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Sub-nanometer resolution in field-free imaging using a Titan80-300 with Lorentz lens and image Cs-corrector at 300kV acceleration voltage

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Lorentz microscopy is used to image magnetic materials in field-free conditions to reveal the magnetic structure on a nanometer scale. Insight into magnetic properties on this scale help to understand and optimize the magnetic properties of functional magnetic material, such as sensors (GMR) and magnetic storage material.

In conventional S/TEM imaging the magnetic structure is destroyed due to the high magnetic fields at the sample area. In the current instruments the resolution in field-free imaging is limited by the performance of the weak Lorentz lens with its high spherical aberration (Cs~10m) to 2nm point resolution at 300kV acceleration voltage.

In this contribution an image Cs-corrector on a Titan80-300 column is used to reduce the Cs of the Lorentz lens by 3 orders of magnitudes from 8m to ~10mm at 300kV acceleration voltage. A special optical set-up is used to compensate the high spherical aberration of the Lorentz lens using the hexapole elements of the image Cs-corrector. The chromatic aberration of the special set-up has been measured to ~93mm by determining the focus change, when the energy of the electrons has been altered. These optical parameter improvements enhanced the resolution in field-free imaging to the Sub-Nanometer level and an information limit of 0.7nm has been obtained. (figure 1). In addition to the compensation of the optical parameters using the image Cs-corrector the stability of the Lorentz lens has been improved compared to conventional Lorentz lenses.

The flexibility of the Titan80-300 is not impaired by this solution and the column with its Cs-corrector can be used in Cs-corrected HR-TEM, HR-STEM mode at different acceleration voltages. Switching between the normal Cs-corrected objective lens on-operation mode (non field-free) and the special Cs-corrected Lorentz mode (field-free mode) can be achieved as a push-button function. The same Zemlin tilt-tableau method to measure and correct for aberrations used in objective lens `on` mode can be used in field-free Lorentz mode. This makes the method easy to use and reliable in performance. (figure 2)

An important performance measure in Lorentz microscopy is not only the optical performance, but the smallest magnetic field at the specimen area in the Lorentz imaging mode. Measurements to determine the magnetic field strength result in field strengths smaller than 2 Oe (figure 3) at the specimen area and the dependence of the field in respect to the Lorentz lens, objective lens and Mini condenser lens are presented. These measurements allow the user to apply magnetic fields to the sample and to determine changes of the magnetic structure in a reproducible and quantitative way.

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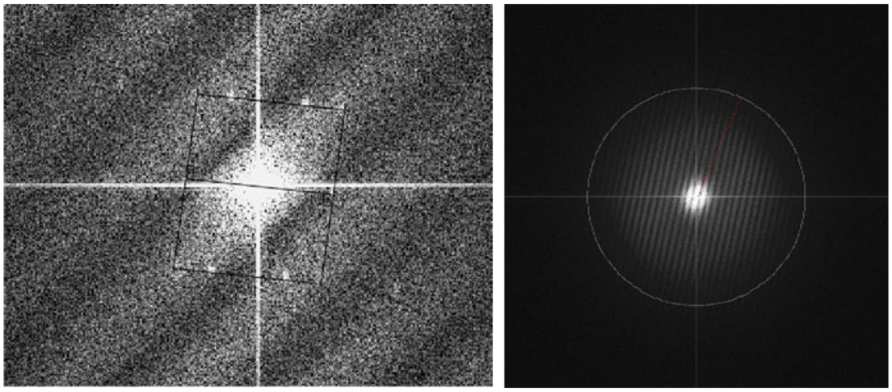
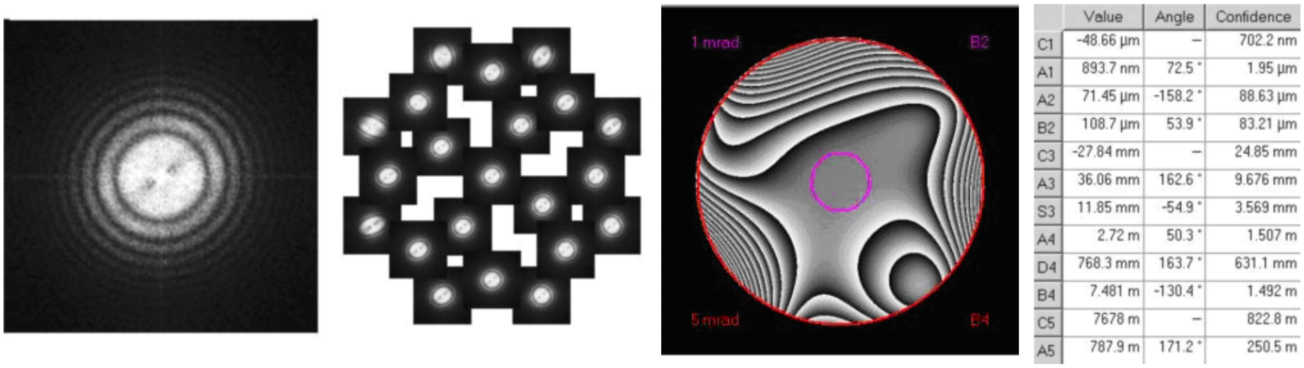


FIG. 1. Left: The catalase specimen offers an internal calibration (long distance = 4.375nm, short distance = 3.39nm). Right: Young fringes on catalase extending to 0.75nm (white circle).



	Value	Angle	Confidence
C1	-48.66 µm	–	702.2 nm
A1	893.7 nm	72.5 °	1.95 µm
A2	71.45 µm	-158.2 °	88.63 µm
B2	108.7 µm	53.9 °	83.21 µm
C3	-27.84 mm	–	24.85 mm
A3	36.06 mm	162.6 °	9.676 mm
S3	11.85 mm	-54.9 °	3.569 mm
A4	2.72 m	50.3 °	1.507 m
D4	768.3 mm	163.7 °	631.1 mm
B4	7.481 m	-130.4 °	1.492 m
C5	7678 m	–	822.8 m
A5	787.9 m	171.2 °	250.5 m

FIG. 2. Cs-Corrector user interface showing the aberration measurement, the tilt tableau on amorphous material and the phase plate in `corrected` Lorentz mode with a Cs~10mm.

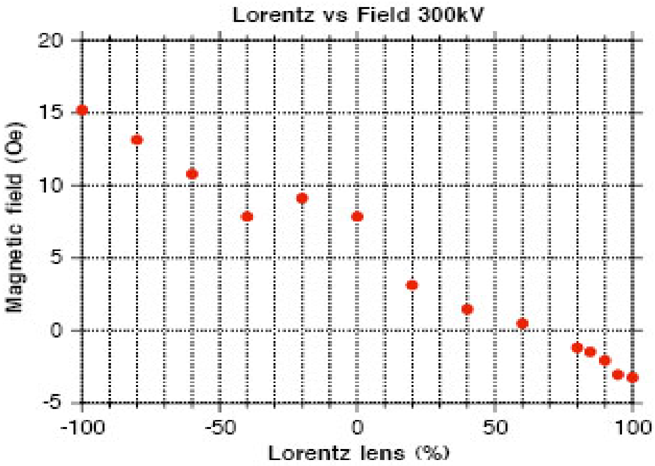


FIG. 3 : Variation of magnetic fields as a function of Lorentz lens strength. OBJ lens: 0%, MC lens: -21%, DIF lens: 100%. Red circle: approached from a positive lens value. The normal imaging conditions in Lorentz mode is around 80% with <2 Oe magnetic field at the specimen area.