

Real-time Diagnostic Tools for the Scanning Electron Microscope

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1 Introduction

1.1 Project Objectives

The scanning electron microscope (SEM) is a type of microscope that produces images using signals generated from the interaction between electrons and the surface under observation. Higher resolution can be achieved compared to the traditional optical microscope, since electrons have much lower wavelength than light. An SEM can have resolution lower than one nanometre, whereas that of an optical microscope is often limited to a few hundred nanometres [4]. This has benefited a variety of fields. For example, scientists have been using the SEM to analyse the doping density in semiconductor [2]. The goal of the project is to develop software tools in Python to support diagnosis of SEM images for the purpose of assisting the operator or automating procedures.

1.2 Theory of the SEM

Figure 1 shows the basic construction of an SEM. The electron gun generates an electron beam, which is transformed into an electron probe after passing through the condenser lens and objective lens. It is scanned across the specimen under the effect of the scanning coil. As a result of the interaction between the incident electrons and the specimen, some electrons are emitted from the specimen. These are called secondary electrons and are collected by the detector, which generates signals whose magnitude depend on the strength of the secondary electrons. The display unit produces one frame after each complete scan of the specimen.

1.3 How Fast Computing Can Aid SEM Operators

The quality of an SEM image is affected by aberrations. While some exist because of the fundamental properties of the microscope and are difficult to get rid of, some can be completely eliminated by adjusting relevant settings. Two important ones are focus and stigmation, which directly affect the resolution and astigmatism of the image, respectively. Figure 3 illustrates the effect of wrong focus and stigmation settings.

Focus determines the focal point of the electron probe. When the focal point is far from the surface of the specimen, the incident electrons interact with the specimen in a larger area. As a result, spots near each other produce signals of closer magnitude. This makes the image appear blurry, as shown in Figure 3b.

Stigmation controls stigmators in the SEM, which are used to compensate for astigmatism. Astigmatism arises due to imperfections in components of the SEM, and describes uneven focus in the electron probe, as shown in Figure 2. When the electron probe is out of focus, astigmatism makes the incident electrons interact with the specimen in an elliptical area, and thus makes the image appear stretched. When the electron probe is in focus, astigmatism makes the image appear blurry. Figure 4 gives some examples of distorted images.

Although experienced SEM operators can often find the right settings for focus and stigmation in a short time, it may not be as straightforward for new users. Sometimes, the surface being observed may have a complex structure and makes adjusting even harder. The complexity arises because any judgement of an image is based on what the operators see through their eyes, which is rather subjective. Intensive training and practical experience are often required for an operator to become efficient in using the SEM.

Fast computing can aid the operators in a few ways. Firstly, a numerical evaluation of the quality of the image may be provided, which eliminates the subjectivity in using human eyes. Numbers are also easier to note down if any record is required. Two operators may have different views on the same image, but the numbers will not be different. Therefore, cooperation and communication between operators can be enhanced. The use of numbers also enable automatic procedures for adjusting settings of the SEM, which save time and may produce better results than doing it manually.

The project focuses on developing tools that use Fast Fourier Transform (FFT) to help operators evaluate the focusing and astigmatism of SEM images, and also looks into an algorithm for the automatic correction of them.

