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a Powerful Tool in the In Situ Toolbox

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The Environmental TEM – a Powerful Tool in the *In Situ* Toolbox

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The addition of aberration correction and monochromation to Environmental Transmission Electron Microscopy (ETEM) has improved the point resolution and reduced image delocalization allowing for a more direct interpretation of surfaces and interfaces. The development of this unique in situ characterization tool has a huge impact on the materials problems, which can be addressed. Below I have listed three (of many) topics, which have benefitted significantly from the use of ETEM.

1. Nanoparticle/gas interaction: Nanoparticles play a significant role in heterogeneous catalysis. The performance of nanoparticles as catalysts is strongly linked to dispersion, size, morphology and chemical state of the nanoparticles during reaction. ETEM is a unique tool for studying and characterizing individual nanoparticles under controlled atmosphere (Figure 1). Detailed studies of nanoparticle formation from precursor *in situ* in the microscope provide valuable input for optimizing synthesis routes for tailor-made nanoparticle-based materials. The ETEM allows *in situ* structural and chemical analysis of nanoparticles in order the address the response to the reaction environment including sintering [1].

2. Light-Induced Reactions: The aberration correction of the objective lens allows for a relative large pole piece gap maintaining the spatial resolution, leaving space for specially designed TEM holders capable of letting visible light onto the sample in the microscope. This way photo induced reactions and phenomena such as Cu_2O degradation (Figure 2) are studied *in situ* under gaseous environments [2].

3. Focused Electron Beam Induced Deposition (FEBID): Operating the ETEM in STEM mode allows studying the initial steps of deposition of metals on substrates using a sub-nanometer electron beam to crack precursors with single molecule resolution. The deposits can be controlled with a line width of one nanometer *in situ* in the ETEM [3].

The presentation will give an insight in the vast diversion of materials problems, which is addressed using ETEM and complementary techniques at DTU Center for Electron Nanoscopy.

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[2] F. Cavalca et al., ChemCatChem 5, (2013) 2667 – 2672.
[3] W. F. van Dorp et al., ACS Nano 6 (2012) 10076.

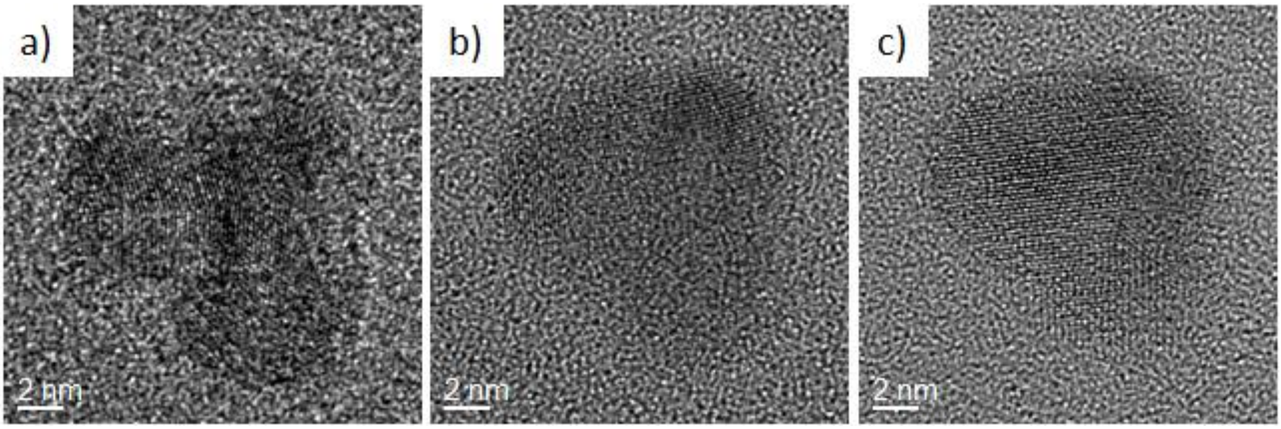

Figure 1 *Ruthenium nanoparticle imaged under different conditions relevant for the methanation reaction. a) Room temperature, vacuum; b) 427°C, vacuum; c) 427°C, 230 Pa 1:10 CO/H2.*

