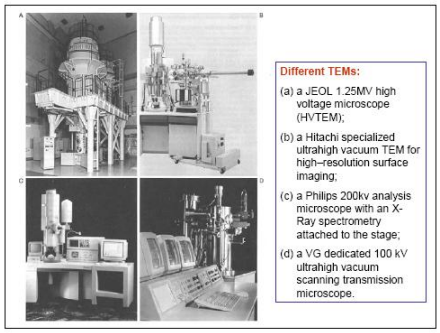
TEM – transmission electron microscopy



Different TEMs:

(a) a JEOL 1.25MV high voltage microscope (HVTEM);

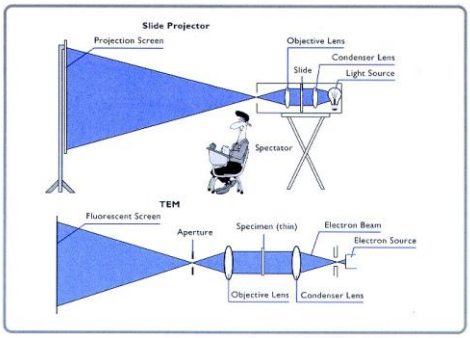
(b) a Hitachi specialized ultrahigh vacuum TEM for high–resolution surface imaging;

(c) a Philips 200kv analysis microscope with an X-Ray spectrometry attached to the stage;

(d) a VG dedicated 100 kV ultrahigh vacuum scanning transmission microscope.

TEM – transmission electron microscopy

A transmission Electron Microscope is anologous to a slide projector as indicated by Philips below

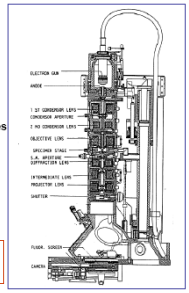


TEM – transmission electron microscopy

II. The instrument

EM

- **TEM**
- **SEM**
- **Dedicate STEM**
- **TEM/STEM: TEM with scanning facilities**
- **HVTEM**



A cross-section through a modern 100 kV TEM

TEM – transmission electron microscopy

In a conventional transmission electron microscope, a thin specimen is irradiated with an electron beam of uniform current density. Electrons are emitted from the electron gun and illuminate the specimen through a two or three stage condenser lens system. Objective lens provides the formation of either image or diffraction pattern of the specimen. The electron intensity distribution behind the specimen is magnified with a three or four stage lens system and viewed on a fluorescent screen. The image can be recorded by direct exposure of a photographic emulsion or an image plate or digitally by a CCD camera.

The acceleration voltage of up to date routine instruments is 120 to 200 kV. Medium-voltage instruments work at 200-500 kV to provide a better transmission and resolution, and in high voltage electron microscopy (HVEM) the acceleration voltage is in the range 500 kV to 3 MV. Acceleration voltage determines the velocity, wavelength and hence the resolution (ability to distinguish the neighbouring microstructural features) of the microscope.
Depending on the aim of the investigation and configuration of the microscope, transmission electron microscopy can be categorized as :

Conventional Transmission Electron Microscopy
High Resolution Electron Microscopy
Analytical Electron Microscopy
Energy-Filtering Electron Microscopy
High Voltage Electron Microscopy
Dedicated Scanning Transmission Electron Microscopy

TEM – transmission electron microscopy

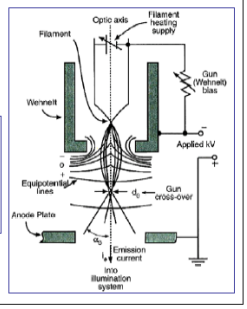
The TEM consists of the following major parts:

1. **The illumination system**
   - **Electron gun**
   - **Condensers**
2. **The image forming system**
   - **Objective lens**
3. **The projective system**
   - **Several projector lens**
4. **Apertures**
   - **afftect the formation of images and diffraction patterns**

TEM – transmission electron microscopy

Electron gun

Schematic diagram of a thermionic electron gun. A high voltage is placed between the filament and the anode, modified by a potential on the Wehnelt which acts to focus the electrons into a crossover, with diameter d_0 and convernegce/divernence angle α_0.



