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A New Era of Imaging – New Results beyond the 1 Ångström -Barrier

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The continued focus on improving materials, combined with the fact that it is now commonly understood that material properties are affected by characteristics at the atomic level, give rise to the need to image material at the best resolution possible. TEM is seen as a powerful technology to deliver this best resolution.

Typically, TEM image resolution has been limited primarily by the spherical aberration (Cs) of the objective lens. Spherical aberration causes an intense oscillation of the microscope transfer function (CTF), making the direct interpretation of images difficult, if not impossible at the resolution levels approaching or breaking the 1 Ångström barrier. It also causes an effect known as delocalization that essentially spreads local information over a broader region. TEM can indeed produce spectacular images of regularly ordered atoms in crystalline samples; however, close inspection reveals that each atom image is actually a composite image including information from neighboring atoms as well. This effect is most apparent in images of discontinuous samples, such as the edge of a particle or at grain boundaries. Often, the regularly repeating pattern appears to extend beyond the boundaries and edges. Delocalization is troublesome in any study of interfaces and boundaries.

Traditionally, the Cs of the objective lens was the most important aspect in terms of resolution and tilt capabilities [1], however this requirement no longer plays a significant role in corrected systems. At FEI Company, the theory of improving the spatial resolution (information limit) capabilities through a new and corrector-dedicated column was put into practice through Titan, a system which has a variable accelerating voltage between 80kV and 300kV. By design, the following aspects were addressed: ultimate stability and ultimate flexibility. The Titan systems have unsurpassed information limit (below 1 Ångström, see Figure 2) even with a 6 mm pole piece gap lens, removing spatial freedom restrictions, allowing tomography, cryo and heating experiments to be carried out with conventional 3 mm samples at resolution below 1 Ångström.

Resolutions beyond the 1 Ångström barrier will open doors for researchers to study morphology. In this contribution, utilization examples of image C_S corrector will be described, bringing electron microscopy into a new era by expanding the boundaries and achieving new information, new results.

The authors thank the involved employees of CEOS GmbH for their excellent contributions to making the next generation of corrector technology on Titan a success. The Titan platform is the basis of the TEAM project of the USA Department of Energy with the goal to arrive at 0.5 Ångström resolutions in TEM and STEM on a single system, in combination with a Cc corrector developed in co-operation with CEOS GmbH.

