Modern Imaging, Spectroscopy and Diffraction Techniques

TIF 030 and FIM 150
August 30th, 2013

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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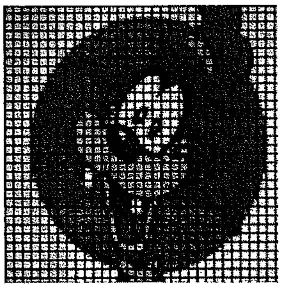
1. Basic optical imaging (4p)

A simple imaging system consists of two thin lenses spaced 12 cm apart, each with focal length f = 3 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 red laser beam incident along the optical axis.
a) What is the magnification of the imaging system? (1p)
b) What is the spatial resolution of the imaging system according to the Rayleigh criterion if the diameters of the lenses are D=4 cm? (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. Contrast mechanisms in optical microscopy (4p)

a) Small particles scatter light according to the formula
$\sigma_{scat}(\omega) \propto \omega^4 |\alpha(\omega)|^2$
What is the meaning of the quantity α and how does the formula explain why the sun becomes more red at sunset and sunrise? (2p)
b) 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 and non-radiative decay. (2p).

3. Modern optical microscopy methods (4p)

a) In a few sentences and drawings, describe the basic principles and use of **two** of the following techniques/phenomena (2p):
FRAP, FRET, NSOM, FLIM, SERS, NIM, FCS, DIC, TIRF
b) Localization microscopy (PALM/STORM) is a novel method that allows one to perform optical imaging with spatial resolution that is substantially better than the "Abbe limit". Explain the working principles behind localization microscopy using some simple drawings and a short text. How is Abbe circumvented? (2p)

4. SEM (3p)

a) Draw the electron beam specimen interaction volume for a bulk specimen in a SEM. Mark typical interaction volumes for secondary electrons, backscatter electrons and X-rays (1p)
b) What is the effect of a lower acceleration voltage on the interaction volume? Explain your answer. (1p)

c) The objective aperture affects the depth of focus in the image. What is the effect of a larger aperture? Explain your answer. (1p)

5. EDS (3p)

a) Draw a schematic diagram of the fluorescence yield of K, L and M lines as a function of Z. (1p)

b) Assume that you have one bulk specimen and one thin specimen with a thickness of 50 nm. Does this give a difference in spatial resolution between the two samples for
   a. secondary electron images?
   b. EDS concentration profiles?

   Explain your answer. (2p)

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? (0.5p)

c) In which plane along the optic axis is the selected area aperture positioned? (0.5p)

d) What effect has the objective aperture on the spatial resolution of the image? (0.5p)

e) How is phase contrast obtained by using the objective aperture? (0.5p)

7. Electron diffraction (3p)

The diffraction patterns in Fig. 1 are obtained for a FCC crystal using a TEM operated at 300 kV.

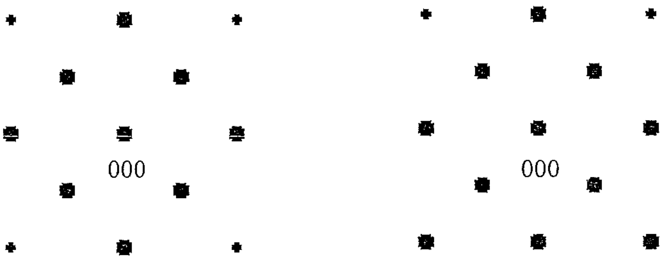
a) Index the pattern. Explain how you check the validity of your indices. (1p)

b) One of the patterns in Fig.1 is obtained with the electron beam incident along the zone axis. Which one? Explain your answer. (0.5p)

c) Draw the Kikuchi lines corresponding to the 8 diffraction spots closest to 000 in the pattern that you choose in Question 6a). (0.5p)

d) The other pattern in Fig. 1 is obtained after rotation around one axis. Which one? Explain your answer. (0.5p)

e) What is the effect on the Kikuchipattern when the specimen is rotated? Explain your answer. (0.5p)



a) b)

Fig. 1. Diffraction patterns from a FCC crystal.

8. EDS in TEM (3p)

An EDS-analysis is carried out in a TEM at 100 kV. The spectrum shows K-lines from Si, Ca and Cu. The number of counts summed over the energy ranges corresponding to the Si, Ca and Cu lines are 18 300, 45 700 and 89 000 respectively. The background intensities are 120, 230 and 350 counts. The specimen thickness is 50 nm and the probe diameter is 0.5 nm.

a) Which background intensity belongs to Si, Ca and Cu? 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 quality and spatial resolution of the analysis. (0.5p)

9. SPM (3p)

a) What is the common denominator of all SPM techniques? (1p)

b) Explain three inherent issues of the piezoelectric materials in in the SPM scanners. (1.5p)

c) Draw the path of the AFM tip apex as it is scanned across the different features on the surface in Fig. 2. (0.5p)

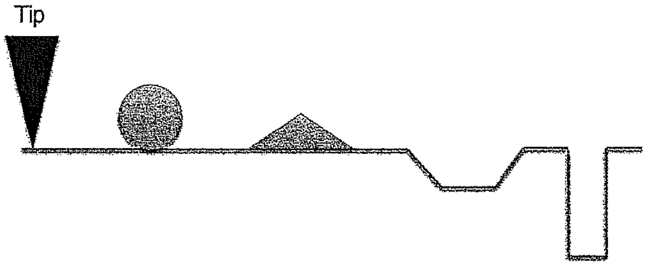
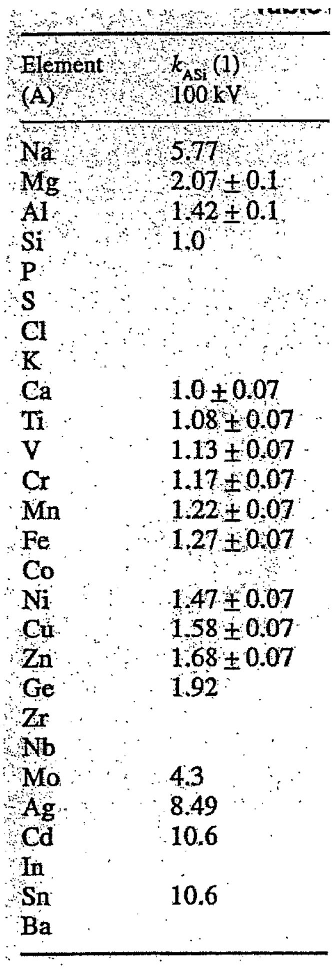


Fig. 2.

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	

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

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

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

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

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

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

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