Functional Modifications Induced via X-ray Nanopatterning in TiO_2 Rutile Single Crystals

*Andrea Alessio, Valentina Bonino, Thomas Heisig, Federico Picollo, Daniele Torsello, Lorenzo Mino, Gema Martinez-Criado, Regina Dittmann, and Marco Truccato**

The possibility to directly write electrically conducting channels in a desired position in rutile TiO_2 devices equipped with asymmetric electrodes—like in memristive devices—by means of the X-ray nanopatterning (XNP) technique (i.e., intense, localized irradiation exploiting an X-ray nanobeam) is investigated. Device characterization is carried out by means of a multitechnique approach involving X-ray fluorescence (XRF), X-ray excited optical luminescence (XEOL), electrical transport, and atomic force microscopy (AFM) techniques. It is shown that the device conductivity increases and the rectifying effect of the Pt/TiO_2 Schottky barrier decreases after irradiation with doses of the order of 10^{11} Gy and fluences of the order of 10^{12} J m^{-2}. Irradiated regions also show the ability to pin and guide the electroforming process between the electrodes. Indications are that XNP should be able to promote the local formation of oxygen vacancies. This effect could lead to a more deterministic implementation of electroforming, being of interest for production of memristive devices.

1. Introduction

Silicon-based electronics has recorded an exponential decrease for decades about the sizes of its basic components to achieve larger and larger integration scales and keep the pace of the so-called Moore's law. Nowadays, approaching the 7 nm technological node, the unavoidable process fluctuations create new challenges and require more and more sophisticated and expensive engineering solutions.[1] In this scenario, alternative approaches and novel device concepts are clearly desirable both to sustain further increase in the integration scale and to improve device functionality and performances. Oxide electronics has recently emerged as one of such promising approaches, having already been able to provide monolithic full-oxide integrated circuits, for instance.[2] But the advent of this new oxide-based technology has also opened the way to the fabrication of conceptually new devices like memristors,[3] i.e., resistive devices with inherent memory properties that previously existed just as theoretical models. Since then, memristor-based electronics has seen a rapid progress and showed great potential for many applications spanning from neuromorphic computing to on-chip memory and storage.[4–6] These devices are typically based on the reversible change of the electrical properties of transition metal oxides upon the application of an electric field that causes the introduction and migration of oxygen vacancies, which act as mobile donors in these systems. The typical two-terminal device structure of memristors consists of a dielectric layer of a material like TiO_2, $SrTiO_3$, or HfO_2 placed between two metallic electrodes. Prior to the reversible operation of the devices, a voltage

A. Alessio, F. Picollo, M. Truccato
Department of Physics, Interdepartmental Centre NIS
University of Torino
via P. Giuria 1, I-10125 Torino, Italy
E-mail: marco.truccato@unito.it

V. Bonino
European Synchrotron Radiation Facility – Experiments Division
71 Avenue des Martyrs, F-38000 Grenoble, France

T. Heisig, R. Dittmann
Forschungszentrum Juelich GmbH
Peter Gruenberg Institute 7, D-52425 Juelich, Germany

The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/pssr.202100409.

DOI: 10.1002/pssr.202100409

T. Heisig, R. Dittmann
JARA-FIT
RWTH Aachen University
D-52056 Aachen, Germany

D. Torsello
Department of Applied Science and Technology
Politecnico di Torino
10129 Turin, Italy

D. Torsello
Istituto Nazionale di Fisica Nucleare
Sezione di Torino, 10125 Turin, Italy

L. Mino
Department of Chemistry, Interdepartmental Centre NIS and INSTM
Centro di Riferimento
University of Torino
via P. Giuria 7, I-10125 Torino, Italy

G. Martinez-Criado
Instituto de Ciencia de Materiales de Madrid
Consejo Superior de Investigaciones Científicas
28049 Cantoblanco, Spain