliero[3], A Agostino[3], C Lamberti[4] and M Truccato[2]**

[1] National Institute of Materials Physics, Str. Atomistilor 105 Bis, RO-77125, PO Box MG-7, Magurele-Bucharest, Romania
[2] NIS Centre of Excellence, Dipartimento Fisica Sperimentale, and CNISM-UdR Torino Università, Via Pietro Giuria 1, I-10125, Torino, Italy
[3] NIS Centre of Excellence, Dipartimento Chimica Generale e Chimica Organica, and CNISM UdR Torino Università, C.so Massimo D'Azeglio 48, I-10125, Torino, Italy
[4] NIS Centre of Excellence, Dipartimento Chimica IFM and INSTM Reference Centre, University of Torino, Via Pietro Giuria 7, I-10125, Torino, Italy

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**Abstract**
Experimental data show that the normal state resistivity of superconducting $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) whiskers increases after a 6 h irradiation by a synchrotron $\mu$-beam with 17 keV photons. We analyse this result on the basis of previously reported effects in Bi-2212 whiskers due to ageing or heating processes. A finite element model of the experimental setup clarifies that the heat load induced by the microbeam has to be excluded as a possible cause for the material changes. The knock on the interstitial, loosely bound, O species by secondary electrons is discussed as the most likely mechanism responsible for this effect.

(Some figures in this article are in colour only in the electronic version)

## 1. Introduction

The $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) high temperature superconductor (HTSC) exhibits a layered structure along the crystal $c$-axis consisting of alternating superconducting and insulating planes, which induces the intrinsic Josephson effect (IJE) in this material [1]. This fact opens the way to a novel class of solid state devices consisting of large arrays of Josephson junctions, densely integrated on an atomic scale level, e.g. THz radiation emitters and voltage standards [2, 3]. Therefore, the ability of Bi-2212 to tolerate harsh working conditions is an important issue for the efficiency of such devices.

The effect of heavy ion irradiation on this material has been widely studied, showing that the critical temperature, $T_c$, starts degrading at fluences higher than $\approx 1$–$2 \times 10^{11}$ ions cm$^{-2}$ [4]. Concerning protons and $\alpha$ particles, it has been proved that they can knock O atoms out of the material at doses $\approx 10^{16}$ particles cm$^{-2}$, affecting both $T_c$ and the normal state resistivity [5]. Also electron irradiation can induce polycrystallinity and amorphization in Bi-2212 at fluences of $\approx 10^{22}$ e$^-$ cm$^{-2}$ [6].

On the other hand, much less is known about the effects induced by energetic photons. To our knowledge, there has been only one experiment about the effect of $\gamma$ rays on Bi-2212, which showed that photons of about 1.3 MeV are able to induce the desorption of extra oxygen atoms from the BiO layers and to reduce the size of the crystallites [7]; however, other investigations confirmed that $\gamma$-rays with similar energy affect the oxygen concentration or carrier distribution in different HTSC compounds as well [8, 9].

Less energetic photons are commonly considered ineffective from the point of view of radiation damage, nevertheless this assumption can be questioned according to the work by Piñera *et al*, who showed, by means of simulations, that photon energies as low as 122 keV can induce non-negligible effects on loosely bound O atoms, like in the case of the Cu–O chains of $YBa_2Cu_3O_{7-\varepsilon}$ (Y-123) [10]. From the experimental point of view, recent developments of micro- and nano-beams at third generation synchrotrons make it possible to test such stability in low energy ($\approx$20 keV) and high power density ($\approx 3 \times 10^5$ W m$^{-2}$) conditions [11]. Recently, we have used such a set up to monitor ageing or thermally induced variations in the stoichiometry of Bi-2212 whiskers [12], without investigating possible damage by the $\mu$-beam. In the present paper, we provide evidence of modifications in the electrical behaviour of Bi-2212 whiskers before and after the $\mu$-beam exposure,

 