Combined transmission and reflection optical microscopy of ice core sections

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Motivation

- Two different microscopy techniques are applied to analyze alpine/polar ice cores.
- Both image types are processed and matched automatically.
- Which additional information is obtained?

Overview: Microscopy techniques and processing

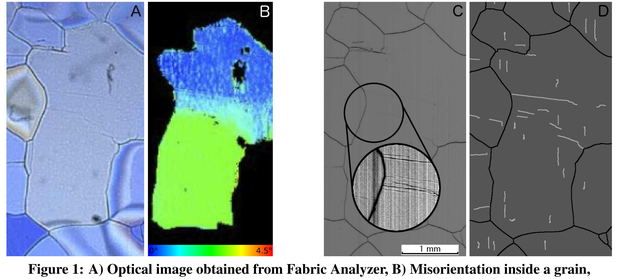

Figure 1: A) Optical image obtained from Fabric Analyzer, B) Misorientation inside a grain, C) Sublimation groove image, D) Extracted (sub-) grain boundaries (polar NEEM core, 1800 m)

Transmission microscopy/Fabric Analyzer	Reflection microscopy of sublimation grooves
• Thin sections (300-500 μm) required	• Suitable for thin or thick sections • Controlled sublimation (1-10 hours)
• 6 x 9 cm^2 section mapped at 20 μm resolution in 45-60 minutes	• 6 x 9 cm^2 section mapped at 5 μm resolution in 4-5 seconds
• Orientation of c-axes acquired	• High resolution properties of grain boundaries acquired (length, shape, curvature)
• Automatic extraction of grain boundaries • Extraction of sub-grain structures complicated by different color/brightness	• Automatic extraction of grain boundaries • Automatic extraction of sub-grain boundaries (See: T. Binder et al., 2013, J. Microsc., in press)

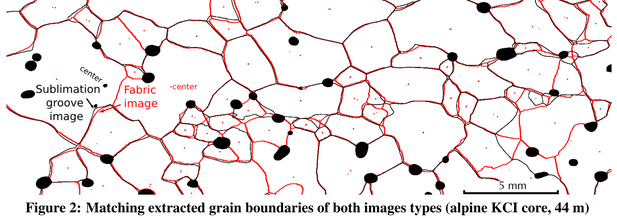

Figure 2: Matching extracted grain boundaries of both images types (alpine KCI core, 44 m)

Automatic matching

Even an "optimal" matching shows displacements between corresponding grains as the Fabric Analyzer (**FA**) records volume information and sublimation grooves occur on the surface. The scanner used is denoted as **LASM** (Large Area Scanning Macroscope) in the following. A global affine transformation is applied to transform coordinates:

$$T : \vec{x}_{\mathrm{FA}} \mapsto \vec{x}_{\mathrm{LASM}} \qquad \vec{x}_{\mathrm{LASM}} = T\left(\vec{x}_{\mathrm{FA}}\right) = A \cdot \vec{x}_{\mathrm{FA}} + \vec{x}_{\mathrm{offset}} \tag{1}$$

with transformation matrix $A \in \mathbb{Z}^2 \otimes \mathbb{Z}^2$ and a constant $\vec{x}_{\mathrm{offset}} \in \mathbb{Z}^2$ representing global displacement.

The six parameters of (1) are derived by Least Squares Fitting to typically 100-200 grain pairs.

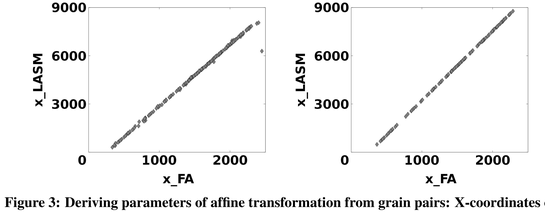

Figure 3: Deriving parameters of affine transformation from grain pairs: X-coordinates of corresponding center of mass points. Left: raw data. Right: RANSAC cleaned data

The topological characteristics (number and size of neighbors) are utilized to detect high probable pairs and to build up a network. Only validated grain pairs are considered for the parameter fit.

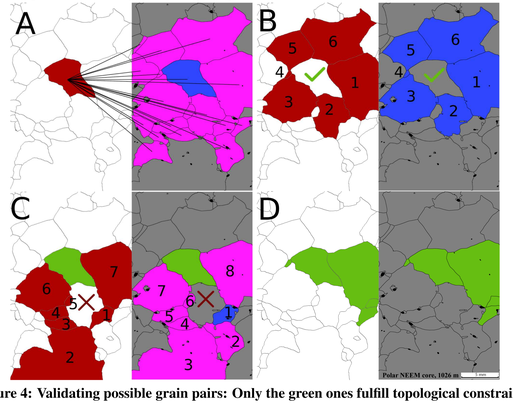

Figure 4: Validating possible grain pairs: Only the green ones fulfill topological constrains.

