Scanning transmission electron microscopy (STEM): Applications in Materials Science

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OUTLINE

1. STEM Basics
2. Experimental STEM
3. Interpretation of STEM Images
4. Case Studies
The electron beam in CTEM and STEM instruments. In many STEM instruments the beam actually travels upwards rather than down as shown here.
Objective lens

First condenser lens

Second condenser lens

Diaphragm

Double deflection scan coils

Focused spot scanning across specimen
2. Signals in STEM

Probe forming lens with aperture

Sample

Diffraction pattern

Direct beam
Bragg scattered electron
Inelastic scattering
Thermal diffuse scattering (e.g. Kikuchi bands)
- Elastic **BF-STEM** images are equivalent to TEM bright-field images. They are mainly produced by Bragg disks hitting the detector. They contain diffraction contrast and are therefore very sensitive to strain/diffraction conditions in the material.

- **HAADF-STEM** images are mainly produced by thermal diffuse scattering (TDS), because at high scattering angles TDS has the highest scattering cross section.

- Medium angle **ADF-STEM** images contain both, Bragg diffraction and TDS contributions.
3. STEM detectors

**ADF, HAADF**

**Defocus map of a STEM probe**

X-Z- cross section through coherent probe with $\alpha=12\text{mrad}$, $E_0=200\text{kV}$

TDS depends on:
- Atomic number
- Relative vibration amplitudes
Annular Bright Field (ABF)

STEM focused probe

YH₂

10-20 mrad

BF APPERTURE

HAADF

ADF

STOPPER

Y-CBED

10 mR

H-CBED

10-20 mrad
4. Lens Aberrations

\( \chi = \text{wave aberration function} \) is defined as the phase \textit{difference} between the perfect spherical wave and the actual wavefront.

\textit{Wave aberration function} has many polynomial expansions:

\[
\chi(\theta, \phi) = A_0 \theta \cos(\phi - \phi_1) + \frac{1}{2} A_1 \theta^2 \cos(2(\phi - \phi_2)) + \frac{1}{2} C_1 \theta^2 + \frac{1}{3} A_2 \theta^3 \cos(3(\phi - \phi_3)) + \frac{1}{3} B_2 \theta^3 \cos(\phi - \phi_{31}) + \frac{1}{4} A_3 \theta^4 \cos(4(\phi - \phi_{44})) + \frac{1}{4} S_3 \theta^4 \cos(2(\phi - \phi_{42})) + \frac{1}{4} C_3 \theta^4 + \frac{1}{5} A_4 \theta^5 \cos(5(\phi - \phi_{55})) + \frac{1}{5} B_4 \theta^5 \cos(\phi - \phi_{51}) + \frac{1}{5} D_4 \theta^5 \cos(3(\phi - \phi_{53})) + \frac{1}{6} A_5 \theta^6 \cos(6(\phi - \phi_{66})) + \frac{1}{6} R_5 \theta^6 \cos(4(\phi - \phi_{64})) + \frac{1}{6} S_5 \theta^6 \cos(2(\phi - \phi_{62})) + \frac{1}{6} C_5 \theta^6 \ldots
\]