TEM – transmission electron microscopy

Three types of electron source:

- Tungsten filament,
- Lanthanum hexboride (LaB_6) emitter
- Field emission emitter (FEG)

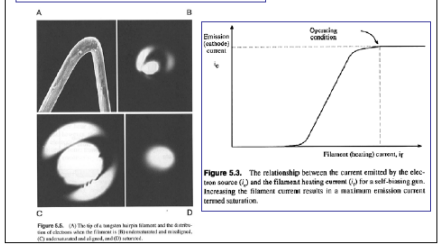


Figure 5.3. The relationship between the current emitted by the electron source (i_e) and the filament heating current (i_f) for a self-biasing gun. Increasing the filament current results in a maximum emission current termed saturation.

TEM – transmission electron microscopy

The condenser system

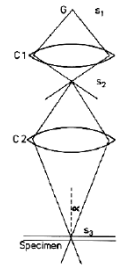
Two lenses:

C1: strong M = 50x

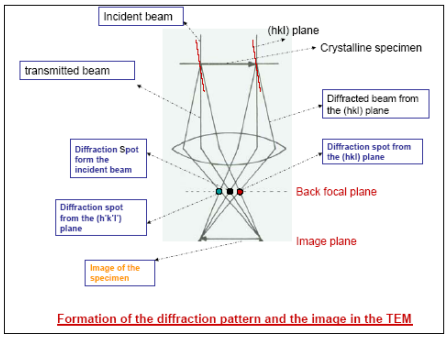
produces a de-magnified image S_2 (~1μm) of cross-over s_1 (~50μm)

C2: weak lens,

produces a image s_3 (~2μm) onto the specimen



TEM – transmission electron microscopy



Formation of the diffraction pattern and the image in the TEM

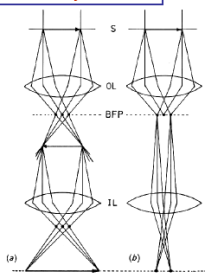
TEM – transmission electron microscopy

2. The image forming system - The objective lens

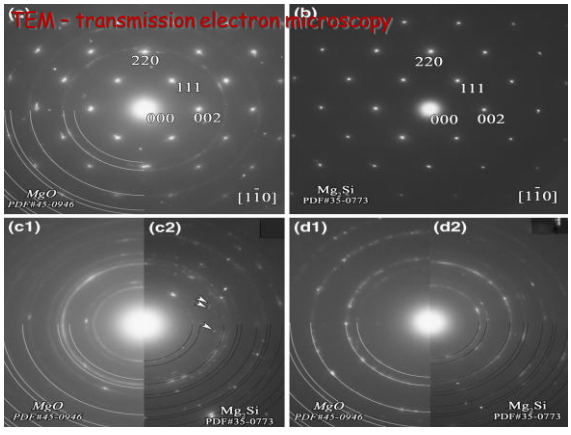
The objective and first intermediate lenses. The objective lens (OL) is focused on the specimen and form an intermediate image as shown in (a).

In imaging mord the intermediate lens (IL) magnifies this image further and passes it to the projector lens for display.

In order to make the diffraction pattern visible, *in diffraction mord* the intermediate lens is refocused on the back focal plane of the objective lens (BFP) and the diffraction pattern is passed to the projector system (b).



