# In situ electron microscopy for electron radiolysis effect and dose dependence of functional metal oxides

Manling Sui[1], Yue Lu[1] and Fu-Rong Chen[2]

[1.] Beijing Key Laboratory of Microstructure and Property of Solids, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing, China.
[2.] Department of Materials Science and Engineering, City University of Hong, Hong Kong.

Advancements of aberration-corrected electron optics system and data acquisition schemes have enabled TEM to acquire images with sub-Ångström resolution and single-atom sensitivity. However, bottleneck of radiation damage is still challenging TEM imaging of soft materials and Knotek-Feibelman effect materials at the atomic level. For the radiation damage, it has been shown that the electron beam may not only alter the shape and surface structure at atomic level, but also induce radiolytic artifacts in chemical reactions at nanoscale, e.g., photocatalysis, metal-insulator transformation (MIT), super-dissolution of oxides [1, 2, 3]. The electron beam effects at nanometer resolution are discussed in this work. One example shows a dose-rate dependence of hydrogen bubble generation accompanying with water dissociation of Pt loaded $TiO_2$ nanoparticles in a liquid cell during in situ TEM observations. As the dose rate of electron beam is setup to be order of 1 $e^{-}Å^{-2}\cdot sec^{-1}$, the hydrogen bubble appears at around 240 seconds, while as the dose rate is increased to the order of $10^3$ $e^{-}Å^{-2}\cdot sec^{-1}$, the appearance of hydrogen bubble is faster by 4 times (at around 60 seconds). It clearly shows that the in-situ observations of photocatalysis can really mix up with radiolysis from the electron beam. Another example, an insulator phase of $VO_2$ is known to transform to metal phase at 68ºC. A nano probe at high electron dose-rate can stimulate phase transformation from insulator phase to metal phase in a $VO_2$ nanowire even at room temperature.

The electron beam effect must be taken into account for interpretation of in-situ EM observation. The dose-rate of incident electrons becomes a very critical and inevitable degree of freedom that must be controlled to surpress radiolysis artifacts and to reveal pristine structure at atomic resolution. In the present paper, we present a systematical analysis of electron microscopy methodology towards probing in-situ dynamics at high temporal resolution and emphasize in particularly the role of controlling the electron delivery.

**References:**

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