Modern Imaging Methods

TIF 030 and FIM 150

Thursday October 23rd, 2008, afternoon

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

Question 1: Basic microscopy (3p)

a) Make schematic drawings of the illumination and imaging paths according to the Köhler design for an inverted optical microscope equipped with an infinity corrected objective. Mark the different conjugate planes and parts of the microscope. (2p)

b) What is approximately the smallest distance between two point-like objects that one can resolve using the highest resolution classical optical microscope available on the market and using visible light? (1p)

Question 2: Contrast (4p)

a) Why is the sky blue and the sun red at sunset? (1p)

b) What is the principal advantage of GFP and other fluorescent proteins compared to traditional fluorophores in biology research? (1p)

b) A "4f correlator", i.e. two thin lenses with focal length f spaced 2f apart, is used as an imaging system with magnification M=1. The object is a Goofy slide illuminated in transmission mode using a collimated beam of light incident along the optical axis. How could one interfere with the image path so that the result is 1) a softer image, i.e. with less detail than originally, 2) an image with details against a dark background instead of against a bright background? (2p)

Question 3: Modern optical microscopy (3p)

In a few sentences and drawings, describe the basic principles and use of **three** of the following techniques/phenomena (1 p each):

FRAP, FRET, NSOM, FLIM, SERS, NIM, FCS, DIC, TIRF

Question 4: SEM (3p)

a) Which are the three most critical lens aberrations in electron microscopy? (1p)

b) Which electron source gives the best spatial resolution? Explain your answer. (0.5p)

c) 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 (1.5p)

Question 5: EDX (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)

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)

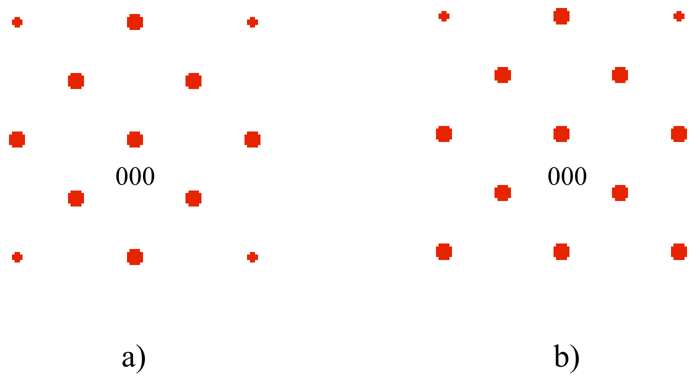


Fig. 1. Diffraction patterns from a BCC crystal.

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 an image showing phase contrast obtained in a TEM? (0.5)

d) How is an image showing amplitude contrast obtained? (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 Al, Ti and Mo. The number of counts summed over the energy ranges corresponding to the Al, Ti and Mo lines are 21 300, 16 700 and 12 000 respectively. The background intensities are 100, 210 and 300 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)

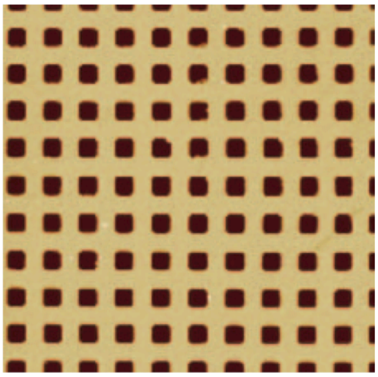
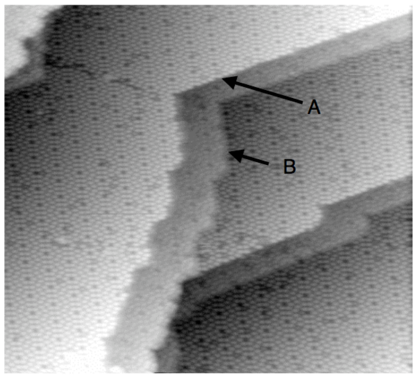
b) Calculate the composition in weight per cent. Neglect the absorption. (2p)

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 of the analysis. (0.5p)

Question 9: SPM- image artifacts (3p)

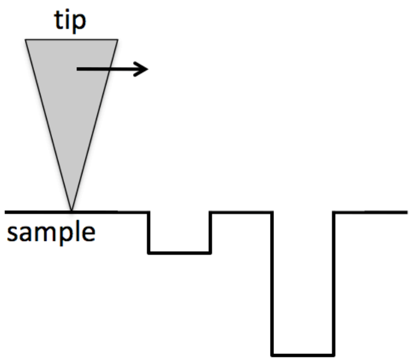
SPM images are often affected by artifacts of various origin. This question deals with the sources of image artifacts, how they are expressed in images, and how they can be reduced or avoided.

