Modern Imaging, Spectroscopy and Diffraction Techniques

TIF 030 and FIM 150
October 20th, 2011

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 imaging (4p)
Draw the light path in an optical microscope that use transmitted light illumination according to the Köhler design.
a) Start from a point in the lamp filament and then trace the light rays through the microscope to the final observation point (eye or CCD chip). (2p)
b) Write out the different parts of the microscope, such as objective lens, condenser lens etc. (1p)
c) Mark the different conjugate planes in the imaging path, that is the object plane and the different image planes in the microscope. (1p)

Question 2. Practical microscopy (3p)
a) Some objectives for inverted microscopes are designed for using immersion oil between the lens surface and the substrate. What is the major advantage of such objectives? (1p)
b) Wide-field (episcopic) fluorescence microscopes usually contains a filter cube. What are the three primary components of a filter cube and where is the cube placed in the microscope? (1 p)
c) What is the primary advantage of so-called fluorescent proteins (e.g. GFP) compared to ordinary fluorescent dyes for imaging of biological cells (1p)

Question 3. Super-resolution optical microscopy (3p)
During the last two decades, several novel methods that are able to beat the classical diffraction limit in optical microscopy have been developed.
a) Describe the basic physical principles that make it possible to obtain "super-resolution" in stimulated emission depletion (STED) microscopy? (1p)
b) Describe the basic technical principles in STED microscopy, that is, how is the STED image formed in practice? (1p)
c) What are the main advantages and disadvantages with STED compared to NSOM - nearfield scanning optical microscopy? (1p)

Question 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. (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)

Question 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 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? (0.25p)

(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. (0.5p)

Question 7. Electron diffraction (3p)

The diffraction pattern in Fig. 1 is obtained for a gold crystal with the electron beam incident along a zone axis 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)

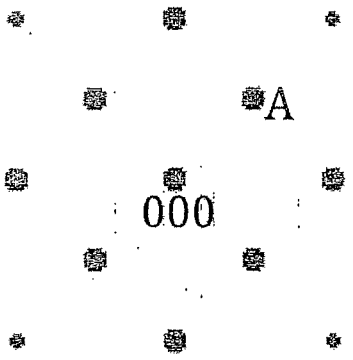

Fig. 1. Diffraction pattern from a gold crystal.

Question 8. EDS in TEM (3p)

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

(b) What determines the spatial resolution of an EDX analysis in TEM? (0.5p)

(c) Assume that you would like to investigate if there is segregation of an element to a grain boundary using EDX in a TEM. Explain the effect of specimen thickness and acceleration voltage on the quality of the analysis. (1p)

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

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)