Modern Imaging, Spectroscopy and Diffraction Techniques
TIF 030 and FIM 150
January 9th, 2012

Aids: Formula sheets attached to the exam, "Physics Handbook", calculator, and writing tools.

Total marks available from exam: 30
Marks required to pass: 12

Question1. Basic optical image formation (3p)
A simple imaging system consists of two thin lenses spaced 9 cm apart, each with focal length $f = 2$ cm and diameter $D = 2$ cm. An object is placed in the object plane and its image is captured by a CCD chip placed 6 cm behind the second lens
a) What is the magnification of the imaging system? (1p)
b) What is the numerical aperture of the imaging system? (1p)
b) Describe how insertion of a spatial filter or screen into the imaging system could be used to create a dark field image (1p)

Question 2. Fluorescence Microscopy (3p)
a) Draw a simplified Jablonski diagram for a fluorophore and, using the diagram, describe what is meant by fluorescence quantum efficiency, vibrational relaxation and fluorescence life-time (1p)
b) b) Wide-field (epi) fluorescence microscopes usually contains a filter cube. What are the primary components of a filter cube and where is the cube placed in the microscope? (1p)
c) A confocal microscope usually contains some form of pinhole. What is the role of the pinhole and where is it placed in the microscope? (1p)

Question 3. Breaking the diffraction limit 3 (4p)
We've talked about three important methods to circumvent the diffraction limit in optical microscopy: scanning near-field microscopy, stimulated emission depletion microscopy and stochastic image reconstruction microscopy. First explain what is meant by "the diffraction limit" (1p), then describe the main idea that allows one to circumvent the diffraction limit in each of the three methods mentioned above with a few sentences and drawings (1p per method).

Question 4. SEM (4p)
(a) The spatial resolution of an image recorded using SEM depends on several parameters. Draw the schematic of the interaction volume and explain the important parameters determining the spatial resolution for imaging using
    (i) secondary electron
    (ii) backscatter electrons
    (iii) EDS-analysis.
The parameters that are to be considered are electron beam diameter, interaction volume and acceleration voltage. (2p)
(b) Determine the depth of focus for an image where 5 nm spatial resolution is acceptable. The image is recorded 5 mm working distance and an aperture diameter of 30 μm. (2p)

Question 5. EDS (2p)

(a) The fluorescence yield depends on Z number and line of emission (K, L, M…). Draw a schematic showing the dependence of fluorescence yield as a function of Z number for K, L and M lines. (1p)

(b) Draw a typical EDX spectrum including characteristic X-ray peaks and background for silicon and cobalt in the interval 0-20 keV. (1p)

Question 6. TEM (2p)

(a) Draw a schematic ray diagram that shows how a diffraction pattern and an image are formed in the TEM. Include the specimen and the objective lens in the diagram. All other lenses can be omitted. (1p)

(b) In which plane along the optic axis is the objective aperture positioned? (0.5p)

(c) What is the function of the objective aperture? (0.5)

Question 7. Electron diffraction (2.5p)

The diffraction pattern in Fig. 1 is obtained for an iron crystal with bcc crystal structure having the electron beam incident along a zone axis in a TEM operated at 200 kV.

(a) Index the pattern. (1p)

(b) Draw the Kikuchi lines corresponding to the 8 diffraction spots closest to 000 in Fig 1. (0.5p)

(c) Draw the Kikuchi lines for spot A when the crystal is tilted so that the Bragg condition for spot A is fulfilled. (1p)

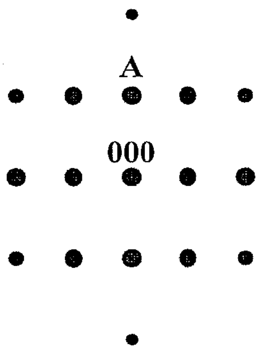


Fig. 1. Diffraction pattern from an iron bcc crystal.

Question 8. EDS in TEM (3p)

An EDS-analysis is carried out in a TEM at 100 kV. The spectrum shows K-lines from Al, Ti and Mo. The number of counts summed over the energy ranges corresponding to the Al, Ti and Mo lines are 17 300, 41 700 and 39 000 respectively. The background intensities are 120, 230 and 390 counts. The specimen thickness is 50 nm and the probe diameter is 0.5 nm.

