The Refurbishment of a STEM

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I.

Abstract

Houghton College is refurbishing a Jeol JEM CX-100 Scanning Transmission Electron Microscope (STEM) for the study of thin metal films. The STEM is capable of SEM, TEM, XRD, electron diffraction, and backscattered electron microscopy, up to 800,000X magnification. A computer program will be developed to read the x and y raster and create and manipulate digital images. To date, most of the work has been invested in restoring the vacuum system and aligning the electron beam.

Motivation

An electron microscope has applications in physics, biology, and chemistry. It is useful for studying thin metal films. This particular microscope has several different imaging settings for different functions and specimens. The topography of thin metal films can be viewed and studied using backscattered electrons and SEM. TEM is useful for studying microstructures, such as grains, grain boundaries, and interfaces. The image capturing techniques are now outdated, so it is desirable to create a way to view and store images on a computer.

II.

How an Electron Microscope Works

Electrons vs. Photons

The electron microscope focuses electrons at a sample to be viewed and then spreads the beam out to display a magnified image on a screen or creates an image of reflected or secondary electrons from scanning the beam across the sample in a raster. Secondary electrons are knocked off of atoms when struck by beam electrons. The advantage of electron microscopy over light microscopy comes from the wavelengths of electrons and photons. Error is proportional to wavelength, so typically maximum resolution is about half the wavelength of the particle. According to Figure 1, high energy electrons have a significantly shorter wavelength than UV or visible light photons, which allows for higher resolution, nearly to atomic scale.

Wavelength vs. Particle Type

Particle	Approximate Wavelength (m)
Photon (visible light)	1×10^{-7}
Photon (ultraviolet light)	1×10^{-8} or 10^{-9}
Electron (80 kV)	1×10^{-12}

Figure 1: A chart of the wavelengths of light waves and energized electrons

Vacuum

In order to provide effective resolution, the microscope must be evacuated to a high vacuum (~10^{-6} torr). Electrons interact with air molecules, so reducing the density of the air in the beam path reduces interactions, improving resolution. These electrons are highly energized, and also need a high vacuum to prevent arcing from the filament (cathode) to the base of the gun chamber (anode). From Figure 2, the high vacuum is achieved with a coupled pumping system consisting of a rotary vane pump (backing pump) and one or two diffusion pumps with water-cooled baffles.

