Modern Imaging Methods

TIF 030 and FIM 150

Wednesday October 24th, 2007, 08.30- 12.30

V Building

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

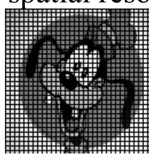
Total marks available from exam: 30

Marks required to pass: 12

Question 1 Basic imaging (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. Images are captured on a CCD chip placed 6 cm behind the second lens. A Goofy slide is placed in the object plane and illuminated with a collimated green light beam incident along the optical axis.

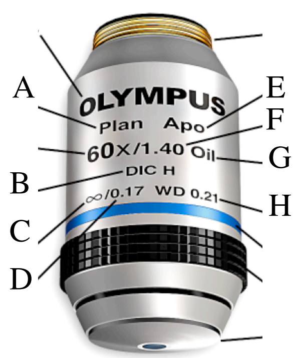
(a) What is the magnification of the imaging system and what is the spatial resolution according to the Rayleigh criterion? (1p)



(b) Describe how and why a spatial filter could be used to hinder the raster pattern in the Goofy slide from being captured by the CCD. (1p)

(c) Describe how the lens system could be complemented by a Köhler illumination system for transmitted white light imaging. (1p)

Question 2 Practical microscopy (3p)



(a) The inscriptions on a microscope objective contains important information on its use. What does A-H in the picture stand for? (1p)

(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? (1 p)

(c) A confocal microscope usually contains some form of pinhole. Why is this important and where is the pinhole placed? (1p)

Question 3 Contrast mechanisms (3p)

(a) Draw a simplified Jablonski diagram for a fluorophore and, using the diagram, describe what is meant by fluorescence quantum efficiency, vibrational relaxation, fluorescence life-time, quenching, and intersystem crossing. (1.5p)

(b) The optical properties of a single electron in an atom or molecule are, in a first approximation, described by the classical dipole polarizability:

$$\alpha(\omega) = \frac{e/m}{\omega_0^2 - \omega^2 - i\gamma\omega}.$$

(c) What is the meaning of the polarizability and how does it relate to absorption, scattering and refraction? (1.5p)

Question 4 (3p)

(a) What is the critical parameter determining the spatial resolution of imaging with secondary electrons in the SEM? (0.5p)

(b) What is the critical parameter determining the spatial resolution of analysis with X-rays in the SEM? (0.5p)

(c) Which electron source gives the best spatial resolution? Explain your answer. (0.5p)

(d) Calculate the depth of field for an SEM image with the spatial resolution of 2 nm and recorded at 10 kV, with 4 mm working distance, 30 μm aperture and 100 000 times magnification. (1.5p)

Question 5 (3p)

(a) Assume that an EDS analysis is performed at 100 kV in a TEM on a TEM specimen. The spectrum shows characteristic peaks of Fe, Ag and Ti. The total signal in each peak is 7564 (Ag, L), 4351 (Ti, K) and 2387 (Fe, K) respectively. The background signals for the three peaks are 632, 256 and 196. Assume that the absorption in the specimen can be neglected. Decide which background signal that corresponds to Fe, Ag and Ti respectively. Determine the composition. (2.5p)

(b) Calculate the beam broadening in a silver TEM specimen that is 50 nm in thickness at 100 and 200 kV. (0.5p)

Question 6 (3p)

The diffraction pattern in Fig. 1 is obtained for a gold crystal with the electron beam incident along the [110] direction in a TEM operated at 200 kV.

(a) Draw the Kikuchi lines corresponding to the 6 diffraction spots closest to 000 in Fig 1. (1p)
(b) Draw the Kikuchi lines for spot A when the crystal is tilted so that the Bragg condition for spot A is fulfilled. (1p)
(c) What happens to the pattern in Fig 1 if the acceleration voltage is reduced to 100 kV? (1p)

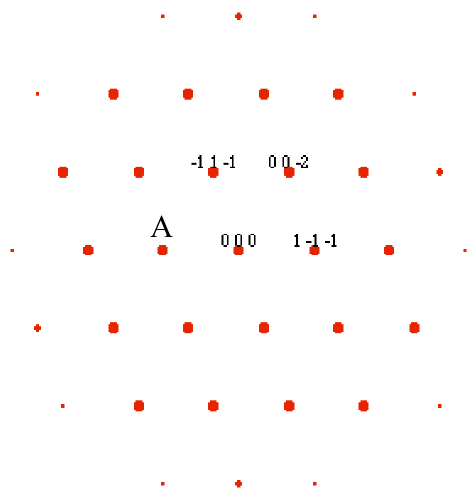


Fig. 1. Diffraction pattern from a gold crystal with the electron beam incident along the [110] direction.

Question 7 (3p)

(a) Draw a TEM. The following parts must be included: electron gun, condenser lens system, objective lens, magnifying lenses, fluorescent screen, selected area aperture, objective aperture, condenser aperture and specimen holder. (0.5p)
(b) Draw a schematic ray diagram that shows how a diffraction pattern and an image is formed in the TEM. Include the specimen and the objective lens in the diagram. All other lenses can be omitted. (1p)
(c) Describe how Bright Field and Dark Field images can be obtained. (0.5p)
(d) How is an image showing phase contrast obtained in a TEM? (0.5)
(e) What are the roles of the condenser lenses in the TEM? (0.5p)

Question 8 (3p)

(a) What is EFTEM and EDX mapping? Describe the procedures. (1p)

(b) What determines the spatial resolution of an EELS anlysis and an EDX analysis in TEM respectively? (1p)

(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 quality of the analysis. (0.5p)

(d) How should the specimen in (c) be oriented? How is this achieved practically? (0.5p)

Question 9 (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 all SPM techniques? (0.5p)
(b) What are the major distinguishing characteristics when comparing STM to AFM? (1p)
(c) When imaging a surface with an STM, one typically runs in either constant-current or constant-height mode. What are the corresponding AFM imaging modes called in the case of contact and tapping mode, respectively? (0.5p)
(d) Which (STM) mode has a higher vertical resolution – constant-current or constant-height mode, and why? (1p)

Question 10 (3p)

Suppose that you are employed with a major AFM manufacturer. Your task is to develop the next generation AFM. In order to accomplish your task, you have decided to scrutinize the following aspects and answer the following questions:

(a) Historical development – what has driven the development from optical microscopy through STM to AFM? Identify 3 driving forces! (1p)
(b) Weaknesses of current AFM system – what are the main weaknesses of and problems associated with current AFM systems? List 3 major issues! (1p)
(c) Suggestions to overcome weaknesses – for <u>one</u> of the issues you have listed in b) above, describe an innovative approach to overcome this issue/problem! (0.5p)
(d) One of your colleagues has suggested developing an instrument, which integrates an AFM into an optical microscope. What do you think about this suggestion – worth trying or needless to discuss further? Motivate your answer very briefly! (0.5p)

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	

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

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

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

$n > (5/C)^2$

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

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

$$I \propto U \rho_S(E,r) e^{-2\frac{\sqrt{2m_e(\phi - E_F)}}{\hbar}d}$$

Thermal expansion coefficient of piezo materials: $4.7 \cdot 10^{-6}\ K^{-1}$