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Measuring the Thickness of Contamination Layers in Scanning Electron Microscopy Using Image Processing

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Abstract
This work focuses on enhancing the accuracy of SEM (Scanning Electron Microscopy) imaging through precise measurement and analysis of contamination layers. Advanced image processing techniques, notably Edge Detection and DeepLabv3, are utilized to achieve accurate quantification of contamination layers. Improved methods for SEM contamination measurement are validated through comparative studies, demonstrating enhanced accuracy over conventional techniques. The result is clearer and more reliable SEM imaging, significantly improving material characterization in scientific research.

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1. Introduction

Motivation The motivation for this thesis arises from Thermo Fisher Scientific's commitment to advancing the technology used in scanning electron microscopy (SEM). The company aims to develop an automated method to measure the thickness of contamination layers on specimens analyzed via SEM, which is expected to be more practical and user-friendly compared to existing manual methods. Currently, there is no automatic tool available that can perform this task, which presents a significant limitation in the field of material science. Accurate and efficient measurement of contamination is crucial as it impacts the quality of the SEM images and consequently the reliability of material characterization and analysis. This research seeks to address these challenges by developing a new automated measurement technique, enhancing the capabilities of SEM technologies in scientific research and industrial applications.

Problem Definition The main challenge addressed in this research is the development of a reliable automated method to measure the thickness of contamination layers using image processing techniques. Current methods often require manual intervention, which can be time-consuming and subject to human error. Moreover, the complexity of the task is heightened by the inconsistency in the contamination images; SEM images from various samples may display a broad spectrum of contamination features, such as varying thicknesses, densities, and even visual aspects, depending on the substance and the environmental conditions during the process of sample preparation and examination. This diversity demands robust image processing algorithms capable of accurately distinguishing and measuring contamination across varied images without loss of detail or accuracy.

Existing Solutions

Recent advancements in SEM image analysis have led to several innovative computational approaches for feature measurement. Notably, Kutálek's algorithm for cut-face edge detection[1], introduced in 2023, presents a methodological evolution by converting SEM images into a one-dimensional vector to enhance edge detection accuracy. This algorithm stands out for its simplicity and effectiveness in material boundary detection. Another significant development is the application of transfer learning with DeepLabv3[2] for image segmentation, demonstrated by Manpreet Singh Minhas[3]. This approach leverages a pre-trained model to address the challenge of limited data availability, showcasing the potential of transfer learning in precise segmentation tasks.

Our Solution

Our solution presents a pioneering Edge Detection-Based Contamination Analyzer (EDCA) specifically for SEM imagery. This approach incorporates comprehensive preprocessing techniques and utilizes the Scharr operator to establish regions of interest (ROI). Through the use of gradient analysis and vertical profiling, we precisely identify both the upper and lower boundaries of contamination layers. A critical aspect of this process is determining the starting point from a vertical profile at the contamination's central column, which sets the initial point for detecting the top and bottom boundaries based on the first derivative of the vertical line profile. Additionally, we implement a DeepLabv3-based approach for segmenting contamination layers. Originally pre-trained across various datasets, this model is meticulously fine-tuned to enhance its segmentation capabilities for SEM images, effectively differentiating between contaminated and uncontaminated regions. We further optimize the model by adjusting its learning rate and loss function to suit our specific binary classification task, ensuring robust learning and consistent performance across new and unseen SEM images.

Contributions

This thesis presents transformative methodologies that set new benchmarks in SEM image analysis for accuracy and efficiency. The introduction of the Edge Detection-Based Contamination Analyzer (EDCA) along with the strategic fine-tuning of the DeepLabv3 model for contamination detection represents a major leap forward in the field. Our integrated solution enhances the resolution and clarity of SEM images and significantly reduces the potential for human error in contamination assessment. These methodological innovations extend their impact beyond academic research, accelerating R&D cycles in material science, improving quality control in manufacturings. The precise quantification of contamination made possible by our approach not only advances our understanding of material properties but also fosters significant technological advancements in nanotechnology and materials engineering. By pushing the boundaries of computational image analysis, our research addresses critical challenges and paves the way for future advancements in SEM image processing, making a pivotal contribution to both academic and industrial applications.

2. Experimental Results

The dataset comprises 658 images, nearly half of which are uncontaminated. For model fine-tuning, three distinct datasets were utilized: one with 341 contaminated images, a second comprising both contaminated and uncontaminated images, and a third augmented dataset created from the first. In this augmented dataset, each image was replicated 10 times, with careful adjustment of perpendicular lines, as these remain unchanged in the originals. This third dataset serves as a comparative baseline, since training datasets cannot be directly used for comparison.

The poster displays a comparison of models against ground truth masks using Intersection over Union (IoU) to assess model precision, showing slightly superior results for the model fine-tuned on augmented images. Below this, the Automation Mask Threshold Finder is featured, which aids in setting a probability map threshold to selectively exclude non-contaminated parts. The optimal threshold value, showing minimal error at approximately 0.419, is determined for the model trained on the augmented dataset. Additionally, the poster includes an error measurement for accuracy comparison between the first and second proposed methods.

3. Conclusions

Our comparative analysis between the Edge Detection-Based Contamination Analyzer (EDCA) and the fine-tuned DeepLabv3 model reveals that the fine-tuned model offers superior accuracy and adaptability for SEM image analysis. The finetuned model excels in handling complex contamination patterns and diverse datasets, demonstrating its potential as a robust tool for advanced material analysis.

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References

[1] Jiří Kutálek. Measuring the thickness of material layers removed from a sample in an electron microscope. Master's thesis, Brno University of Technology, Brno, 2023.

[2] Liang-Chieh Chen, George Papandreou, Florian Schroff, and Hartwig Adam. Rethinking atrous convolution for semantic image segmentation. 2017.

[3] Manpreet Singh Minhas. Transfer learning for segmentation using deeplabv3 in pytorch. blogpost,

Dec 2020. Towards Data Science, 11 min read,
Last accessed: 2024-04-10.