An Easy Method for Oriented Conductive Nanowires Formation on SrTiO$_3$(100)

D. Wrana$^1$, C. Rodenbücher$^2$, B. R. Jany$^1$, J. Rysz$^1$, K. Szot$^{2,3}$, F. Krok$^1$

$^1$Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow
$^2$Forschungszentrum Jülich GmbH, Peter Grünberg Institute (PGI-7), Jülich
$^3$August Chelkowski Institute of Physics, Silesian University, Katowice

One of the most promising classes of oxide materials are perovskites ABO$_3$, with SrTiO$_3$ as a model material. For such ternary oxides it is crucial to control the actual chemical composition during preparation, especially near the surface. E.g. it was found that high mobility two-dimensional electron gas (2DEG) between grown LaAlO$_3$ and SrTiO$_3$ substrate is formed for TiO$_2$ termination only [lao_sto]. A driving force for the stoichiometry changes is related to oxygen activity – for oxidizing conditions SrO-rich structures are preferred [szot_afm], whereas for oxygen depleted conditions various TiO$_x$ phases evolve [sqr5]. Reduction of SrTiO$_3$ results in d-electrons emergence, improving electronic properties, towards novel applications such as memristive devices fabrication.

We studied the thermal reduction of SrTiO$_3$(100) single crystals at ultrahigh vacuum conditions. Our approach was holistic – combining crystallographic information (LEED), topography (STM, C-AFM, NC-AFM, SEM) with local work function (KPFM) and conductivity (conductive-AFM). Chemical composition was analysed by SIMS, EDX and EELS measurements, whereas actual atomic arrangements were obtained by HR-STEM.

Controlled reduction provides an easy method of tuning electronic structure of SrTiO$_3$. From conductivity measurements we found out that there is a transition from semiconducting to metallic behaviour on the surface after annealing to 800-900°C. Up to 1000°C the surface is flat, however reconstruction changes. Above a threshold temperature, phase segregation occurs and crystalline TiO nanowires of micrometer length are formed. The thickness of the nanowires increased with temperature following an Arrhenius behaviour, indicating that the underlying diffusion process is activated with temperature. Nanowires have a few orders of magnitude better conductivity than the rest of the surface and higher work function by as high as 0.8 eV. Unlike the reduced SrTiO$_3$ surface, nanowires are indifferent to in situ pure oxygen exposure.

SIMS measurements show that the surface is depleted by Sr (nanowire region) but no Sr segregation towards the bulk was observed. A lamella was cut by FIB in the nanowire region and analysed by HR-TEM. It could be seen that the nanowire consists of TiO in a rocksalt structure, however surface between them is still SrTiO$_3$(100). On the nanowire/SrTiO$_3$ interface there is a small region with valence +3 as seen by EELS indicating an additional interfacial phase.

Due to their stability, electronic properties and epitaxial growth, the created nanowires may have technological potential as micro-nanoscale electrodes, substrate for selective thin films growth or for catalytic applications.