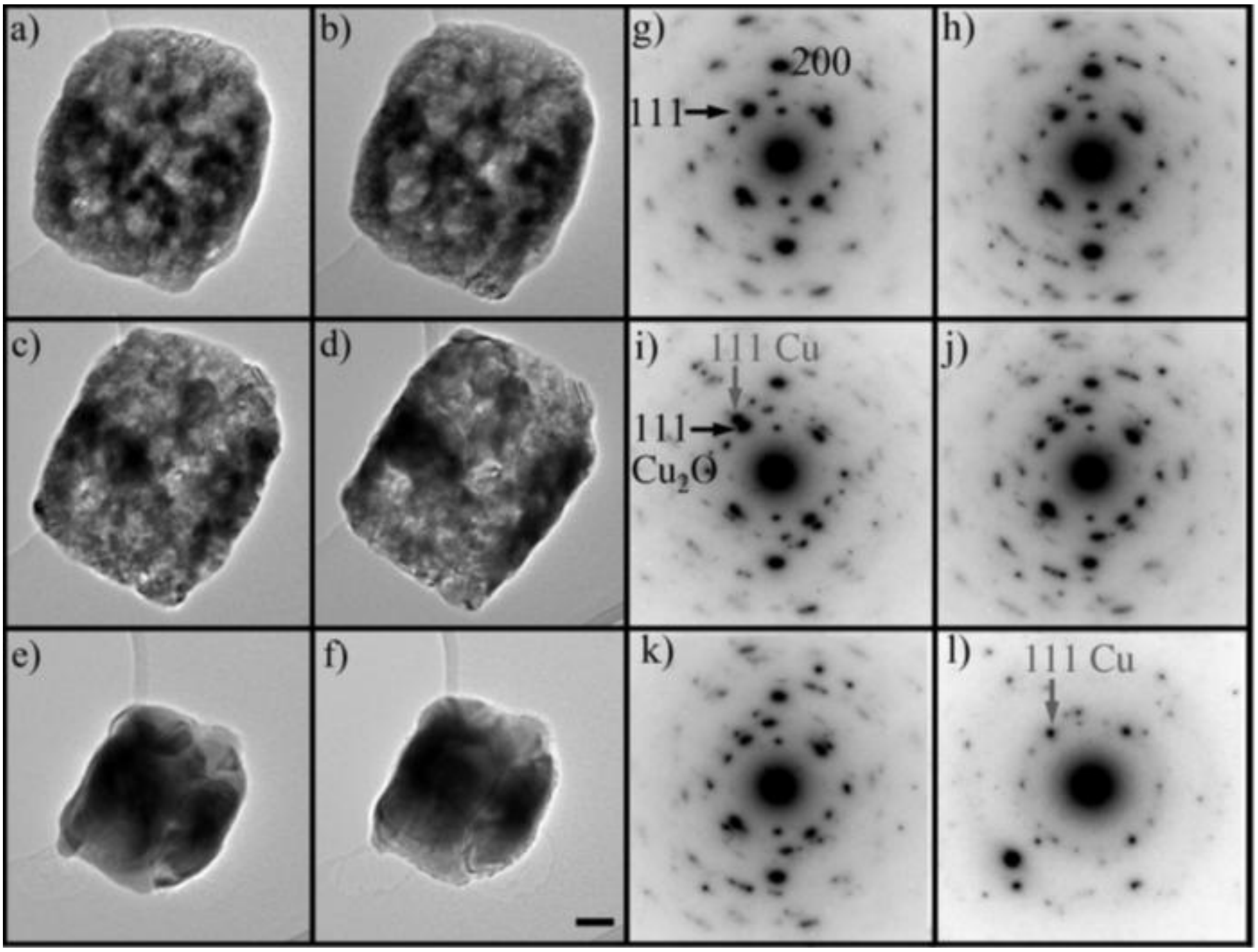

Figure 2 *Dynamic study of degradation of Cu_2O to metallic Cu in 500 Pa H_2O under irradiation of visible light in situ in the ETEM. a)-f) TEM imaging. Scale bar 50nm. g)-l) corresponding SAD. Each frame separated by 15 min.*