USC Viterbi School of Engineering
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Laboratory for Complex Materials & Devices
Ravichandran Group at University of Southern California

Center for Electron Microscopy & Microanalysis
University of Southern California

Demonstrating Interactions of Electron and Electromagnetic Waves with Matter

Objective:

The activity will demonstrate the practical applications for electromagnetism, you learnt in the Physics class. Specifically, we will show state-of-the-art materials characterization equipments, which work on the principle of electron and electromagnetic wave interaction with matter.

Equipments:

Transmission Electron Microscopy, Scanning Electron Microscopy and x-ray Photoelectron Spectroscopy.

1. Transmission Electron Microscopy:

Transmission electron microscopy (TEM) at CEMMA uses electrons accelerated to a voltage of 200 kV to illuminate a sample. Relying on an ultra-thin sample with a thickness of 10 – 100 nm the electrons transmit or pass through a sample to create an image. At the top of the TEM column is an emission source called an electron gun, which is used to generate a beam of electrons. An anode is then used to accelerate the electrons to an electromagnetic lens (condenser lens) that will allow the beam to be focused on the sample. Once the beam of electrons has passed through the sample, the objective lens focuses these transmitted electrons to form a projected image of the sample. Additional electromagnetic lenses magnify the image and project it on to a phosphorescent screen or recording device such as a CCD camera. The projected image is viewed as groups of black, white and grey (contrast) that determine how the electrons have interacted with the sample. Some electrons may be reflected or absorbed, giving a simple contrast from thickness and atomic number density. Instrument: JEOL JEM-2100F

Proposed Activity:

1. Imaging nanoscale structures

In this activity, you will be demonstrated how TEM can be used to image nanoscale structures. TEM works in a transmission mode, i.e. the electron beam has to go through your sample and you collect the beam after going through your sample, to study the atomic and nanoscale information available in the sample. TEM is essentially a complicated version of your typical optical microscope, but instead of the visible light, you are using electron beams to image your sample. As explained earlier, the wavelength of the electron beam is related to its energy and is much smaller than the visible light. This is the important reason why we can use TEM to image even atoms!

2. Scanning Electron Microscopy:

In scanning electron microscopy (SEM), an electron beam is focused to a small spot size and scanned over the sample's surface in a raster pattern producing various signals that contain information about the sample's surface topography and composition. The type of image depends on the variety of signal collected. The most commonly produced signals are: secondary electrons, which are used to image the surface morphology; backscattered electrons for compositional imaging; and X-rays for compositional analysis. The sample in theory can be of any size as the signal produced from the interaction of the electron beam and the sample is ejected upward from the sample's surface. This electron beam is generated in the same fashion as in the TEM by the use of an electron gun, although, the energy of the electrons in an SEM are of a much lower energy, normally between 1–30 kV. Instrument: JEOL JSM-7001F-LV

Proposed Activity:

1. Imaging really small objects such as wires of diameter similar to the hair.

In this activity, you will be shown how SEM can be used to image nanoscale objects with dimensions much less than your hair (100 microns) or less. In an SEM we can resolve objects of dimension 100 nm fairly easily (1000 times smaller than the width of your hair!). SEM also works using an electron beam as an imaging medium, but in this case, you use the electron beam to "bombard" your sample (non-destructive though), and are "ejected" back from your sample to image the sample. The energy range of electron beam used to bombard your sample is ~ 10-30 keV. As you can note, this is much smaller than the TEM electron beam energy.

2. Chemical composition of materials using EDS

Turns out, when you bombard your sample with the electron beam, you will excite the electrons to a higher energy state. This electron in higher energy state is not stable, so it has to loose its energy to return back to its normal state (lets call this ground state). When it does return back to its ground state, the energy is lost in terms of an electromagnetic radiation. In this case it is an x-ray. When you collect this x-ray information, it can be used to learn about what elements are present in your sample. This technique is called as Energy Dispersive x-ray Spectroscopy. You can do this same experiment in a TEM too!