The spherically symmetric aberrations (C3, C5, \ldots) are present even in perfect (round) lenses. Special correcting elements must therefore be designed to correct for them.
<table>
<thead>
<tr>
<th>Aberration</th>
<th>Krivanek notation</th>
<th>Order in $k$</th>
<th>azimuthal symmetry</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_0$</td>
<td>$C_{0,1}$</td>
<td>1</td>
<td>1</td>
<td>Image shift</td>
</tr>
<tr>
<td>$A_1$</td>
<td>$C_{1,2}$</td>
<td>2</td>
<td>2</td>
<td>Two fold astigmatism</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_{1,0}$</td>
<td>2</td>
<td>inf</td>
<td>Defocus (over focus positive)</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$C_{2,3}$</td>
<td>3</td>
<td>3</td>
<td>Three fold astigmatism</td>
</tr>
<tr>
<td>$B_2$</td>
<td>$C_{2,1}$</td>
<td>3</td>
<td>1</td>
<td>Axial coma</td>
</tr>
<tr>
<td>$A_3$</td>
<td>$C_{3,4}$</td>
<td>4</td>
<td>4</td>
<td>Four fold astigmatism</td>
</tr>
<tr>
<td>$S_3$</td>
<td>$C_{3,2}$</td>
<td>4</td>
<td>2</td>
<td>Axial star aberration</td>
</tr>
<tr>
<td>$C_3$</td>
<td>$C_{3,0}$</td>
<td>4</td>
<td>inf</td>
<td>Spherical aberration</td>
</tr>
<tr>
<td>$A_4$</td>
<td>$C_{4,5}$</td>
<td>5</td>
<td>5</td>
<td>Five fold astigmatism</td>
</tr>
<tr>
<td>$B_4$</td>
<td>$C_{4,1}$</td>
<td>5</td>
<td>1</td>
<td>Fourth order axial coma</td>
</tr>
<tr>
<td>$D_4$</td>
<td>$C_{4,3}$</td>
<td>5</td>
<td>3</td>
<td>Three lobe aberration</td>
</tr>
<tr>
<td>$A_5$</td>
<td>$C_{5,6}$</td>
<td>6</td>
<td>6</td>
<td>Six fold astigmatism</td>
</tr>
<tr>
<td>$R_5$</td>
<td>$C_{5,4}$</td>
<td>6</td>
<td>4</td>
<td>Fifth order rosette aberration</td>
</tr>
<tr>
<td>$S_5$</td>
<td>$C_{5,2}$</td>
<td>6</td>
<td>2</td>
<td>Fifth order axial star aberration</td>
</tr>
<tr>
<td>$C_5$</td>
<td>$C_{5,0}$</td>
<td>6</td>
<td>inf</td>
<td>Fifth order spherical aberration</td>
</tr>
<tr>
<td>$A_6$</td>
<td>$C_{6,7}$</td>
<td>7</td>
<td>7</td>
<td>Seven fold astigmatism</td>
</tr>
<tr>
<td>$B_6$</td>
<td>$C_{6,1}$</td>
<td>7</td>
<td>1</td>
<td>Sixth order axial coma</td>
</tr>
<tr>
<td>$D_6$</td>
<td>$C_{6,3}$</td>
<td>6</td>
<td>3</td>
<td>Sixth order three lobe aberration</td>
</tr>
<tr>
<td>$F_6$</td>
<td>$C_{6,5}$</td>
<td>6</td>
<td>5</td>
<td>Sixth order pentacle aberration</td>
</tr>
<tr>
<td>$A_7$</td>
<td>$C_{7,8}$</td>
<td>8</td>
<td>8</td>
<td>Eight fold astigmatism</td>
</tr>
<tr>
<td>$G_7$</td>
<td>$C_{7,6}$</td>
<td>8</td>
<td>6</td>
<td>Seventh order hexagon aberration</td>
</tr>
<tr>
<td>$R_7$</td>
<td>$C_{7,4}$</td>
<td>8</td>
<td>4</td>
<td>Seventh order rosette aberration</td>
</tr>
<tr>
<td>$S_7$</td>
<td>$C_{7,2}$</td>
<td>8</td>
<td>2</td>
<td>Seventh order star aberration</td>
</tr>
<tr>
<td>$C_7$</td>
<td>$C_{7,0}$</td>
<td>8</td>
<td>inf</td>
<td>Seventh order spherical aberration</td>
</tr>
</tbody>
</table>
Two fold astigmatism

\[ W(\theta, \phi) = \frac{1}{2} A_1 \theta^2 \cos 2(\phi - \phi_{22}) \]

Three fold astigmatism

\[ W(\theta, \phi) = \frac{1}{3} A_3 \theta^3 \cos 3(\phi - \phi_{33}) \]

Coma

\[ W(\theta, \phi) = \frac{1}{3} B_2 \theta^3 \cos(\phi - \phi_{31}) \]

\[ \Delta f = 50 \text{nm} \quad \Delta f = 0 \text{nm} \quad \Delta f = -50 \text{nm} \]

A1 = 25nm
\[ \Phi = 30^\circ \]

X and Y focus at different planes.

3-fold astigmatism is an asymmetric aberration.

Beam is tilted off axis.
Spherical Aberration

For $C_s > 0$, rays far from the axis are bent too strongly and come to a crossover before the gaussian image plane.

