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Interaction of high-energy density synchrotron radiation with functional oxides and their X-ray nanopatterning

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Material damage related to heavy X-ray irradiation has become increasingly important with the recent development of nanofocused hard X-ray beams. Recently, the possibility has emerged to exploit this damage in order to locally modify in a controlled way the structural and electronic properties of materials. In the case of superconducting oxides like $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) and $YBa_2Cu_3O_{7-\delta}$ (Y-123), photon damage has been used to fabricate devices based on their intrinsic Josephson junction structure. Photon fluxes of the order of 10^{10}-10^{11} ph s^{-1} have been used over areas about 50 × 50 nm^2 to draw the desired pattern in pristine single crystals.[1, 2] Experimental evidences indicate oxygen loss from the crystals and the appearance of grain boundaries during the fabrication, whose misalignment increases with the irradiation dose.[3, 4] Our method has been demonstrated also in TiO_2. We have shown the possibility of locally increasing the electrical conductivity upon irradiation, and of guiding the electroforming process needed for the fabrication of memristive devices. These modifications are most probably related to a local increase in the concentration of oxygen vacancies.[5] Corresponding computer simulations have been performed at room temperature and at a cryogenic temperature (8 K). The deposited energy density has been evaluated via Monte Carlo simulations considering the avalanche of relaxation processes induced by the beam. Then, heat propagation has been calculated by means of temperature-dependent finite element models. These simulations have taken into account the pulsed time pattern of the synchrotron beam. Results reveal temperature spikes corresponding to the synchrotron pulses. The temperature locally increases by tens of degrees, with a stronger effect at 8K because of the lower heat capacity at low temperature. These results indicate that rapid thermal dilation and contraction cycles occur, most probably with corresponding shock waves induced by the extreme temperature gradients (10^9 K m^{-1}) and heating rates (10^{12} K s^{-1}).

Biography

Marco Truccato is Professor at the Physics Department of University of Torino, Italy, where he teaches Solid State Physics and Physics of Superconductors. His almost 30-year long research activity in material science has encompassed many topics like diamond, semiconducting oxides, and superconducting oxides. He has been leading about 10 research projects at the local, regional, national and European level. In the past 10 years he has focused especially on the interaction between synchrotron radiation nanoprobes and matter - including living matter - taking part in about 20 experiments at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. He is also responsible for the Metal-Jet X-ray laboratory of the University of Torino. As of January 2022, he has published 65 papers and received over 570 citations.

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