3. X-ray Photoelectron Spectroscopy:

X-ray photoelectron spectrometer (XPS) also known as ESCA (electron spectroscopy for chemical analysis) provides both elemental and chemical state information on a solid surfaces material. The sample is illuminated with x-rays (monochromatic soft X-rays-one energy) and photoelectrons are emitted from the surface of the material. The kinetic energy of these emitted electrons is characteristic of the element from which the photoelectron originated. Surface analysis can identify the elements present at the materials surface (qualitative analysis), chemical bonding state (chemistry) and the distribution of elements across the surface (elemental map) The instrument has a typical sampling depth of 2-10 nm. Instrument: Kratos Axis Ultra DLD

Proposed Activity:

1. Studying chemical composition of materials

This system does something similar to the EDS, but is more powerful and can provide you more information about the composition of your material. Instead of the electron beam, this uses x-ray beam to bombard your sample. This x-rays eject the electrons in the ground state to excited state. You can collect these excited electrons and study their properties to learn about the composition of the sample.

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Questions for Each CEMMA Station

All of the instruments in CEMMA are designed to help see small things. What does it mean to be small? What is the smallest something can be? What is a micrometer and what is a nanometer?

You will go to each station, at each but one you will be taught how the microscope works, and, at one particular station, work on a small project to help you understand the nanoscale.

Ask lots of questions!

XPS (X-ray Photoelectron Spectroscopy) Kratos Ultra-Axis (Andrew)

1) Draw a diagram and write a brief description that explains how x-rays are generated in this instrument.

2) What is the average x-ray energy (in keV) from the monochromated Aluminum x-ray source?

3) Draw a diagram and write a brief description that explains how the x-ray monochromator benefits the acquisition and analysis of spectra acquired for XPS.

4) Briefly explain the process of photoemission.

5) An electron in an excited state decays back to its initial state by emitting what?

6) What is UHV and why does the use of XPS require UHV?

SEM (Scanning Electron Microscope)
JEOL JSM-6610LV (Shanyuan)

1) What type of source does this SEM have: tungsten wire, LaB6, FEG?

2) What is the size of the electron source relative to the others?

3) How much energy does an electron have after it is accelerated the electron gun?

4) What wavelength do the electrons have after they are accelerated (use dimensional analysis to estimate, voltage, electron mass, speed of light, electron charge)?

5) How would you make the wavelength smaller and what benefit would that have?

6) How do we typically form an image in this type of SEM?

SEM (Scanning Electron Microscope)
JEOL JSM-7001F (Casey)

1) What type of source does this SEM have: tungsten wire, LaB6, FEG?

2) What is the size of the electron source relative to the others?

3) How are samples loaded into this SEM?

4) What type of vacuum range does this SEM allow?

5) List and describe four different ways to generate an image inside this SEM. In what ways is each imaging modality useful?

SEM (Scanning Electron Microscope) /FIB (Focused Ion Beam) JEOL JIB-4500 (Leo)

1) What type of source does this SEM have: tungsten wire, LaB6, FEG?

2) What is the size of the electron source relative to the others?

3) This microscope has an electron source and an ion source, what type of ion is used in the ion source?

4) Ions are useful for both imaging and milling, describe what changes in the microscope to help provide better imaging and what changes to provide better milling?

5) How is a lens for electrons different than a lens for ions?

6) What is the ion source commonly used to make?

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TEM (Transmission Electron Microscope) JEOL JEM-2100F (Lang)

1) What type of source does this TEM have: tungsten wire, LaB6, FEG?

2) How much energy does each electron have after they are accelerated through the electron gun?

