Tuning the functional properties of oxides by means of high-power X-ray nanobeams

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In the past 20 years the evolution observed in synchrotron sources has pushed the beam power density towards the limit where modifications in condensed matter can take place. Whereas in X-ray free-electron lasers this phenomenon is widely investigated, in synchrotrons not much is known about its features. In this context, we have studied the impact of hard X-ray nanobeams on the structural and electrical properties of functional oxides like $Bi_2Sr_2CaCu_2O_{8+\delta}$, $YBa_2Cu_3O_{7-\delta}$, and TiO_2 [1-4]. Local changes in the conducting properties of these systems were observed, leading us towards the definition of a novel direct-write, photoresist-free, patterning technique: the X-ray nanopatterning (XNP).

Concerning the $Bi_2Sr_2CaCu_2O_{8+\delta}$ and $YBa_2Cu_3O_{7-\delta}$ superconducting compounds, we have shown how the successive irradiations lead to an increase of the electrical resistivity and to a modification of their superconducting properties [1, 3]. Monte Carlo simulations of the photo-induced processes in $Bi_2Sr_2CaCu_2O_{8+\delta}$ have highlighted how the decrease of the non-stoichiometric oxygen content δ, consisting in loosely-bound interstitial atoms, can be directly induced by the photoelectrons and how it can only partially explain the electrical modifications observed [2]. By pushing these effects till to the local suppression of the superconducting properties, we have deviated the supercurrent path by means of XNP and fabricated some devices based on the Josephson junctions, which are naturally present in the crystal structure of these materials.

On the other hand, by irradiating semiconducting TiO_2 rutile crystals, a decrease in electrical resistance has been measured both by online monitoring and by *ex situ* conductive atomic force microscopy [4]. Swelling corresponding to the irradiated regions has been associated with the formation of electrically conductive channels embedded in the insulating TiO_2 matrix. We have also been able to use XNP to obtain resistive switching behavior and IV characteristics typical of memristor devices, suggesting that irradiation induces the appearance of electrically conducting paths because of the formation of oxygen vacancies.

All of these results demonstrate the material modification capabilities of X-ray nano-beams at third generation synchrotron facilities, and prove that they can be used to fabricate devices based on oxides. With the advent of the ESRF Extremely Brilliant Source, which is expected to be able to reach a photon flux density per pulse of the order of 10^6 ph/μm^2 over areas of the order of 50×50 nm^2, these effects are expected to expand in their importance, providing even better opportunities for XNP.

References
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