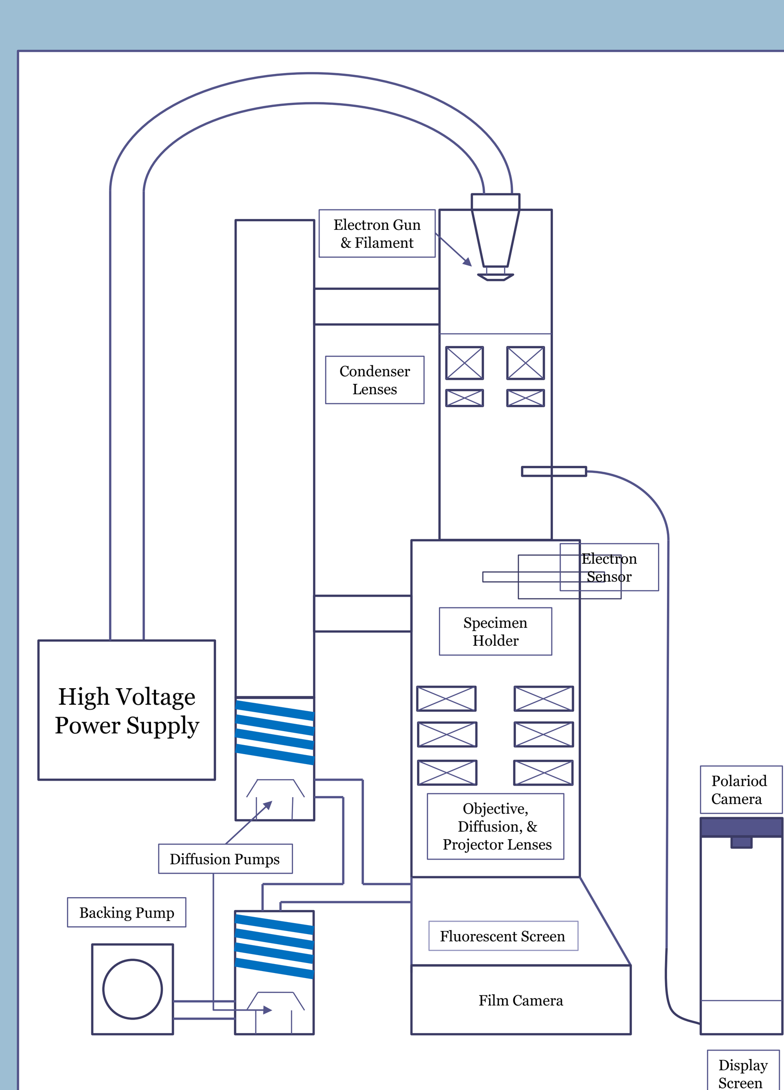

Figure 2: A diagram of the Jeol CX-100 STEM

Electromagnetic Lenses

An electron microscope uses electromagnet lenses to focus electrons, since electrons accelerate in magnetic fields due to their charge ($\vec{F} = q\vec{v} \times \vec{B}$). The magnets are built as coils in pairs. Electrons rotate through a magnetic field, so a second magnet is necessary to correct the rotation. Magnets always act as convex lenses, so a pair of lenses with opposite current will correct rotation but preserve focusing.

III.

Electron Microscopy Techniques

Transmission Electron Microscopy (TEM)

TEM is useful for observing densities of structures and samples. A very thin sample is prepared (~ 10^2 nm). The electrons that pass through are spread out and an image can be taken of the pattern (Figure 3). The thicker and denser the sample the darker the image will be. If the sample is too thick it will absorb all the electrons.

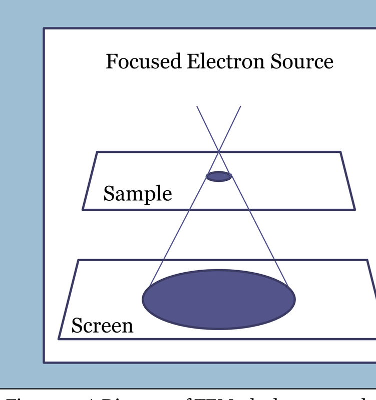

Figure 3: A Diagram of TEM: the beam travels through the sample and is projected onto a screen.

Scanning Electron Microscopy (SEM)

SEM is used for mapping surface structures and topographies of samples. The SEM sample does not need to be as thin as the TEM sample; however, for maximum resolution the sample should not vary too much in thickness. The beam scans the sample in a raster, and a sensor picks up the electrons and sends out information regarding the intensity, which can be converted into an image on a screen.

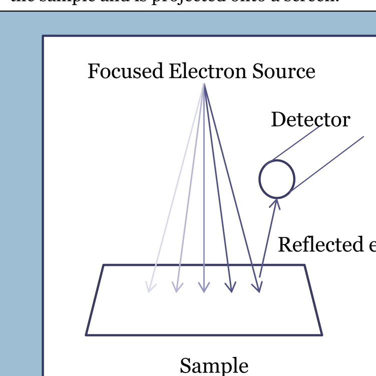

Figure 4: A Diagram of SEM: the beam is reflected off of the sample along a raster

Scanning Transmission Electron Microscopy (STEM)

STEM is similar to TEM, where the beam passes through the sample. The beam is concentrated to a very small area, and it makes a raster across the sample. The intensity of the transmitted beam is picked up by a sensor and converted to a pixelated image. This technique allows for higher resolution or higher magnification since the entire beam is concentrated on a single point per sample.