a) The tip is often a critical parameter for obtaining good AFM images, and AFM images are often affected by tip artifacts. Can you identify any tip artifact(s) in the two images below? If yes, which one(s)? (0.75p)

Image:		
Artifact(s) in image? (yes/no)		
If yes, which one(s)?		

b) Suppose that you are acquiring constant-height contact mode images with the (imaginary) AFM-tip / sample combinations below. Schematically draw the path of the tip apex for each of the two situations (directly in the schematic)! If applicable, describe what types of artifacts the respective tip/sample combination will suffer from. (0.75p)

Tip-sample combination 1:



Artifacts for tip-sample combination 1: ______________________________

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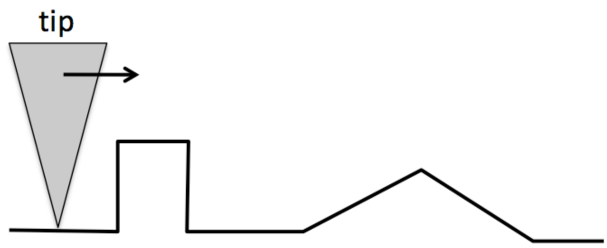
Tip-sample combination 2:



Artifacts for tip-sample combination 2: ______________________________

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c) Is STM as susceptible to tip artifacts as AFM? Briefly motivate your answer! (0.25p)

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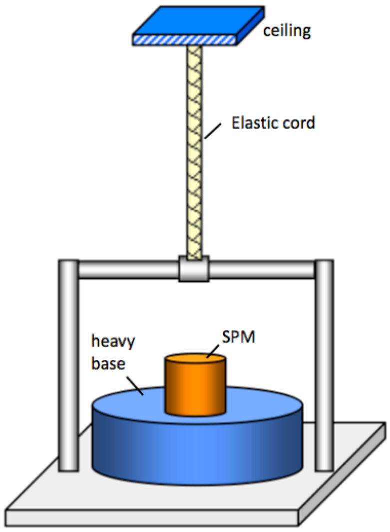
d) The schematic below illustrates a simple setup, which helps to reduce a great deal of noise in SPM images. What type of noise will such a setup remove and what is the physics behind it? (0.5p)



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e) Do you know any other sources, which can give rise to artifacts in SPM images and which have not been mentioned above? List three of them! (0.75p)

Source 1: ____

Source 2: ____

Source 3: ____

Question 10: SPM- matching measurement situation and analytical technique (3p)

Different applications may pose very different requirements to an analytical technique, and people with different backgrounds oftentimes ask very different questions. The "art" is to formulate well-defined questions, and to then select an analytical technique, which can provide a clear answer to these questions.

a) For the measurement tasks described below, decide if any of the SPM techniques treated in the lectures (STM, AFM (including variations thereof), and SNOM) would be able to tackle the respective problem. If yes, indicate which technique you think is suited best! Give a short motivation for your answers, also in cases where you think that none of the SPM techniques is suitable! Please compile all your answers in the table below the task descriptions. (0.5p per task, i.e. 2.5p in total)

Task 1: you would like to measure the exact spacing between (identical) metallic dots, which are arranged in a regular lattice on a glass substrate. The diameter of the dots is roughly 5-10nm and their spacing is expected to be in the 80-100nm range.

Task 2: you would like to determine the crystallographic structure of a thin Fe-Cr-Ni film (ca. 100nm thick) on a conductive carbon support, and you would like to know how the crystallographic structures changes upon annealing of the film.

Task 3: you would like to investigate the (comparably fast) diffusion of oxygen atoms on a Ru(0001) single crystal surface (very flat) at slightly elevated temperature. The size of an oxygen atom is on the order of 6Å.

Task 4: you would like to measure the lateral (frictional) force between silicon and gold for small contact areas (in the nano-range). You need to vary the normal force and the sliding speed.

Task 5: you have a glass substrate, which is covered by randomly distributed gold and silver nanoparticles. Assume that all nanoparticles have the exact same size and shape, independently of whether they are made from Au or Ag; their diameter is about 50nm and the spacing is about 200-300nm. You would like to determine the relative amounts of Au and Ag nanoparticles. (Are there as many Au nanoparticles as Ag nanoparticles, or do particles of one sort prevail?)

Task:	Can you use SPM? (yes/no)	If SPM is suitable, which technique would you choose?			Motivation
		STM	AFM	SNOM	
1					
2					
3					
4					
5					

b) For all tasks above where you have selected STM as the most suitable analytical technique, decide whether there is a preference to run the experiment in either constant-height or constant-current mode! Motivate your answer. (0.5p)

Task:	Is there a preferred imaging mode?			Motivation
	No.	Yes, constant height.	Yes, constant current.	

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: $4.7 \cdot 10^{-6}\ K^{-1}$