For a lens with aperture angle $\alpha$, the minimum blur is

$$d_{\text{min}} = \frac{1}{2} C_s \alpha^3$$

Typical TEM numbers: $C_s = 1$ mm, $\alpha = 10$ mrad $\rightarrow d_{\text{min}} = 0.5$ nm
Spherical aberration is always finite positive for lenses that are:

- Rotationally Symmetric
- Static (field constant)
- Real image is produced

Scherzer (1936)

For TEM / STEM the only practical solution to correct aberrations is to break rotational symmetry by the incorporation of multipole elements.
## 5. Aberration correctors

<table>
<thead>
<tr>
<th>instrument</th>
<th>type of corrector</th>
<th>correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEM (100-300 kV)</td>
<td>hexapole corrector: 2 hexapoles + 2 transfer round-lens</td>
<td>$C_s + \text{coma}$</td>
</tr>
<tr>
<td>LVSEM</td>
<td>quadrupole-octopole corrector: 2 electric + 2 crossed el. and magn. quad. + 3 octopoles</td>
<td>$C_s + C_r$</td>
</tr>
<tr>
<td>Ion probe</td>
<td>ECO: 2el. quadrupoles + 2 &quot;Scherzer&quot; correction elements + 3 electric octopoles</td>
<td>$C_s + C_c$</td>
</tr>
<tr>
<td>STEM</td>
<td>a) quadrupole-octopole corrector</td>
<td>$C_s + (C_c)$</td>
</tr>
<tr>
<td></td>
<td>b) hexapole corrector</td>
<td>$C_s$</td>
</tr>
<tr>
<td>Projection electro</td>
<td>Ultracorrector: 2 el. and magn. quadrupole septuplets + 15 (19) octopoles</td>
<td>all primary chromatic and geometrical aberr.</td>
</tr>
<tr>
<td>lithography</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEEM, PEEM</td>
<td>mirror corrector: tetrode mirror combined with aberration-free beam separator</td>
<td>$C_s + C_{CM}$, $C_s + \text{coma}$</td>
</tr>
<tr>
<td>PEEM</td>
<td>pulsed source combined with time-varying lens field and detection</td>
<td>$C_s + C_c$</td>
</tr>
</tbody>
</table>

Dr Peter Hartel, CEOS
Schematic and ray path diagram of a hexapole corrector. The corrector consists of two hexapoles (Hex1 and Hex2) and four round lenses arranged in two pairs of transfer doublet. The radial elongation of the beam through the corrector is indicated along two axes $a$ and $b$ as indicated (the line traces overlap when the beam is round).
Cs Corrected beam profile

Cs=0.005mm

FWHM 0.1 nm

Cs=0.5mm

Cs ~ 0

miran.ceph@ijs.si  JSI Colloquium, November 27, 2013
Ronchigram is the convergent beam diffraction pattern of an amorphous region (crystal).

Out of focus, the Ronchigram gives a shadow image (projection image, inline hologram) of the sample in the diffraction plane.
Focusing with the Ronchigram

Reduce under-focus until infinite magnification rings are of minimum diameter =>

Scherzer-like defocus

-700 nm

-450 nm

-250 nm

Fit correct “aperture to the “sweet spot” region of constant phase within this diameter
The Electron Ronchigram in Cs-corrected STEM

Ronchigram are used to tune aberration correctors:

- Loss of radial symmetry (no Cs)
- Region of flat phase greatly expanded
- Use of larger probe-forming aperture

150μm CA, CL 40cm
1. STEM Basics
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1. Microscopes for STEM imaging

Dedicated STEMs

Nion UltraSTEM

- < 1 Å resolution
- >0.5 nA of current
- diffraction
- CTEM images.

VG HB501

http://www.nion.com/products.html
2. Probe semi-angle ($\alpha$) determination

<table>
<thead>
<tr>
<th>CA (um)</th>
<th>$\alpha$ (mrad)</th>
<th>2$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3,75</td>
<td>7,5</td>
</tr>
<tr>
<td>40</td>
<td>4,85</td>
<td>9,7</td>
</tr>
<tr>
<td>50</td>
<td>6,50</td>
<td>13,0</td>
</tr>
</tbody>
</table>

$d_0 = 0.43 C_s^{1/4} \lambda^{3/4}$

$\alpha_0 = \left(\frac{4\lambda}{C_s}\right)^{1/4}$
3. ADF, HAADF, ABF detector acceptance angles determination

