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High-stability, highly-automated double-eucentric (S)TEM sample stage

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The Nion 200 kV UltraSTEM™ will be able to produce electron probes as small as 0.5 Å in diameter [1]. Its ability to analyze the chemical composition of the sample at atomic resolution will be even more revolutionary. Reaching this level of performance requires an ultra-stable sample holder, free of short-term vibrations and long-term drift.

We have therefore designed an ultra-stable sample stage for the UltraSTEM™. The guiding principles of the design were:

1) Minimize backlash and stiction, so as to make the correspondence between the computer-controlled setting of the stage drive motors and the actual sample position as exact and reproducible as possible.
2) Minimize sensitivity to environmental factors, such as changes in room temperature and pressure, in order to ensure that the microscope is not as sensitive to the environment as has become the norm.
3) Minimize the "suspended mass", i.e., the mass that moves when the sample position or tilt is changed. This minimizes resonant vibrations of low and medium frequency.
4) Ensure that there are at least 250,000 positions in the three shift axes (x, y and z), and 1200 in the tilts (alpha and beta). This gives smallest mechanical shifts and tilts of the order of 10 nm and 1 mrad, respectively.
5) Maximize the sample tilt available for a given objective lens gap.
6) Maximize access to the sample (for in-situ experiments).
7) Make the design compatible with ultra-high vacuum levels, and baking temperatures of at least 120° C.
8) Allow sample exchange under computer control (so that remote-control sample exchange becomes possible).

Accordingly, our design (Fig. 1) uses a side-entry cartridge which decouples from the outside world when in the working position, and has a double-gimbal for two independent tilts. The cartridge clips into a cartridge receptacle attached to a titanium ring that encircles the polepiece symmetrically, and is suspended on three rolling zirconia balls. For minimizing backlash and stiction, all the motions employ either elastic hinges, rolling balls, or jewel ball bearings. The whole stage uses radial symmetry in a manner such that there is no change in sample position when the stage temperature changes uniformly, and the motions are transferred from outside the vacuum to the inside of the sample chamber such that the sample position is not influenced by atmospheric pressure. A stepper motor coupled to a ball-screw is used for each motion, with 10:1 reduction of the screw motion to sample stage.

The double-tilt mechanism (Fig. 2) uses a double gimbal oriented at 45° to the detachable cartridge axis, with the tilts introduced via drive arms attached to rotating cylinders running the length of the cartridge body. With a 4 mm objective lens gap, it achieves ±30° of tilt in any direction. There is no obstruction at the end of the cartridge, allowing ready access to the sample from the principal user port which lies opposite the cartridge insertion port.

The sample chamber has twelve side ports. Eight of these are presently used by Nion: five for motions, one for sample introduction, one for pumping, and one for electrical feed-throughs. This leaves four ports for user-specified requirements. All the ports and the polepieces are sealed either by copper gaskets or metal C-rings, allowing baking to 120° C and vacuum levels better than $1x10^{-9}$ torr.

The sample cartridge is inserted into the stage (under computer control) from a storage chamber attached to the side of the column. The chamber accommodates a storage magazine holding up to five sample cartridges. It uses double Viton O-rings plus guard (differential) vacuum and is ion-pumped, for maintaining pressures in the 10^{-9} torr range. The storage magazine incorporates a heater for heating the samples to 120° C, and there is also provision for an optional ion gun with a line-of sight towards the sample.

The non-eucentricity and crosstalk between motions inherent in double-gimbal designs are compensated for by the software driving the stage. The software characterizes the sample motion and is able to drive the five stepper motors in the proportions required to make the shifts and tilts "pure." The minimized residual backlash of the system is further compensated by driving the specimen to the desired coordinates plus an offset, after which an appropriate recovery translation is applied to obtain reproducible positioning. A similar procedure is also applied to the tilts.

The new stage is thus able to achieve double-tilt eucentricity entirely under software control. The software also allows the user to simply click on a feature in an image and have the stage move to it automatically. Moreover, it allows the user to click on a pole in a diffraction pattern, and have the pole brought onto the beam axis automatically and eucentrically.

Further details of the design and performance of the stage will be reported at the meeting.

[1] O.L. Krivanek et al., Ultramicroscopy **96** (2003) 229-237.

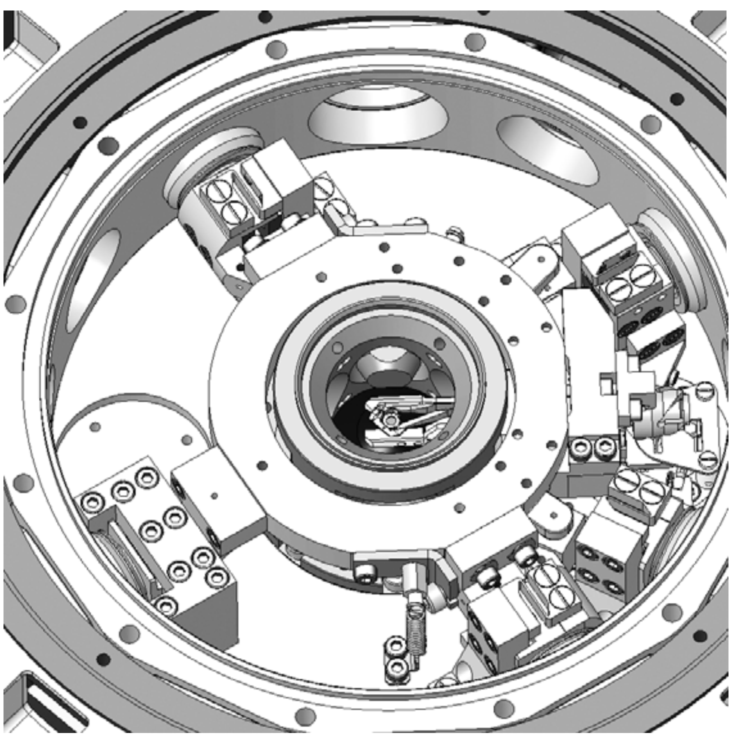

Fig. 1. Top view of the sample stage module demonstrating accessibility to the sample from multiple external ports. A double-tilt cartridge is shown in the observation position. The top objective polepiece is removed for clarity.

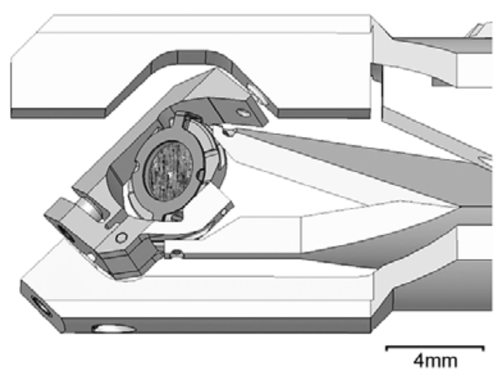

Fig. 2. Close-up of the double-tilt cartridge showing the double-gimbal assembly and drive arms.

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