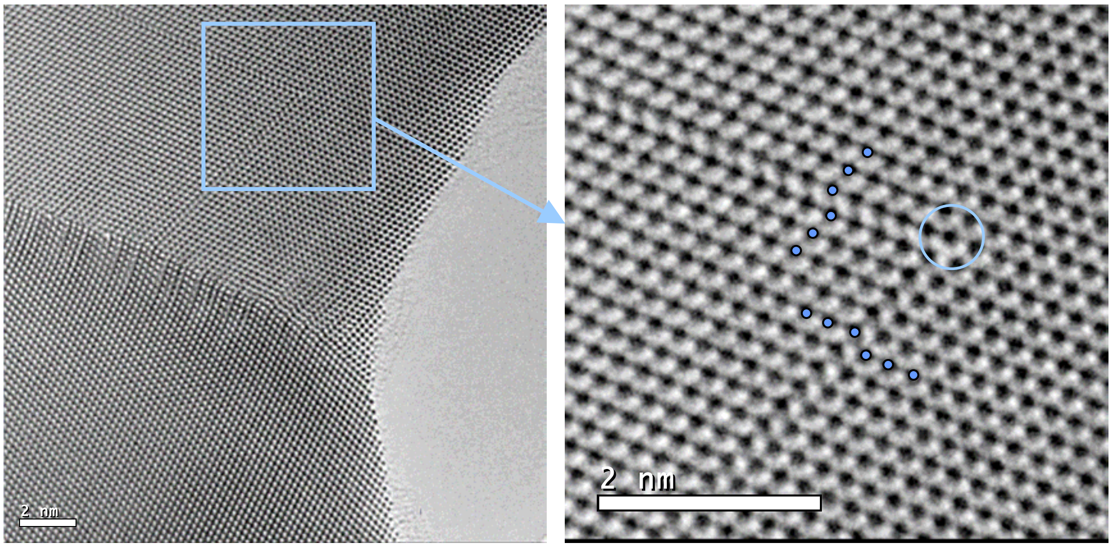

Fig. 1. Cs-corrected HR-TEM image of gold in <110> direction at 300kV. In the upper crystal two twins touch each other under an angle of 60^0. The area of interest is magnified in the right image. The blue dots indicate the atomic positions across the twins. The point, in which the twins are touching each other, can be clearly resolved, exemplifying the benefits of an image Cs-corrector.

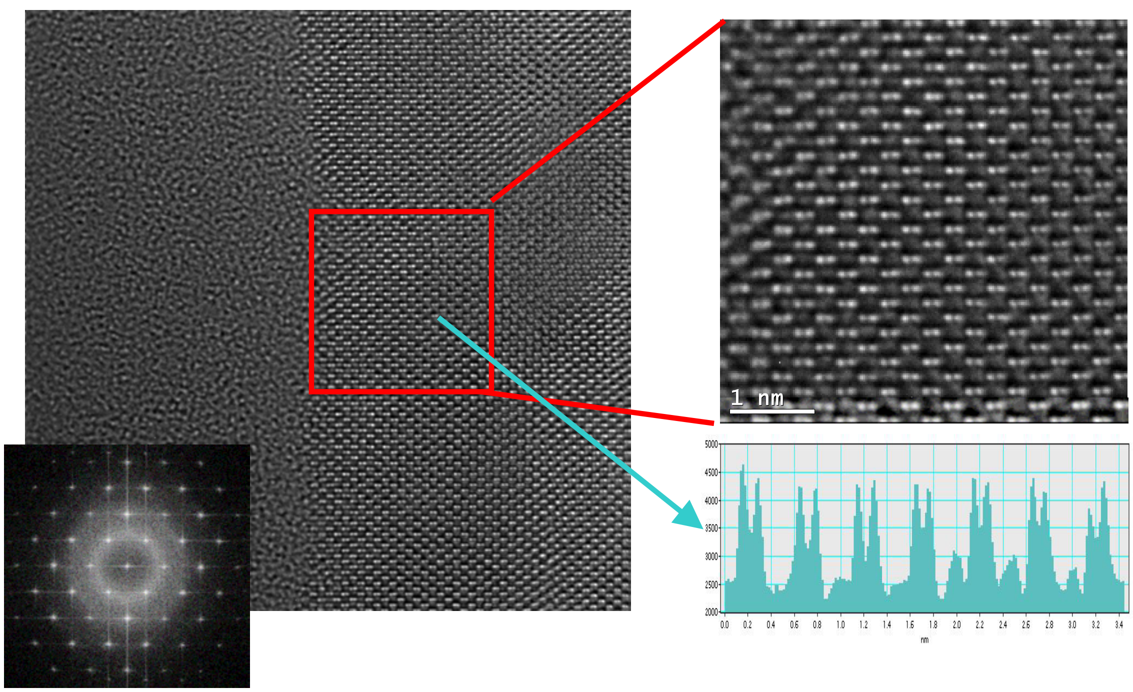

Fig. 2. Cs-corrected HR-TEM image of $Si\text{-}SiO_2$ interface at 300kV acceleration voltage. The insert on the right side shows an intensity profile, resolving the silicon dumbbell of 0.136nm in resolution. The roughness of the $Si\text{-}SiO_2$ interface can be clearly imaged. In the magnified insert on the right side variations of the dumbbell structure, especially near to the interface (left side of the image) can be visualized. The power spectrum of the image (bottom left) clearly shows sub-Angstrom frequencies being transferred.

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