ARM 200F, Sunum, Sabanci University
EXPERIMENTALLY DETERMINED VALUES
EXTRAPOLATED VALUES

<table>
<thead>
<tr>
<th>CL (cm)</th>
<th>ADF1</th>
<th></th>
<th>ADF2</th>
<th></th>
<th>ABF (3 mm AP)</th>
<th></th>
<th>ABF (6 mm AP)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>106.8</td>
<td>438</td>
<td>63.0</td>
<td>252</td>
<td>16.8</td>
<td>35.0</td>
<td>16.8</td>
<td>72.0</td>
</tr>
<tr>
<td>5</td>
<td>91.5</td>
<td>366</td>
<td>54.0</td>
<td>214</td>
<td>14.3</td>
<td>30.0</td>
<td>14.3</td>
<td>61.5</td>
</tr>
<tr>
<td>6</td>
<td>70.2</td>
<td>288</td>
<td>42.0</td>
<td>168</td>
<td>11.1</td>
<td>23.4</td>
<td>11.1</td>
<td>47.8</td>
</tr>
<tr>
<td>8</td>
<td>53.4</td>
<td>219</td>
<td>31.5</td>
<td>126</td>
<td>8.4</td>
<td>17.5</td>
<td>8.4</td>
<td>36.0</td>
</tr>
<tr>
<td>10</td>
<td>45.8</td>
<td>183</td>
<td>27.0</td>
<td>107</td>
<td>7.2</td>
<td>15.0</td>
<td>7.2</td>
<td>30.8</td>
</tr>
<tr>
<td>20</td>
<td>23.0</td>
<td>91.5</td>
<td>13.5</td>
<td>53.5</td>
<td>3.6</td>
<td>7.5</td>
<td>3.6</td>
<td>15.4</td>
</tr>
<tr>
<td>40</td>
<td>12.5</td>
<td>46.0</td>
<td>6.8</td>
<td>26.5</td>
<td>1.8</td>
<td>3.8</td>
<td>1.8</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Maximum acceptance angle for ARM 200F is 174.5 mrad
4. Specimen thickness

Sample thickness (nm)

(collection angle 100-220 mrad, Scherzer focus)
5. Collection angles

(Ti-O/Ca=1.17)

60 - 160 mrad

85 - 215 mrad

100 - 220 mrad

125-250 mrad

Detector collection ranges (mrad)

Ti-O/Ca intensity ratio

(near Scherzer, specimen thickness 80 nm)
6. Processing of STEM images

- STEM images are acquired **sequentially**, i.e. pixel by pixel. Reproducibility of the beam positioning is essential.

- The emission current of some FEG sources (cold FEGs) may **fluctuate**.

- The signal recorded from the detector is usually amplified with an adjustable bias (threshold) and gain (amplification). This makes it often **impossible to quantify** the number of electrons per pixel in a given STEM image.

- Less than 10% of the incident electrons scatter to the HAADF detector (depends on detector geometry, of course). This makes HAADF images **very noisy**.
Processing of distortion free HR HAADF-STEM images

experimental image

average filter

A. Rečnik
IMAGE-WARP procedure

- Locating the image maxima in the original STEM image
- Applying a scaled structure model reconstructed by QHRTEM from same region.
- Polynomial warping of the corresponding STEM image maxima to scaled structure model.

A. Rečnik et al, Ultramicroscopy, 103, 2005, 285-301
7. Specimens for STEM/TEM observation

Criteria of sample quality:

- Uniform specimen thickness
- Low surface roughness
- Thin/no amorphous surface layers
- Minimum re-deposition during ion-milling
- No preferential thinning
- Minimum ion implantation
- No contamination (STEM!!)

Real specimen

amorphous layer, “contaminatin layer

Ideal specimen

crystalline part
(a) High-energy ion-milled CaTiO$_3$ specimen with a surface amorphous layer and surface damage. (b) The same Low-energy ion-milled specimen.
1. STEM Basics
2. Experimental STEM
3. Interpretation of STEM Images
4. Case Studies
1. Qualitative interpretation of HAADF-STEM images

- STEM transfer function has no reversals
- Qualitative interpretation of HAADF-STEM images is therefore relatively straightforward.

