Understanding the Mechanism of Resistive Switching via *In Situ* Observations of Bias-Induced Crystallization in Amorphous TiO$_2$ Films

Jae Hyuck Jang$^{1,2}$, Yunseok Kim$^{3}$, Young-Min Kim$^{1}$, Sang-Joon Park$^{4}$, Donovan N. Leonard$^{1}$, Stephen Jesse$^{3}$, Woo Lee$^{4}$, Sergei V. Kalinin$^{3}$, Albina Y. Borisevich$^{1}$

(1) Materials Science & Technology Division, Oak Ridge National Laboratory, Oak Ridge 37831, U.S.
(2) Research Institute of Advanced Materials, Seoul National University, Seoul 151-744, S. Korea.
(3) The Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, 37831, U.S.
(4) Korea Research Institute of Standards and Science (KRISS), DaeJeon 305-340, S. Korea

In the search for the next generation memory devices, multiple types of the nonvolatile memory have been extensively studied. One of the most promising architectures is resistive switching random access memory (ReRAM).$^1$ In a ReRAM, two different memory states are distinguished by resistance values, which can be controlled by voltage sweep - high resistance state (HRS) or low resistance state (LRS). Several mechanisms have been proposed for switching from HRS to LRS, such as filamentary switching and interfacial effect mechanisms.$^2$ Most of proposed mechanisms imply local inhomogeneity, yet were formulated based on the electrical response of the device as a whole. In fact, there are very few microscopic studies among the published literature. Studies of the Al/amorphous layer/epi-NiO structures indicate that voltage-induced crystallization plays an important role in the switching process.$^3$ We intend to understand the exact electroforming process and resistance switching phenomena in TiO$_2$ films by (Scanning) Transmission Electron Microscopy ((S)TEM) and electron energy loss spectroscopy (EELS), combined with (a) *in situ* bias application or (b) *ex situ* atomic force microscopy (AFM).

Amorphous TiO$_2$ (α-TiO$_2$) thin films on Pt were prepared by atomic layer deposition and investigated by TEM before and after applying bias sweep through AFM tip. In addition to *ex situ* AFM, *in situ* I-V measurements were performed. STM tip was used as a top electrode, see schematic in the Fig.1(a). Initial state of the film is shown in the Fig. 1(b). After applying voltage (+7 volt), α-TiO$_2$ film was crystallized in the area where bias was applied, see Fig.1(c). *In situ* studies show that crystallization starts happening quickly at very low voltages, while reduction of TiO$_2$ (proceeding via formation of irregular stacking faults to periodic Magnéli phases) occurs at higher voltages. Direct *in-situ* observations of the crystallization and the early stage of the formation of conducting phase in TiO$_2$ structures can reveal key information for fundamental understanding of conducting filaments and continued optimization of this promising technology.

References
Fig. 1. (a) Schematic of the experimental setup for *in situ* measurements (b) TEM image of as-deposited amorphous TiO$_2$/Pt/Si substrate; corresponding diffractogram shows amorphous ring pattern. (c) TEM image and diffractograms of the crystallized region of TiO$_2$ after local voltage to +7 V.

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