Fast Determination of the Thickness of Electron-Transparent Specimens Using Quantitative STEM-in-SEM and Monte-Carlo Simulations

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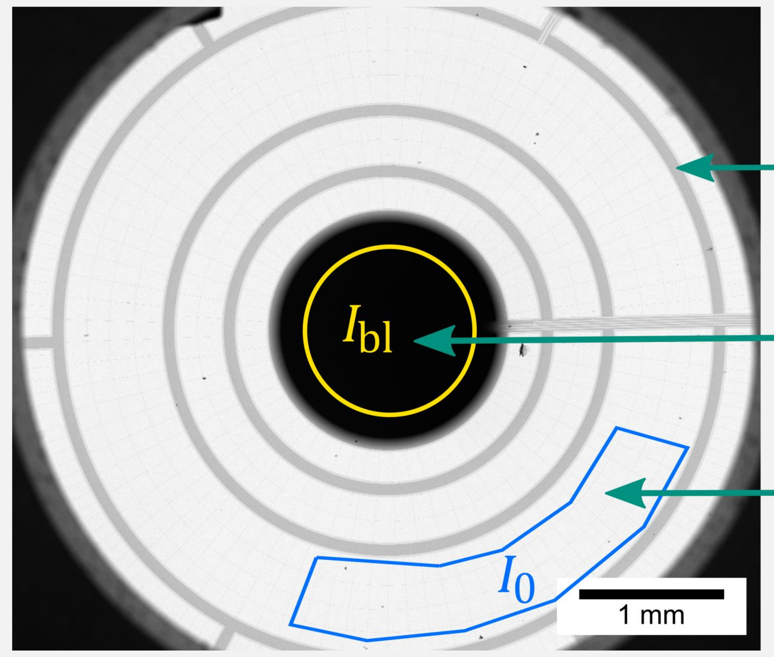
Thickness Determination: Overview

- Available techniques: e.g. EELS/EFTEM [Zha], CBED [Wil], thickness contours [Wil]
  - Drawbacks: limited accuracy, time consumption, limited to small sample regions, energy filter or crystalline sample needed
- Alternative solution: thickness determination using STEM-in-SEM combined with Monte-Carlo simulations [Vol, Čal]
  - Advantages: high precision (uncertainty of thicknesses ~7%), no further costly equipment is needed, fast, covers large regions
  - Requirements: STEM detector in scanning electron microscope , knowledge of composition and material density of the specimen

Step 1: Determination of Detector-Specific Properties

- Inner and outer radii of the active segments → investigated scattering-angle range
- Images taken with HAADF STEM; BF STEM yields less reliable results
- Contrast and brightness settings to avoid under- and oversaturation
- Measurement of the intensity in active and inactive detector areas (I_0 , I_{bl})



less sensitive area (e.g. contact lines) = 3% of the total area → geometrical correction factor c=0.97

inactive area ~ black level intensity (I_{bl})

active area ~ intensity of the primary electron beam (I_0)

Image of the STEM detector obtained by scanning the detector, adapted from [Hug]

Step 2: Calculation of the Normalized HAADF-STEM Intensity

- I_{exp} = measured HAADF-STEM intensity of a sample region
- Normalization of I_{exp} with respect to I_0 and I_{bl}

$$I_{nor} = \frac{I_{exp} - I_{bl}}{c \cdot I_0 - I_{bl}} \quad (0 \le I_{nor} \le 1)$$

- Next step: comparison of normalized image intensities with data obtained by Monte-Carlo simulations

Summary

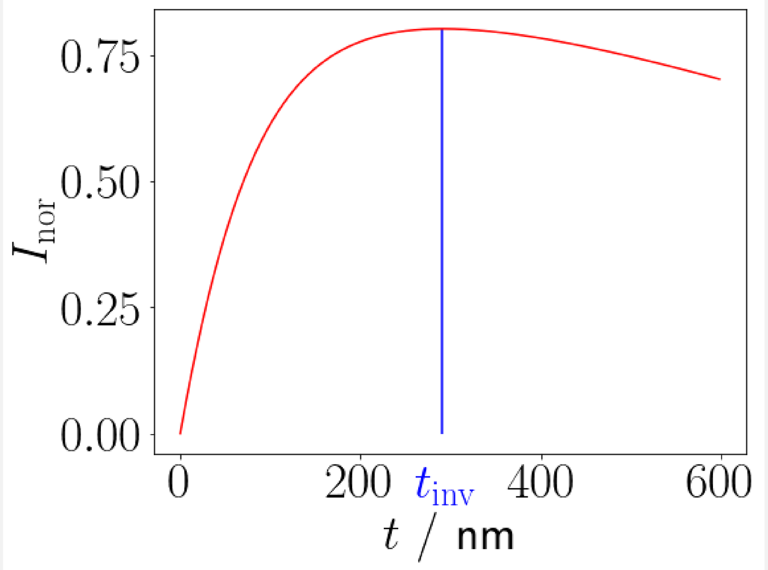
✓ Determination of local sample thickness by STEM-in-SEM