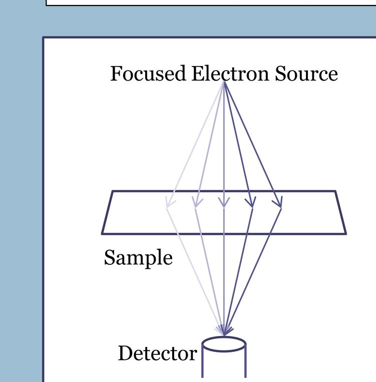

Figure 5: Diagram of STEM: the beam travels through the sample along a raster

IV.

Image Capturing Techniques

Old Method

Using SEM, a sensor located above the specimen collects information about the intensity of the electron reflection/backscatter and sends the signal to a closed peripheral box with a screen at the bottom end and a Polaroid camera at the top (See figure 2, lower right). A picture is taken of the image on the screen.

New Method

Specifically for SEM, I will redirect the output from the sensor to a computer input. I will write a program to take the intensity data from the sensor and make a 2D raster to display an image of the sample. From there I will be able to manipulate and print the images.

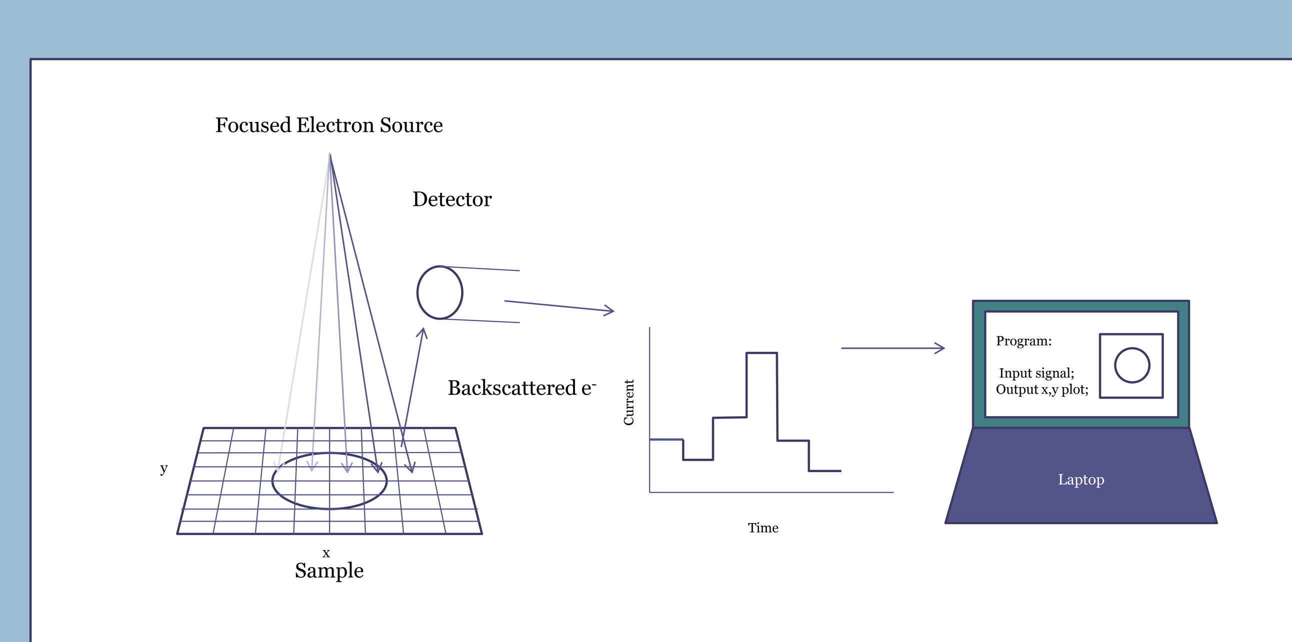

Figure 6: from left to right, scanning a sample using a raster; a graph of the output of the e- detector; a representation of a program designed to render images from the detector