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Imaging Atomic Processes in Catalysts using a New High-Order Imaged-Corrected Environmental-TEM

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Background incl. aims:
The current quest for sustainable energy and environmental technologies calls for a new view on catalysis. Today, catalysis of chemical reactions is commonly perceived as a complex surface phenomenon that inescapably links structural dynamics and functionality of the catalytic nanomaterials [1]. However, insight into this intricate relation between catalytic active surface sites and their mechanistic actions has remained limited due to the lack of suitable atomic-resolution imaging competences. The Center of Visualizing Catalytic Processes (VISION) addresses this core scientific challenge by introducing new electron microscopy technology and applications. In this contribution, we demonstrate a new-generation environmental transmission electron microscopy (ETEM) enabling three-dimensional atomic-resolution imaging of catalytic nanomaterials under exposure to reactive gas atmosphere in a chemical meaningful way.

Methods:
The VISION PRIME microscope is based on an ultra-stable Thermo Fisher Scientific SPECTRA ULTRA platform and designed for in-line holography to retrieve time-resolved exit-wave functions of catalyst nanomaterials during exposure to reactive gas environments at pressures of up to 10-20 mbar. The microscope is equipped with (i) a new 5th order aberration-corrector for the objective lens in broad-beam mode (CETCOR Prime), (ii) a four-stage differential pumping system for confining a reactive gas environment in the mbar range to the vicinity of the sample (ETEM), (iii) a monochromator setup to extend the information limit below 50 pm and (iv) direct electron detection acquisition (Falcon 4i) for low-dose-rate imaging to suppress electron-beam-induced sample alterations.

Results:
Here we present the design of this new-generation ETEM as well as selected performances and applications. Specifically, the ultra-stable electron optics allow the high-resolution transmission electron microscopy (HRTEM) mode to reach 60 pm resolutions routinely, and to further extend the resolution toward 50 pm, in both high vacuum and environmental modes. This is achieved by exploiting the high stability base and optics of the Spectra platform and integrating the ETEM module into it.

Using the flexible microscope illumination system enables to generate Nelsonian illumination with a rapid and flexible electron dose-rate control. This is key to suppress electron-beam-induced sample alterations [2,3]. Furthermore, direct electron detection capability in HRTEM mode helps to achieve the largest image signal for the fewest number electrons. In conjunction with the ultra-stable electron optics direct detection enables the recovery of the electron exit-wave functions at the highest sensitivity from focal image series acquisitions. This uncovers the three-dimensional atomic structure of the catalyst nanomaterial [3,4].

Conclusions:
The VISION PRIME electron microscope offers a sample-limited rather than optical-limited resolution under high vacuum and environmental conditions. This atomic scale visualization capability offers new means to address the three-dimensional atomic structure and dynamic behavior of catalytic nanomaterials during exposure to relevant reaction conditions. The VISION PRIME is therefore key for uncovering the role of gas-surface interactions in complex catalytic nanomaterials at the atomic-scale and for advancing new catalyst design strategies.

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Keywords:

Catalysis, high-resolution-transmission electron microscopy, ETEM

Reference:

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