STEM transfer function for 200 kV, Scherzer defocus $\Delta f = -45$ nm, $Cs = 0.5$ mm and objective aperture size 20 mrad.

- The intensity of atom columns in HAADF-STEM imaging depends on the average atomic number $Z$ of individual atom columns (proportional app. to $Z^{1.7}$)
2. Quantitative HAADF-STEM

Quantitative Image interpretation requires comparison of experimental data with simulations.

**Incoherent Imaging Model:** The Image is the convolution of object potential and probe intensity (Bloch wave approach).

\[ I_{\text{image}}(\vec{r}) = I_{\text{probe}}(\vec{r}) \otimes V_{\text{proj}}^2(\vec{r}) \]

**Multiple Scattering Image Simulation:** Quantitative agreement between simulation and experiment. For each beam position a complete multislice dynamical scattering simulation is performed, applying the frozen phonon approximation.

Note: The HAADF-STEM signal consists to a large part of thermal diffuse scattering (TDS). It is therefore essential for quantitative simulations to include TDS.
Diffraction pattern is computed for each pixel position using the Multislice algorithm.

Only part of detector is shown in DP to see its size.
Software for STEM image calculations

CD-ROM: win32exe, macPPC, mfiles, csource

2. T. Yamazaki

3. K. Ishizuka: WinHREM™/MacHREM™
Website: www.hremresearch.com

4. K. Koch: QSTEM
website: http://elim.physik.uni-ulm.de/?page_id=834

5. V.Grillo: STEM_CELL
Ref: Grillo V, A novel method for focus assessment in atomic resolution STEM HAADF experiments, Ultramicroscopy, 106 (7), 2006, 603-613
http://tem-s3.nano.cnr.it/stemcell.htm

Sr/Ti-O intensity ratios range from 2.1 to 2.5 (app. 15% variation). The major contribution to the observed variation is due to different reported Debye-Waller factors.

Comparison of different calculation procedures

Calculated HAADF images for the [001] SrTiO$_3$ zone axis for thicknesses 10, 30, 50 and 70 nm, and for defocus values -25 nm, and -45 nm).
The \( \frac{((\text{Sr/Ti})\text{W}-(\text{Sr/Ti})\text{K})}{(\text{Sr/Ti})\text{W}} \) relative ratio as a function of defocus value.
1. STEM Basics
2. Experimental STEM
3. Interpretation of STEM Images
4. Case Studies
1. Al-doped ZnO thin films

**Motivation:** ZnO thin films-photonic devices (3.37 eV)

**Objective:** Basic microstructural examination

Preparation of ZnO thin films:
- MBE (molecular beam epitaxy)
- MOCVD (metalo-organic CVD)
- PLD (pulsed laser deposition)
- ALD (atomic layer deposition)

Total 1500 cycles

- 49 cycle of each
- 1 cycle of each

Atomic layer deposition (ALD) of heavily Al-doped ZnO thin films. ALD for the Zn:Al (2%) film is indicated.
Bright-field (BF) and (b) high-angle dark-field (HAADF) STEM images of ZnO:Al(2 %)
2. Strained AlGaN/GaN superlattice

**Motivation:** GaN based violet laser diodes (data storage devices)

**Objective:** SLS layer thickness determination
Experimental bright-field STEM image of $n$-Al$_{0.14}$Ga$_{0.86}$N/$n$-GaN SLS cladding layer and $n$-GaN:Si layer on the sapphire substrate.
Simulated HAADF-STEM images of GaN and Al_{0.14}Ga_{0.86}N. The difference in the absolute intensities between the two compositions is clearly observable.

Experimental HAADF-STEM image of the SLS region. The bright and dark layers correspond to GaN and Al_{0.14}Ga_{0.86}N, respectively.
(a) Experimental HAADF-STEM image of the SLS cladding layer. About 200 couples of $\text{Al}_{0.14}\text{Ga}_{0.86}\text{N}$ (dark bands) and GaN layers (bright bands).
(b) BF-STEM image of the same area. Dislocations are visible in strong diffraction contrast.
Average filtering of the experimental HAADF-STEM image of the SLS. (a) Low-pass mask filter is applied to the original image. (b) Low-frequency HAADF-STEM image. (c) The normalized HAADF-STEM image and (d) average filtered normalized HAADF-STEM image. The thickness of the layers was determined according to the FWHM criterion in the line profile.
The thickness of GaN and Al$_{0.14}$Ga$_{0.86}$N layers is:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>Atomic Planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaN</td>
<td>2.34 ± 0.15 nm</td>
<td>9 planes</td>
</tr>
<tr>
<td>Al$<em>{0.14}$Ga$</em>{0.86}$N</td>
<td>2.24 ± 0.09 nm</td>
<td>9 planes</td>
</tr>
</tbody>
</table>