TEM – transmission electron microscopy



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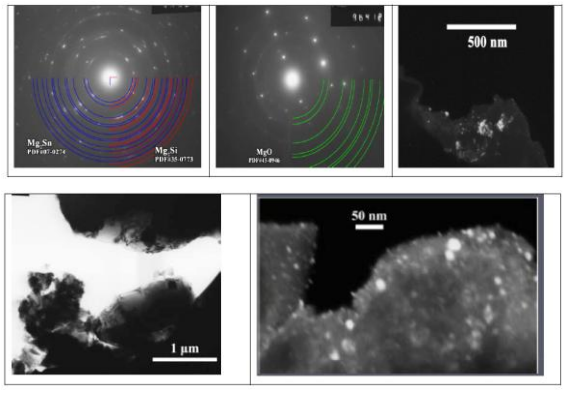
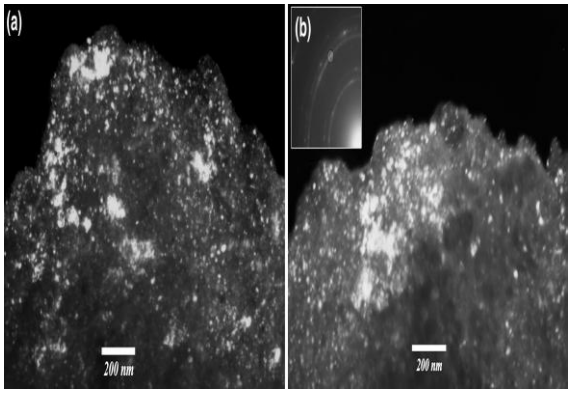
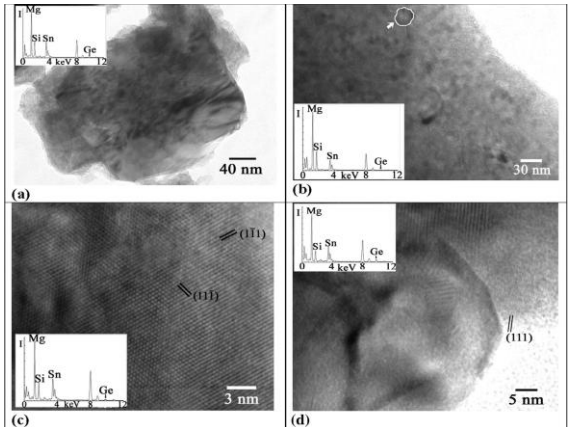
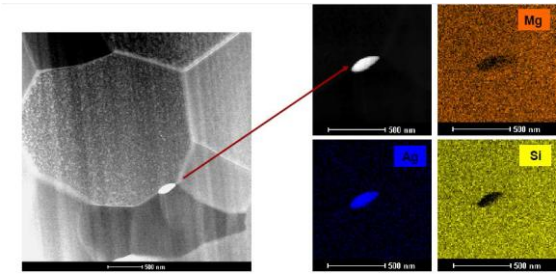


TEM – transmission electron microscopy



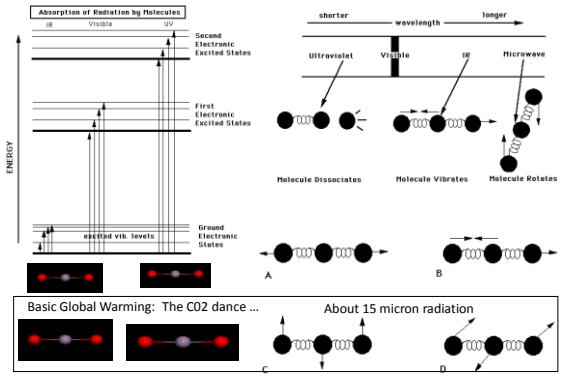


TEM – transmission electron microscopy



Fourier Transform Infrared (FTIR) & FTIR Spectrometers

Energy Levels: Basic Ideas



Wavelength and Wavenumber

- Wavelength = 1 / Wavenumber
- For the IR, wavelength is in microns.
- Wavenumber is typically in 1/cm, or cm^{-1}.
- 5 microns corresponds to 2000 cm^{-1}.
- 20 microns corresponds to 500 cm^{-1}.

- **15 microns corresponds to 667 cm^{-1}. Much 'terrestrial' IR energy at the wavenumber.**

What is a FTIR Spectrometer?

- A spectrometer is an optical instrument used to measure properties of light over a specific portion of the electromagnetic spectrum, 5 microns to 20 microns.
- FTIR (Fourier Transform InfraRed) spectrometer is a obtains an infrared spectra by first collecting an interferogram of a sample signal using an interferometer, then performs a Fourier Transform on the interferogram to obtain the spectrum.
- An interferometer is an instrument that uses the technique of superimposing (interfering) two or more waves, to detect differences between them. The FTIR spectrometer uses a Michelson interferometer.

FOURIER TRANSFORMS

- Fourier transform defines a relationship between a signal in time domain and its representation in frequency domain.
- Being a transform, no information is created or lost in the process, so the original signal can be recovered from the Fourier transform and vice versa.
- The Fourier transform of a signal is a continuous complex valued signal capable of representing real valued or complex valued continuous time signals.

Fourier Transforms cont.

