Modern Imaging Methods

TIF 030 and FIM 150
Wednesday October 21st, 2009, 14-18
V Building

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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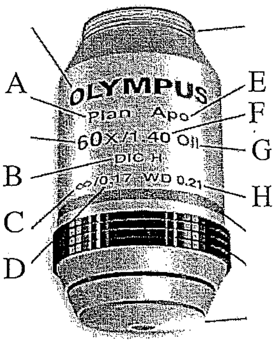
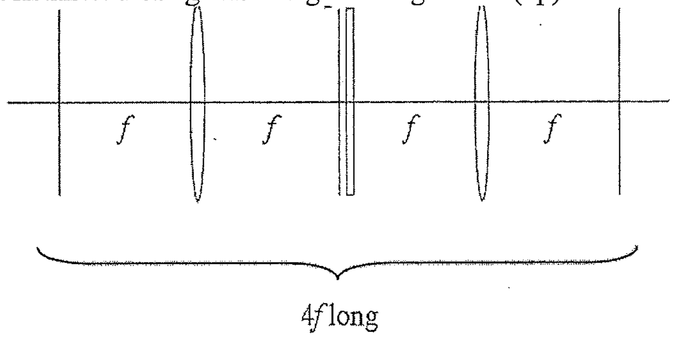
1) Basic optical microscopy (4p)

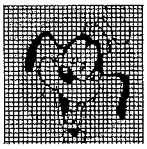


(a) The inscriptions on a microscope objective contains important information on its use. What does A-H in the picture stand for? (1p)

(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) The picture below shows a so-called 4f correlator that consists of two lenses with focal length f spaced 2f apart. The Goofy slide is placed in the object plane and is illuminated by a laser beam incident along the optical axis. Explain 1) how a spatial filter could be used to remove the raster pattern from the image, 2) how a spatial filter could be used to see the image against a dark instead of against a light background. (2p)





2) Contrast in optical microscopy (3p)

Based on energy level diagrams, explain fluorescence/Förster resonance energy transfer (FRET), how it can be measured, why it is useful.

3) Modern optical microscopy methods (3p)

a) What is the meaning of the auto-correlation function $G(\tau)$ in FCS and what can one learn from it? (1p)

b) What is the meaning of "confocal" in confocal microscopy and why is it important? (1p)

c) Based on a simplified ray-optics diagram, explain why an object is drawn to the laser focus in an optical tweezers. (1p).

Question 4: SEM (3p)

a) The depth of field is significantly larger for the SEM compared to the optical microscope. What determines the depth of field in an SEM? Calculate the depth of field for an image recorded at 20 kV, 7 mm working distance, 30 μm aperture and 40 000 times magnification. (2p)

b) The scan speed is increased. Will the image quality be the same, noisier or less noisy? Explain your answer. (1p)

Question 5: EDX (2p)

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

b) Is the detection limit better for light or heavy elements? Explain your answer. (1p)

Question 6: 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 6b). (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 for 6d)? Explain your answer. (0.5p)

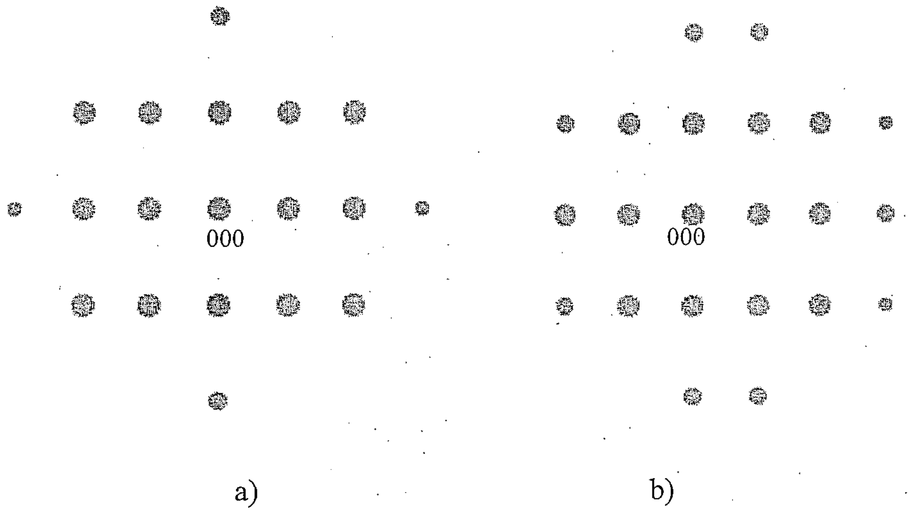


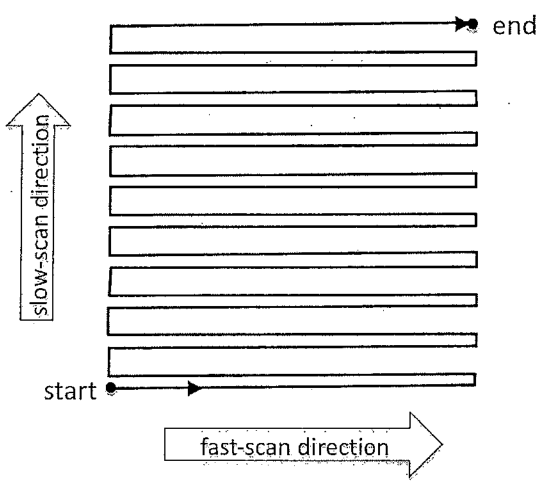
Fig. 1. Diffraction patterns from a BCC crystal.

