Modern Imaging, Spectroscopy and Diffraction Techniques

TIF 030 and FIM 150
October 22^{tnd}, 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

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1. Basic imaging (3p)
A 4f correlator consists of two lenses with focal lengths f spaced 2f apart. Imagine an object positioned at the regular position f in front of the first lens.
a) What kind of screen could be used to decrease the image resolution in a controlled way? How and why would it work? (1p)
b) How could one move the lenses and object to obtain an upright image that is magnified two times? (2p)

2. Classical sources of contrast (2p)
a) Why is the sun red at sunset? (1p)
b) How is a "phase object" imaged in a phase contrast microscope? (1p)

3. Fluorescence microscopy (3p)
a) What are the constituents, optical properties and use of a filter cube for fluorescence microscopy. (1p)
b) A confocal microscope equipped with an objective with 100x magnification and NA=1.4 is used to image cells stained with Rhodamine 6G (λ_{abs}=530 nm). What is the ideal diameter of the confocal hole for these conditions? What happens to the image if one increases or decreases the diameter of the hole compared to the ideal case? (2p)

4. Optical Nanoscopy (4p)
STED microscopy and localization microscopy (PALM/STORM) are two novel methods that allows one to perform optical imaging with spatial resolution that is substantially better than the "Abbe limit".
a) Explain the working principles behind STED and STORM using some simple drawings and a short text. How is Abbe circumvented? (2p)
b) Compare the pros and cons of the two methods in terms of simplicity, speed, cost, experimental complexity, experimental restrictions, fluorophores needed etc. (2p)

5. SEM (4p)
a) Describe spherical aberration in electron microscopy? (0.5p)
b) Describe chromatic aberration in electron microscopy? (0.5p)
c) List the three types of electron sources. (1.5p)
d) Which electron source gives the best spatial resolution? Explain your answer. (0.5p)
e) What is the most critical parameter that limits the spatial resolution for secondary electron imaging and backscatter electron in the SEM (1p)

6. EDS (2p)

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

b) What factors determine the spatial resolution in EDS analysis in the SEM? Answer the question for both a thick bulk specimen and a thin specimen. Is there a difference between the two cases? (1p)

7. 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)

8. Electron diffraction (3p)

The diffraction patterns in Fig. 1 are obtained for a BCC crystal using a TEM operated at 200 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)

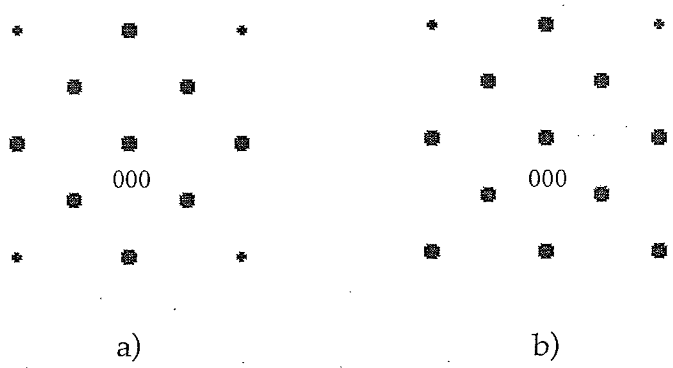

Fig. 1. Diffraction patterns from a BCC crystal.

9. 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 27 300, 11 700 and 19 000 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 quality and spatial resolution of the analysis. (0.5p)

10. 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)

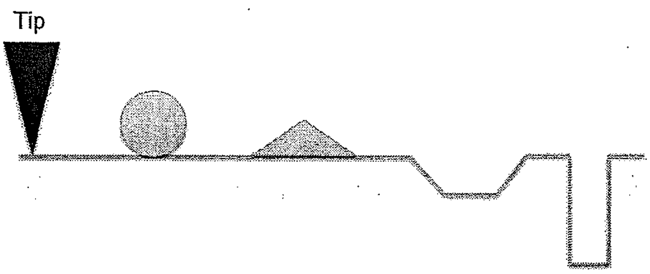

Fig. 2.

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	

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

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

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

$n > (5/C)^2$

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

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

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