# Modern Imaging, Spectroscopy and Diffraction Techniques

TIF 030 and FIM 150
August 21st, 2012
Afternoon, Väg och vatten

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

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

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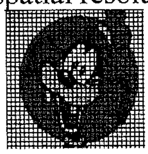
**1) Basic imaging (3p)**

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)

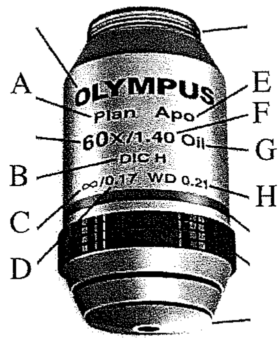


b) Describe how and why a spatial filter could be used to hinder the raster pattern in the Goofy slide from being captured by the CCD. (1p)

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

**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)

**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:

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

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

**4) SEM (4p)**

(a) Describe spherical and chromatic aberration in a lens. (1p)

(b) What is the most critical parameter that limits the spatial resolution for secondary electron imaging, backscatter electron imaging and EDS-analysis respectively of a bulk specimen in the SEM. Draw a schematic of the interaction volume for the different signals. (1p)

(c) Assume that you are recording an image of a planar specimen in the SEM using the backscattered electrons. The specimen contains Si and Ge and you know from earlier X-ray diffraction experiments that two phases with different composition and lattice parameters are present in the specimen. You observe two intensity levels in the image, i.e. there are dark and bright domains in the image. What causes the difference in intensity levels? Assume that one of the intensity levels corresponds to pure Si. Is it the lower or the higher level? (2p)

**5) EDS (2p)**

(a) The fluorescence yield depends on Z number and line of emission (K, L, M...). Is the fluorescence yield of Cu higher for the K or the L line? (1p)

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

**6) TEM (3p)**

(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? (0.25p)

(c) In which plane along the optic axis is the selected area aperture positioned? (0.25)

(d) Draw a schematic of an electron energy loss spectrum (EELS) and describe the three main parts of the spectrum. (1p)

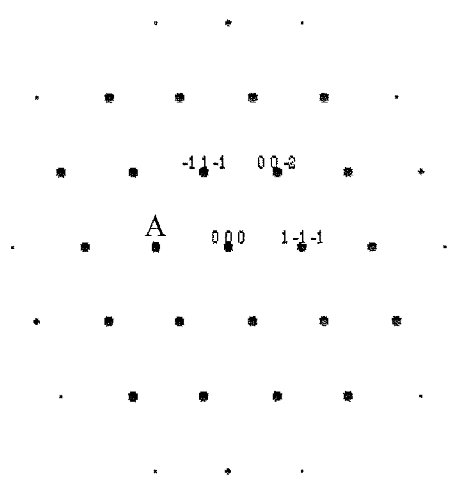
**7) Electron diffraction (3p)**

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 distance between the diffraction spots 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.

8) EDS in TEM (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 grain boundary plane in (c) be oriented with respect to the inident electron beam? How is this achieved practically? (0.5p)

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)

10) SPM-2: Imaging artifacts (3p)

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

Table

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

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

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

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

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

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

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

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