Displacement of grains

In Fig. 2 center of mass positions are shown as dots. For validated grain pairs the vector in between represents the displacement which should vanish when averaging over the whole image.

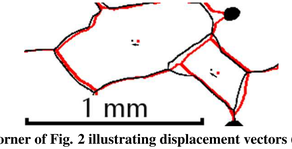

Figure 5: Upper left corner of Fig. 2 illustrating displacement vectors (alpine KCI core, 44 m)

Interestingly, the scattering of displacement vectors varies from image to image even if the way of processing the ice core section is very similar. The mean displacement of FA grain center of mass points with respect to the LASM grain center of mass points has been calculated (in pixel corresp. 5μm) for KCI, 44 m depth: $\begin{pmatrix} 2.08 \\ -1.15 \end{pmatrix} \pm \begin{pmatrix} 16.12 \\ 9.65 \end{pmatrix}$ and for KCI, 58 m depth: $\begin{pmatrix} -7.50 \\ 0.75 \end{pmatrix} \pm \begin{pmatrix} 30.35 \\ 33.92 \end{pmatrix}$.

Identification of sub-grain boundaries

In ice sub-grains are defined as regions with a misorientation smaller than 5°. For a reliable identification, information on the orientation of c- and a-axes is required. The distribution of c-axes can be measured by the Fabric Analyzer, whereas the characterization of sublimation grooves as boundaries of sub-grains resp. grains is more difficult. By matching both image types misorientation estimates are assigned to sublimation grooves.

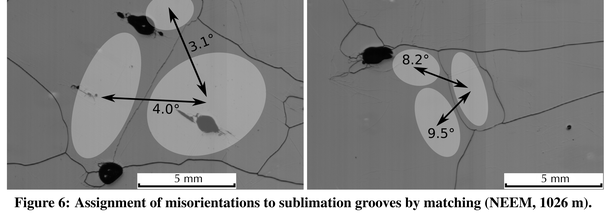

Figure 6: Assignment of misorientations to sublimation grooves by matching (NEEM, 1026 m).

Gray values in sublimation groove images

In reflection microscopy of sublimation grooves gray values are influenced by

1. Duration of surface sublimation
2. Camera configuration (focus, illumination)
3. Energy/misorientation of the grain boundary

On the basis of matched large data sets the different influences can be estimated.
If the first two influences are well defined or minimized, it will be possible to derive a relation between gray value and estimated misorientation.

To analyze how the mean gray values of grain boundaries change during sublimation a series of reflection images is taken from a polished surface. As the temperature is below -30°C in the present case and the humidity is relatively high the sublimation process takes much longer than in a dry cold room at -20°C. It is observed that the distribution of mean gray values of grain boundaries becomes wider but stays unimodal.

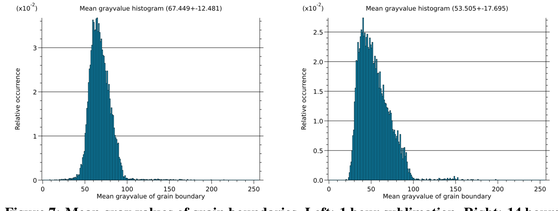

Figure 7: Mean gray values of grain boundaries. Left: 1 hour sublimation. Right: 14 hours sublimation (polar B40 core, 76 m)

The influence of gray values on the camera configuration is larger than on the duration of sublimation.

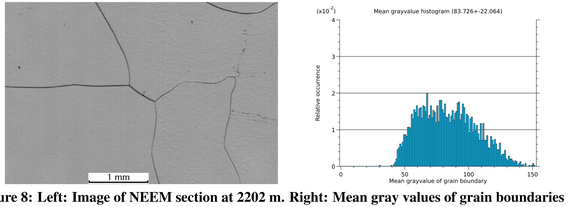

Figure 8: Left: Image of NEEM section at 2202 m. Right: Mean gray values of grain boundaries

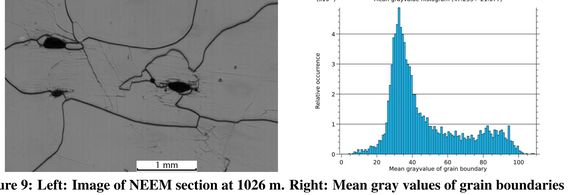

Figure 9: Left: Image of NEEM section at 1026 m. Right: Mean gray values of grain boundaries

Summary

- Matched grain boundary networks contain grain displacements with different scattering.
- Misorientation estimates can be assigned to sublimation grooves.
- Different dependencies of the gray value of mapped sublimation grooves are estimated.