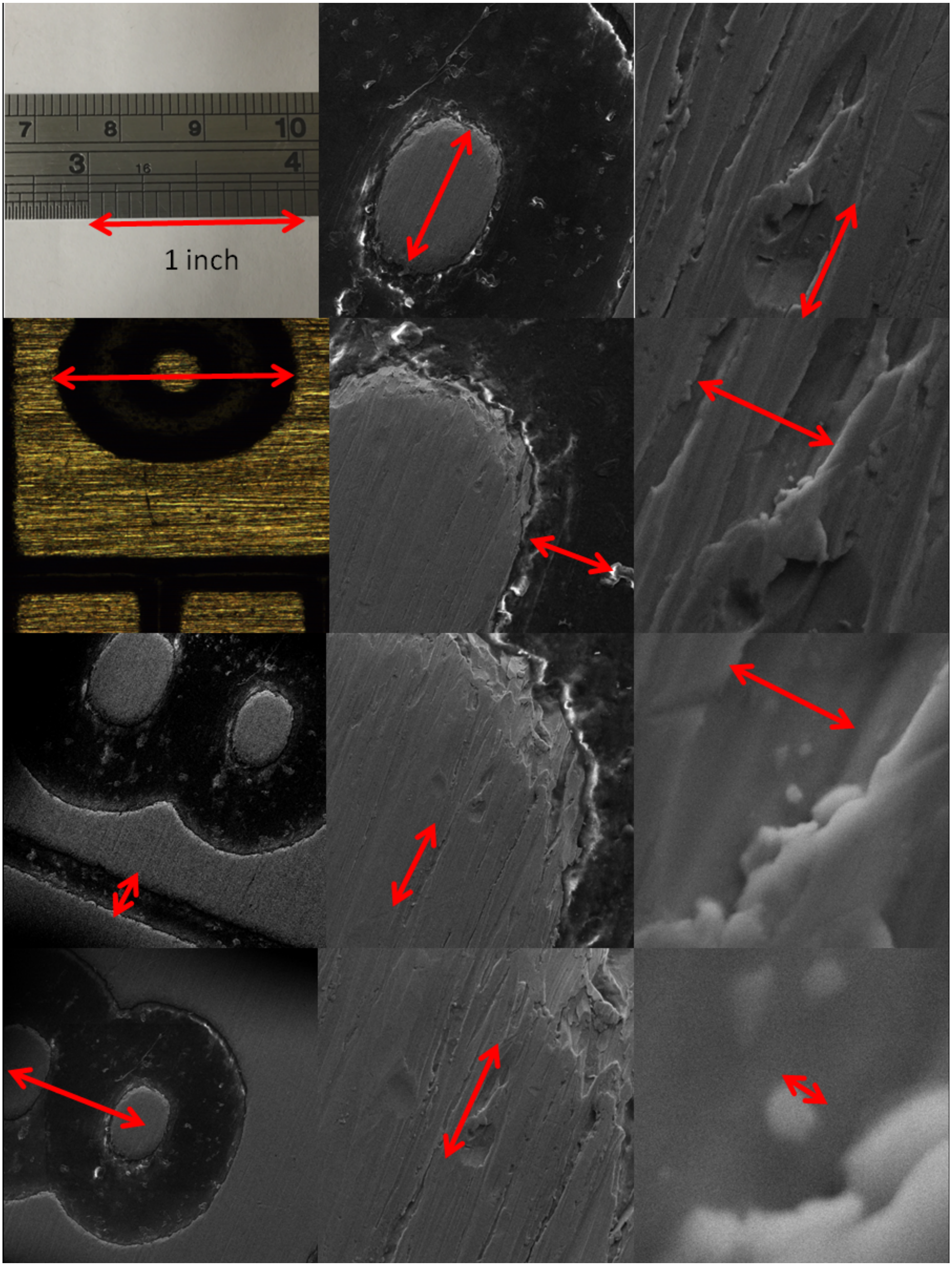
3) For 1 nA of beam current how many electrons pass through any point in the microscope (on average) per second?

4) How fast are the electrons moving after they are accelerated (use dimensional analysis to estimate, voltage, electron mass, speed of light, electron charge)?

5) What is the benefit of using electrons with small wavelengths?

6) What restrictions are there in using a TEM?

7) What benefits are there in using a TEM?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