Dynamics of Supported Metal Nanoparticles Observed in a C_S Corrected Environmental Transmission Electron Microscope

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Many catalysts consist of metals or metal alloys, which are deposited onto a support material in the form of nanoparticles in order to maximize their exposed surface area. In a catalytic reactor, the particles tend to sinter, resulting in a decrease in catalytic performance. Several models of sintering have been put forward [1, 2]. However, most experimental investigations have been post mortem studies, revealing only the final state of the catalyst.

Transmission electron microscopy (TEM) has been used extensively in catalysis research [3]. However, in contrast to chemical reactors, a conventional TEM is a high vacuum tool. Thus, observations do not always reflect the active states of materials. Environmental TEM (ETEM) provides the capability to expose samples to gases during imaging and analysis [4]. Even though the gap between reactor and high-vacuum pressures has not yet been fully bridged, progress has been made towards observing materials in their working environment.

The combined capabilities of ETEM and image C_S correction provide unique possibilities to study relationships between the surface structures of catalytic materials and surrounding atmospheres. However, as industrial catalysts are usually complex high surface area materials, they are often not suited for fundamental studies. Accordingly, we have studied a model system comprising gold nanoparticles on sheets of boron nitride and graphite. The nanoparticles were formed from a sputter coated thin film of gold, which readily formed nanoparticles ranging from a few nm up to 20 nm in size. The samples were exposed to oxidizing and reducing environments at various temperatures *in situ* in the ETEM.

Under these conditions, mobility of the particles was clearly visible, while maintaining lattice resolution of both the support material and the Au nanoparticles. Some particles remained immobile during observation, while others behaved dynamically. Some of the particles sintered by migration and coalescence, while others were observed to shrink in size and finally disappear as neighboring particles grew by Ostwald ripening. These observations indicate that several sintering mechanisms may occur simultaneously. Particles on steps were observed to be significantly smaller than those on terraces, suggesting a stronger interaction of the metal and support at these sites. By quantifying these observations, fundamental insight into activation energies and energy barriers for sintering processes can be studied. In the future, in order to fully quantify image contrast in such experiments, a deeper understanding of the scattering of fast electrons in the presence of gas molecules in the pole piece gap of the microscope is needed.

References

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