✓ 3-step workflow:

- Determination of detector-specific properties
- Normalization of measured HAADF-STEM intensities
- Comparison with detector-specific Monte-Carlo simulations

Step 3: Comparison with Monte-Carlo Simulations

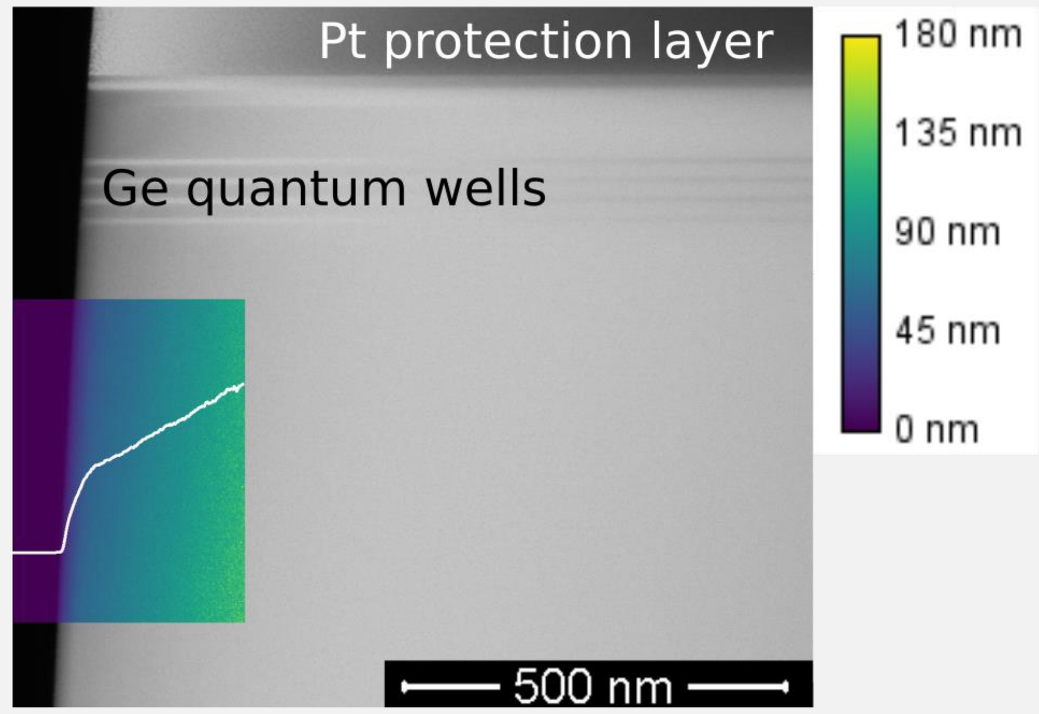
- Calculate I_{nor} for scattering-angle range of detector segment as a function of sample thickness t (modified NISTMonte 1.2 [Rit])
- Input parameters: geometrical set-up of the detector, composition and density of the material, electron energy
- Normalize calculated count number with total count number
- Compare measured and simulated I_{nor}
- Accuracy of the input parameters determines simulation accuracy
- Limitation: $t < t_{inv}$ (inversion point)



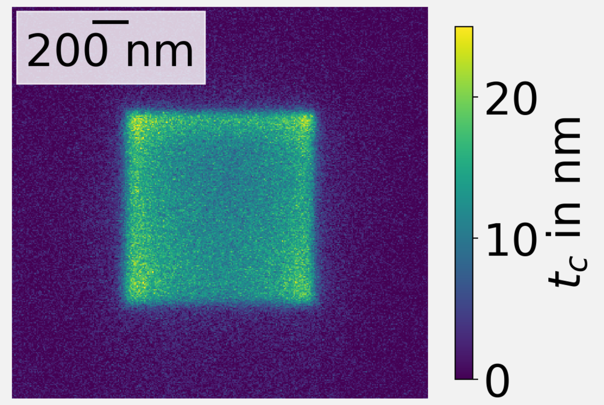
Monte-Carlo simulations of I_{nor} at 30 keV as a function of thickness for Si

Application Examples

- Wedge-shaped TEM sample of Si
- Color-coded inset is a thickness map



- Determination of contamination thickness (square patches) on an amorphous carbon film



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MC 2021 – August 2021

Deutsche Forschungsgemeinschaft

Excellence Strategy, EXC 2082/1 – 390761711

3D MATTER MADE TO ORDER