Modern Imaging, Spectroscopy and Diffraction Techniques

TIF 030 and FIM 150
October 24th, 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. OM (4p)
a) You are observing a sample in transmission using an upright microscope equipped with infinity corrected optics. Sketch the image forming path from the lamp filament to the retina of the eye and mark all conjugate planes. (3p)
b) How does the numerical aperture (NA) of an objective affect its light gathering ability and the resolution of the image? (1p)

2. OM (3p)
a) Draw a Jablonski diagram of the low-energy quantum levels of a typical molecule and mark the following processes with arrows 1) fluorescence excitation; 2) vibrational relaxation; 3) intersystem crossing, 4) phosphorescence. (2p)
b) What is the characteristic time-scale for 1) fluorescence, 2) vibrational relaxation, 3) phosphorescence? (1p)

3. OM (3p)
a) What do you think are two most important factors that limit spatial resolution in STORM/PALM? (1p)
b) What do you think is the main advantage and the main disadvantage of SIM compared to STORM/PALM and STED? (1p)
c) Describe the photophysical processes of importance to sub-wavelength resolution in STED based on a Jablonski diagram for a molecule residing in the peripheral part of the laserspot in a STED microscope (1p).

4. OM (3p)
A tightly focused laser beam illuminates a small glass bead in water. Using appropriate drawings, explain which forces that the laser beam exert on the bead and how these forces can be utilized for moving the bead. (3p)

5. SEM (3p)
a) What type of samples can you image in the SEM? Which are the limitations? (1p)
b) What type of electron source would you like to use for obtaining the best possible spatial resolution. Explain your answer (0.5p)
c) Draw schematically the interaction volume for 20 kV electrons hitting a Ni sample. What signals are generated and from which depths are they coming? (1p)
d) What happens to the interaction volume in (c) if the accelerating voltage is lowered to 5 kV? (0.5p)

6. TEM (3p)

a) Describe mass-thickness contrast in the TEM. Draw a ray diagram to show how this works. Include the specimen and the objective lens in the diagram. All other lenses can be omitted. (1.5 p)
b) How is amplitude contrast obtained by using the objective aperture? (0.5p)
c) The objective aperture is positioned according to Fig. 1. What will you see in the image? Make a drawing. (1p)

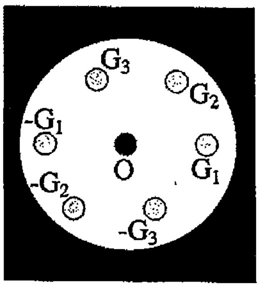

Fig. 1. Position of the objective aperture in a diffraction pattern

7. Electron diffraction (3p)

The diffraction pattern shown schematically in Fig. 2 is obtained for a gold crystal (FCC). The planes corresponding to points A and C are at perfect Bragg positions.

a) Index the pattern. Explain how you check the validity of your indices. (1p)
b) Draw the Kikuchi lines corresponding to A, B, C and D. (0.5p)
c) All of the diffraction spots in the schematic DP in Fig. 2 have the same intensity. Is this a valid representation? Explain your answer. (0.5p)
d) What are the differences between a selected area electron diffraction (SAED) pattern and a convergent beam electron diffraction (CBED) pattern? Are there any advantages of using CBED instead of SAED (1p)

8. STEM, EDS and EELS (4p)

(a) There are three main parts of EELS spectra. Describe them. (1p)
(b) You are to investigate the presence of light elements like oxygen and nitrogen in a TEM specimen. Would you prefer EDS or EELS? Why? (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. (1)
(d) How should the grain boundary plane in (c) be oriented with respect to the incident electron beam? How is this achieved practically? (1p)

9. SPM (4p)

(a) Draw an STM tube scanner's electrodes+piezoelectric tube arrangement. How do you apply voltage to get bending (lateral movement)? (1p)
(b) Give expression for the tunneling conductance, assuming low temperature and known tip density of states (DOS). Give the typical detected tunneling current in a low-temperature STM experiment under applied bias voltage of 10^{-2} V: microampere (μA), picoampere (pA) or nanoampere (nA)? (1p)
(c) In AFM you could encounter artifacts in your images originating from either the tip or the scanner. One artifact related to the tip is the broadening effect. Picture that you are imaging a

DNA strand on a flat surface (rigidly attached) with a tip that has a radius of curvature of 15 nm. If you approximate the DNA strand to a cylinder with a radius of 2 nm, how wide would it appear in your image? Further, how high would such DNA appear in the image? (2p)

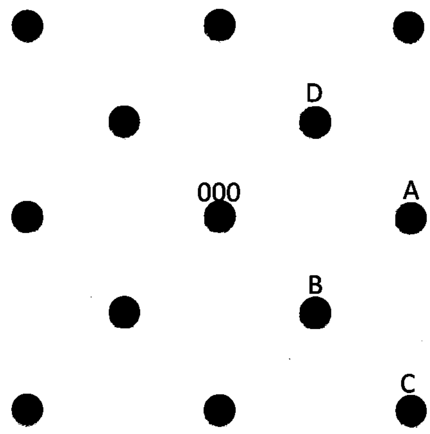

Fig. 2. Diffraction patterns from a gold crystal.

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	

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

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

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

$n > (5/C)^2$

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

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

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