- The Continuous Fourier Transform, for use on continuous signals, is defined as follows:

$$F(w) = \int_{-\infty}^{\infty} f(x)\, \mathbf{e}^{(-2\pi w i x)}\, dx$$

- And the Inverse Continuous Fourier Transform, which allows you to go from the spectrum back to the signal, is defined as:

$$f(x) = \int_{-\infty}^{\infty} F(w)\, \mathbf{e}^{(2\pi w i x)}\, dw$$

F(w) is the spectrum, where w represents the frequency, and f(x) is the signal in the time where x represents the time. i is sqrt(-1), see complex number theory.

Fourier Transforms cont.

- A computer can only work with finite discrete signals, not with continuous signals. Thus, we need to define the Discrete Fourier Transform (DFT).
- In DFT, the infinite borders of the integrals can be replaced by finite ones, and the integral symbol can be replaced by a sum. So the DFT is defined as:

$$f_k = \frac{1}{N} \sum_{n=0}^{N-1} F_n e^{2\pi i k n / N}$$

And the inverse DFT is defined as:

$$F_n \equiv \sum_{k=0}^{N-1} f_k e^{-2\pi i n k / N}$$

- The spectrometer described here is a modified Bomem MB-100 FTIR.
- The heart of the FTIR is a Michelson interferometer (figure 2).
- The mirror moves at a fixed rate. Its position is determined accurately by counting the interference fringes of a collocated Helium-Neon laser.
- The Michelson interferometer splits a beam of radiation into two paths having different lengths, and then recombines them.
- A detector measures the intensity variations of the exit beam as a function of path difference.
- A monochromatic source would show a simple sine wave of intensity at the detector due to constructive and destructive interference as the path length changes (refer figure 3).

- In the general case, a superposition of wavelengths enter spectrometer, and the detector indicates the sum of the sine waves added together.
- Figure 3 shows some idealized light sources, and the interferograms that they would theoretically produce.
- The difference in path length for the radiation is known as the retardation d (OM = OF + d) in figure 1 and 2.
- When the retardation is zero, the detector sees a maximum because all wavenumbers of radiation add constructively.
- When the retardation is l/2, the detector sees a minimum for the wavelength l. An interferogram is the sum of all of the wavenumber intensities.

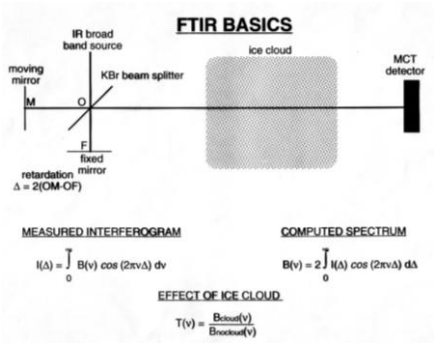


Figure 1.

Schematic of Michelson Interferometer

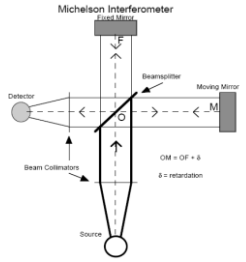
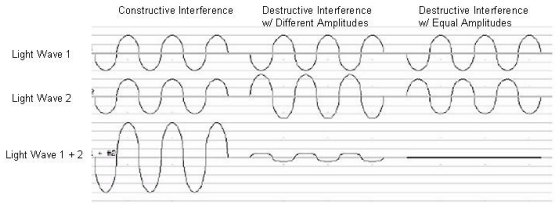
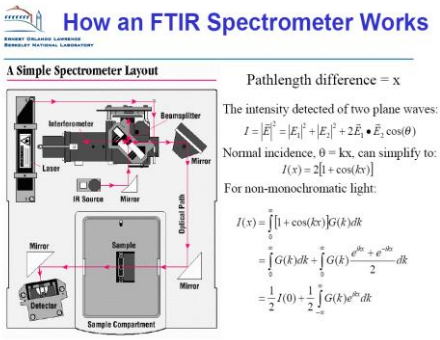


Figure 2.

Source: MS thesis submitted by Carl George Schmitt, UNR, 1998.

Wave Interference





APPLICATIONS

- Identification of inorganic compounds and organic compounds
- Identification of components of an unknown mixture
- Analysis of solids, liquids, and gasses
- In remote sensing
- In measurement and analysis of Atmospheric Spectra
  - Solar irradiance at any point on earth
  - Longwave/terrestrial radiation spectra
- Can also be used on satellites to probe the space