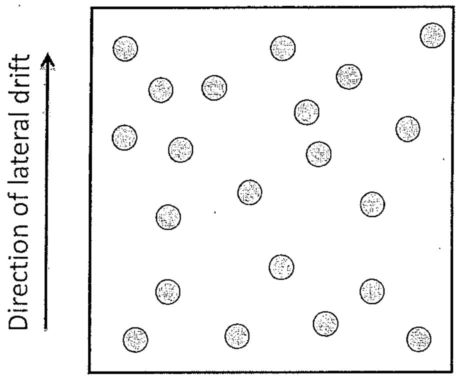
Question 7: TEM (3p)
a) Draw a schematic ray diagram that shows how a diffraction pattern and an image are formed in the TEM. Include the specimen and the objective lens in the diagram. All other lenses can be omitted. (1p)
b) Describe how Bright Field and Dark Field images can be obtained. Which aperture is used? (0.5p)
c) How is a high resolution TEM image obtained? (0.5)
d) Which are the two most critical parameters that limit the spatial resolution in the high resolution TEM image? (0.5p)
e) What is the role of the first and second condenser lenses? (0.5p)

Question 8: Analytical EM (3p)
An EDS-analysis is carried out in a TEM at 100 kV. The spectrum shows K-lines from Mg, Zn and Mo. The number of counts summed over the energy ranges corresponding to the Mg, Zn and Mo lines are 32 700, 8 900 and 13 200 respectively. The background intensities are 150, 340 and 570 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. You can vary the acceleration voltage. Would you choose a higher, lower or the same voltage to improve the spatial resolution of the measured concentration profile across the boundary? Explain your answer. (0.5p)

Question 9 SPM- drift and noise issues (3 points)
Drift and noise are serious issues, which need to be carefully considered whenever acquiring and interpreting SPM images.
a) What is the most common source of drift in SPMs? (0.25 points)
b) Assume that you have a vertical drift in your AFM, which drives the tip towards the sample at a constant speed of 1nm/sec; assume that there is no lateral drift. Will you be able to run the AFM in constant-height and/or constantforce contact mode despite this drift? Decide for each of the two modes if this is possible, and if yes, describe how this drift will affect your image(s)? (1.0 points)
c) Assume now that you have no vertical drift, but a significant lateral drift along the slow scan direction. You run the AFM in constant-force contact mode and try to image round features on a flat surface (see schematic below for an explanation of "slow-scan" direction and sample geometry). How will lateral drift affect the shape of the features? Does your answer depend on whether the slow-scan direction is from "bottom-to-top" (as shown in the schematic) or from "top-to-bottom" (i.e. opposite to what is shown in the schematic)? (0.5 points)
d) How can you minimize the effects of the lateral drift in c)? (0.25 points)
e) You observe periodic features in one of your SPM images, which you suspect to be related to electronic noise rather than real surface features. How can you check whether you are indeed looking at electronic noise? (0.25 points)
f) Assume that you have acquired a new AFM and that you need to find a place to set it up. List three characteristics of the "optimal room" for your new instrument!

(0.75 points)


Scanning path:


Sample to be imaged (seen from top):

Question 10- SPM: scanning tunneling microscopy – STM (3 points)

a) Describe three main aspects concerning the principle and operation of a scanning tunneling microscope. (0.75 points)

b) In constant-current mode, one sometimes records significant height variations when imaging samples, which are known to actually exhibit a completely flat topography. What could be the origin of these "artificial" height variations? List two possible origins. (0.5 points)

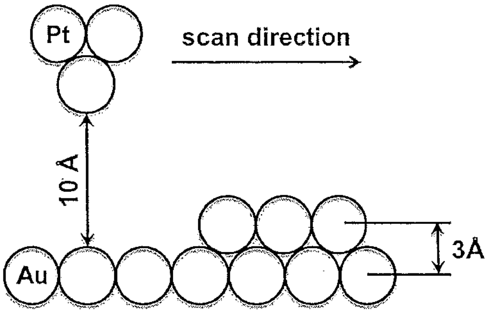
c) What requirements do a material, from which you would like to fabricate STM tips for imaging in air, have to meet? List two requirements! (0.5 points)

d) If you had infinite resources at hand and were asked to fabricate the best STM tip ever, how would its shape look like? (0.25 points)

e) Assume that you use a platinum tip to image a step on a gold surface using a total tunneling current of 1 nA and a bias voltage of 0.01 V (see schematic below). How would the step on the surface be imaged in constant-current mode? Calculate both the z-position and the current after passing the step (0.5 points)

f) Will the tip-sample distance increase or decrease if you change the bias voltage in e) from 0.01V to 0.02V while keeping the current constant? (0.25 points)

g) You would like to measure the exact spacing between (identical) metallic nanoparticles, which are arranged in a regular lattice on a glass substrate. The diameter of the dots is roughly 2-3nm and their spacing is expected to be in the 20-30nm range. Can you use STM to tackle this task? Motivate your answer briefly. (0.25 points)


Pt
scan direction
10 Å
3Å
Au

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	

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

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

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

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

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

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

$$I \propto U\rho_s(E,r)\, e^{-2\frac{\sqrt{2m_e(\phi - E_F)}}{\hbar}d}$$

Thermal expansion coefficient of piezo materials: $4.7 \cdot 10^{-6}\ K^{-1}$