Electron Channeling Contrast Imaging Performed by ZEISS GeminiSEM 500
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Electron channeling contrast imaging (ECCI) is a technique for quantitative characterization of deformation structures in scanning electron microscopy (SEM). Relative orientation of crystalline lattice and incident electron beam influence back scattered electrons (BSE). ECCI makes use of this. ECCI in SEM is especially useful for imaging crystallographic defects such as dislocations, stacking faults and twin boundaries and thus starts to have an impact on materials science.

Introduction

The BSE yield of crystalline samples depends on the relative orientation of the electron beam to the crystalline lattice [1]. In particular when the incident electron beam fulfils the Bragg condition with respect to the lattice, the backscattered electron yield will have an abrupt change (Fig. 1a). This variation of signal can be used to qualitatively distinguish materials with different crystalline orientations.

A particularly interesting feature of channeling contrast is that the BSE yield has a very large change around the Bragg condition. Even small changes in crystallographic direction can be detected when the electron beam and the sample are aligned to fulfil the Bragg condition. The distorted lattice around the defects in crystalline materials can thus be imaged. An example for a dislocation is shown where an extra half-plane of atoms is introduced (Fig. 1b).

This extra atomic plan causes local distortion of the crystalline lattice, which can be detected due to the large variation of BSE yield around the Bragg condition.

Electron channeling contrast imaging of crystalline defects

In order to effectively image defects in material using ECCI, it is important to adjust the orientation of the sample such that the Bragg condition is fulfilled for the incident electron beam. This condition can be achieved when imaging a single crystalline sample where the orientation of the sample can be readily determined.

Epitaxial GaN thin film is imaged using ECCI. The GaN thin film is grown by molecular chemical vapor deposition...
(MOCVD) along the [0001] direction of single crystalline sapphire substrate. Because of the lattice mismatch between sapphire and GaN, various kinds of dislocations are produced [2]. When scanning across the sample in low magnification, the incident angle of the electron beam with respect to crystalline direction changes continuously. The obtained signal variation is called electron channeling pattern (ECP) (Fig. 2a). The lines across the ECP indicate where the Bragg condition is fulfilled. By tilting and rotating the sample, the center of the ECP is brought to coincide with the line patterns. Two different Bragg conditions are selected by tilting the sample to 4.5° and 7.1° (Fig. 2b-c).

The point-like features in the image indicate the presence of dislocations where the lattice distortion around the dislocation is manifested as a dipole shape contrast variation around the dislocation points [3] (Fig. 3).

**Figure 2:** Principle of electron channeling pattern (ECP) obtained by scanning across a large area on a single crystalline sample (a) and ECP obtained on epitaxial GaN thin film with 4.5° tilt (b) and 7.1° tilt (c). The red circles indicate the center of the image.

**Figure 3:** Channeling contrast imaging of dislocations on epitaxial GaN thin film. The sample is imaged at 30 kV electron beam energy and tilted by 4.5° (a) and 7.1° (b).
In polycrystalline material, the grain size is usually at the micrometer range and is too small to be obtained by ECP. However, due to its random crystalline orientation, some grains will always match a certain diffraction condition. This can be observed as particularly bright or dark grains in the BSE image. An example is demonstrated on a highly deformed stainless steel sample. Multiple grains of several micrometers in size, as well as a strong contrast variation within each grain can be observed.

The deformation results in strong crystalline orientation changes within the grains (Fig. 4a). Higher magnifications reveal the dislocation networks formed by the deformation (Fig. 4b) as well as by individual dislocation points and lines (Fig. 4c-d).

Optimizing channeling contrast imaging condition
The amount of channeling contrast is influenced by the properties of the incident electron beam and the detector. An increase of primary electron energy decreases the channeling contrast and simultaneously increases the penetration depth of the electron \(^{10}\). This avoids multiple scattering from surface layers and facilitates the obtaining of channeling contrast. Thus, there is an optimum electron energy, which depends on the material and its thickness. Under normal SEM working conditions, higher electron beam energy usually leads to better channeling contrast. The effect of increase in electron beam energy on channeling contrast is demonstrated on a gold thin film on carbon (Fig. 5). At 5 kV and at 10 kV beam energy most of the contrast is due to surface topography. The strongest channeling contrast is observed at 30 kV.
Figure 5: Influence of electron beam energy to the channeling contrast. The gold islands on carbon substrate are imaged at 5 kV (a), 10 kV (b), 20 kV (c) and 30 kV (d) beam energy.

The channeling contrast will also increase with decreasing take-off angle. This effect is demonstrated by changing the working distance of the sample (Fig. 6).
Smaller working distance places the sample closer to the annular BSE detector under the pole piece, leading to a smaller take-off angle. The image taken at the smallest working distance used here shows the strongest channeling contrast. However, BSE with low take-off angle also enhances the topographic contrast, which can be seen as a strong signal variation around the edges of the gold islands. A sample suitable for channeling contrast imaging needs to be flat and ideally have a polished surface to reduce topographic contrast.

**Summary**

- Strongest channeling contrast is observed when orientation of the incident electron and the crystalline lattice fulfil the Bragg condition.
- Lattice defects such as dislocations can be observed by channeling contrast.
- Higher electron beam energy and lower working distance are suitable for getting good results in channeling contrast.
- Ideally the sample should have a polished surface.

**Figure 6:** Influence of BSE angle to the channeling contrast. The gold islands on carbon substrate is imaged at 30 kV beam energy. The working distances vary from 4 mm to 13 mm: 4 mm, image with the strongest channeling contrast (a), 7 mm (b), 10 mm (c), 13 mm (d).

**References:**