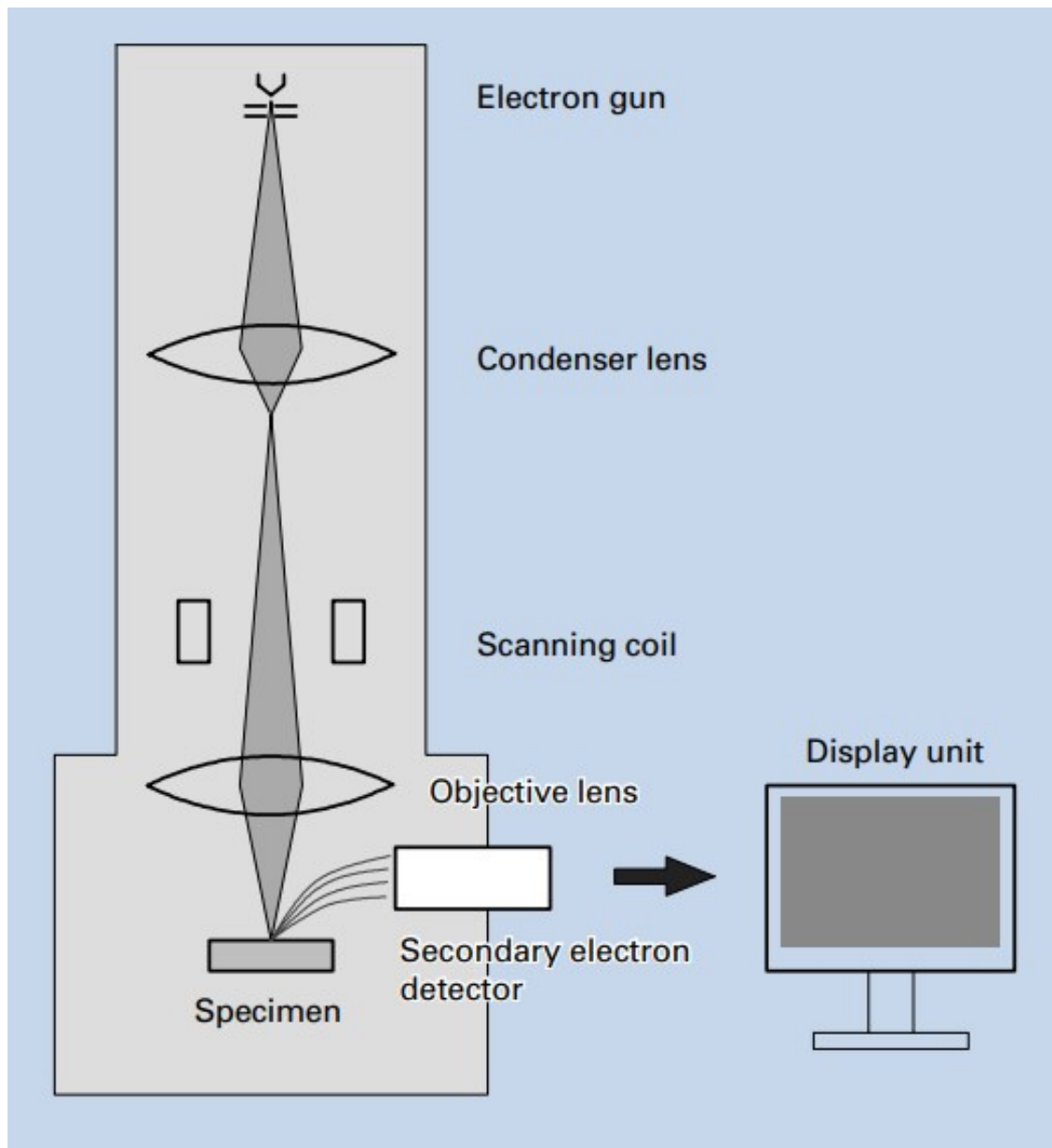


Figure 1: Basic construction of an SEM [1]

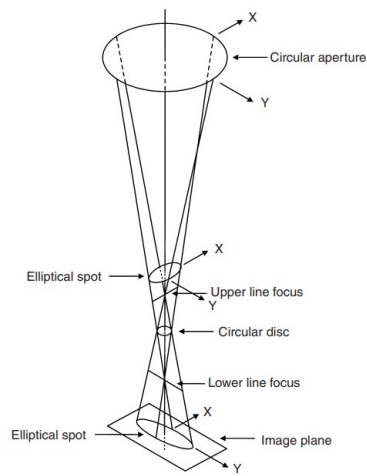
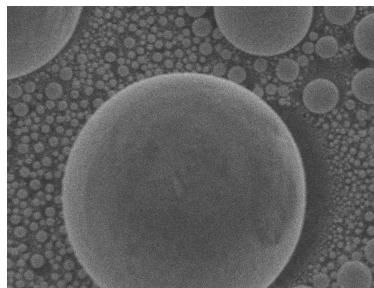
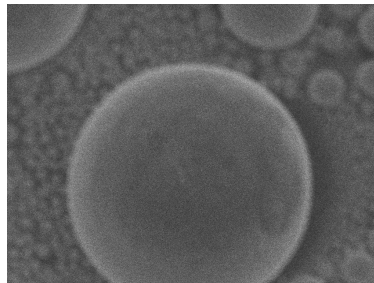


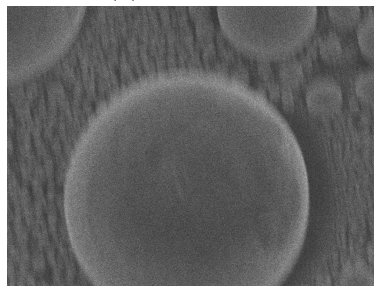
Figure 2: Uneven focus of the SEM



(a) In focus

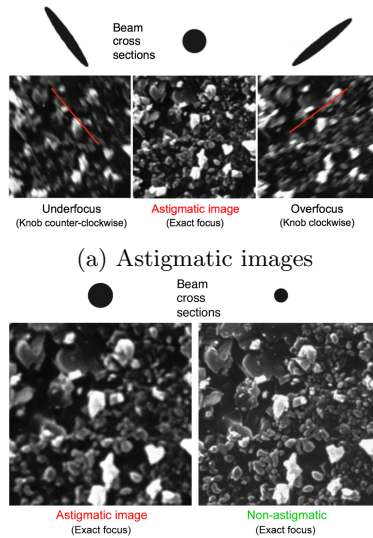


(b) Out of focus



(c) In focus with astigmatism

Figure 3: Sample SEM images



(b) Astigmatic and non-astigmatic image

Figure 4: Sample astigmatic SEM images [5]

2 The Algorithms

2.1 Histogram Equalisation

The idea of histogram. The maths of histogram. Demonstration of the algorithm. Speed test of the algorithm.

2.2 Fast Fourier Transform

Idea of FT. Maths of FFT. Demonstration. Speed test.

2.3 Focusing and Astigmatism Correction

Idea. Algorithm and flow chart. Demonstration of current result. Next step.

3 The Software

3.1 Overview

Overview of all modules.

3.2 The SemImage Module

Idea of the module. Classes and functions. Demo code. Possible improvements.

3.3 The SemTool Module

Idea of the module. Classes and functions. Demo code. Possible improvements.

3.4 The SemCorrector Module

Idea of the module. Classes and functions. Demo code. Possible improvements.

4 Demonstrations

4.1 Real-time Histogram Equalisation

Screenshots of the software.

4.2 Real-time Fast Fourier Transform

Screenshots of the software.

4.3 Automatic Focusing and Astigmatism Correction

Screenshots of the software. Test results.

5 Next Steps

Next steps.

References

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