(a) Which background intensity belongs to Al, Ti and Mo? Explain your answer. (0.5p)

(b) Calculate the composition in weight per cent. Neglect the absorption. (2p)

(c) Assume that you would like to investigate if there is segregation of an element to a grain boundary. Explain the effect of specimen thickness and acceleration voltage on the spatial resolution of the analysis. Draw a diagram with curves showing the concentration extracted from spectra recorded as a function of distance from the interface for two thicknesses and for two acceleration voltages. (1p)

Question 9. SpM: Common denominators and distinguishing characteristics (3p)
There are a large variety of SPM techniques (including STM, AFM, SNOM, etc.). In fact, one often talks about a "family" of SPM techniques. This is related to the fact that most SPM techniques historically have been derived from the mother of all SPM techniques – STM– and that there exist many communalities between the various SPM techniques.

a) What is the common denominator for most SPM techniques? (0.5p)

b) What are the major distinguishing characteristics when comparing scanning tunneling microscopy (STM) to atomic force microscopy (AFM)? (1p)

c) The two most common STM imaging modes are constant-current and constant-height mode. What are the major distinguishing characteristics between these two modes? (1p)

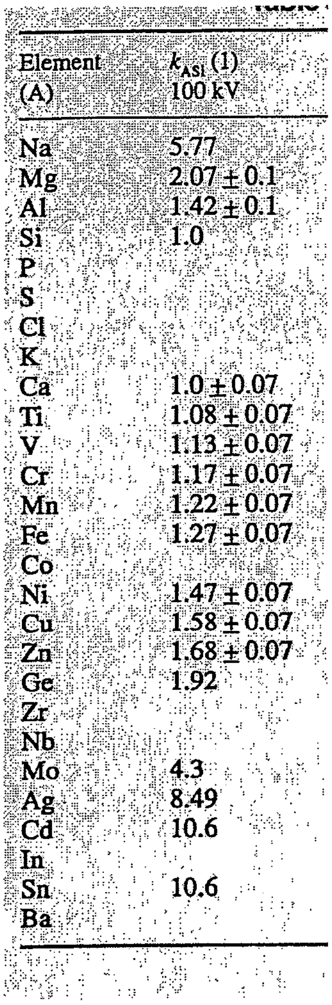
d) When operated in constant-height mode, which of the two techniques STM or AFM is more susceptible to a small vertical drift and why? (0.5p)

Question 10. SPM-2: Imaging artifacts (3 p)
The tip is often a critical parameter for obtaining good AFM images, and AFM images are often affected by tip and other artifacts.

a) List three common tip artifacts! For each tip artifact, describe briefly its origin and discuss how it affects image appearance. (1.5p)

b) Do you know of any other (i.e. not tip-related) sources, which can give rise to artifacts in AFM images? List three of them and describe briefly how they affect image appearance! (1.5p)

Formula sheet



Element (A)	k_{ASi} (1) 100 kV
Na	5.77
Mg	2.07 ± 0.1
Al	1.42 ± 0.1
Si	1.0
P	
S	
Cl	
K	
Ca	1.0 ± 0.07
Ti	1.08 ± 0.07
V	1.13 ± 0.07
Cr	1.17 ± 0.07
Mn	1.22 ± 0.07
Fe	1.27 ± 0.07
Co	
Ni	1.47 ± 0.07
Cu	1.58 ± 0.07
Zn	1.68 ± 0.07
Ge	1.92
Zr	
Nb	
Mo	4.3
Ag	8.49
Cd	10.6
In	
Sn	10.6
Ba	

$$\lambda = h / [2m_0eV(1 + eV/2m_0c^2)]^{1/2}$$

$$d_p = (d_g^2 + d_s^2 + d_d^2 + d_c^2)^{1/2}$$

$$r_{Sch} = 0.66\ C_s^{1/4}\ \lambda^{3/4}$$

$$n > (5/C)^2$$

$$2\ d_{hkl}\ \sin\Theta = n\lambda$$

$$b = 7.21 \times 10^5\ (\rho/A)^{1/2} t^{3/2}\ (Z/E_0)$$

$$I \propto U\rho_s(E,r)e^{-2\frac{\sqrt{2m_e\phi}}{\hbar}d}\ with\ \phi = \tfrac{1}{2}\left(\phi_{sample} + \phi_{tip}\right)$$