3. KTiO$_2$(OH) channel structures

**Motivation:** Catalysis

**Objective:** Pottasium occupancy within channels

Experimental and processed HAADF-STEM image of KTiO$_2$(OH) showing even distribution of K atoms in channels. [0001] zone axis.
4. CaTiO$_3$

**Motivation:** Dielectric

**Objective:** Model material to show sensitivity of STEM on small variations in the structure

Perovskite structure: CaTiO$_3$ has distorted perovskite structure with small Z difference between Ti-O and Ca atom columns (Ti-O/Ca=1.17).
Defocus-thickness map

[110]_{CT}  

[001]_{CT}  

thickness

0  defocus  45  0  defocus  45
\[ \text{Ti-O/Ca}=1.27 \pm 0.12 \]  
\[ \text{Ti-O/Ca}=1.94 \pm 0.14 \]  
\[ \text{(Ti-O/Ca}=1.20) \]  
\[ \text{(Ti-O/Ca}=2.02) \]
5. La(Ti,Mg)O₃- CaTiO₃ solid solutions

Motivation: Microwave ceramics (ε=46, Tf=0, Q>20k)
Objective: Solid solution homogeneity determination

LTM is isostructural with CaTiO₃. La and Ca on A-sites and Ti and Mg on B-sites are not ordered. Experimental images were taken from thick part of the specimen, i.e. > 50nm. [001]ₚ zone axis.
In thin regions differences in intensities are observed, which can not be attributed to the surface effects.

Different intensities correspond to varying occupancy of La and Ca on A sites and Ti and Mg on B sites.

No average filters can be used!
6. $\text{In}_2\text{O}_3$-doped ZnO

**Motivation:** Thermoelectrics

**Objective:** Analysis of inversion boundaries

- Modulated structure $(\text{ZnO})_k \text{In}_2\text{O}_3$
- Phase dependency on the local $\text{In}_2\text{O}_3$ concentration

$$d = k + 1$$
HRTEM of IB’s
HAADF of IB’s

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HAADF vs ADF

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JSI Colloquium, November 27, 2013
EDXS

ARM 200F, Sunum, Sabanci University

miran.ceh@ijs.si
EDXS line profile
7. SrO,Nb₂O₅-doped SrTiO₃ thermoelectrics

**Motivation:** Thermoelectrics

**Objective:** Analysis of RP faults, Nb distribution

![Graph showing ZT as a function of Nb content](image)


The planar faults are expected to block the phonon transport without disturbing the electrical conductivity → better ZT
Two Sr(Ti,Nb)O$_3$ grains. The left grain has coherently intergrown Sr$_3$(Ti,Nb)$_2$O$_7$ polytypic phase.
Single SrO planar faults running along low index planes of the Sr(Ti,Nb)O$_3$ perovskite structure.
HRTEM of RP faults

ARM 200F, Sunum, Sabanci University
HRSTEM of RP faults

ARM 200F, Sunum, Sabanci University

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Case Studies

Nanostructured Materials
Center for Electron Microscopy

Case Studies

ARM 200F, Sunum, Sabanci University

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JSI Colloquium, November 27, 2013
Case Studies

Nanostructured Materials
Center for Electron Microscopy

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8. Sr-hexaaluminate

Motivation: Phosphorescence materials
Objective: Oxygen detection

Experimental HAADF

Calculated HAADF

1 nm
ABF

EXPERIMENTAL

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ABF

NOISE FILTERED
Conclusions

- STEM imaging (HAADF, ADF, ABF) readily provides qualitative information on chemical composition on nano and atomic scale.

- ABF STEM enables viewing light elements.

- Image simulation are imperative for quantitative interpretation. However, for quantitative interpretation of STEM images the exact structure and microscope parameters should be known.

- The sample preparation is crucial for acquiring (any) high quality experimental STEM images.
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