Exam on AM003 “Characterization of Materials”

Coordinator: Maxim Pchenitchnikov

Thursday April 10, 2014; 5115.0013, 9:00 – 12:00

Answers to the questions can be written in both **Dutch or English**

Name:…………………………………………………………………………………….

Student Number: ……………………………………………………………………..

For administrative purposes; do NOT fill the table

	Maximum points	Points scored
Question 1	15	
Question 2	15	
Question 3	15	
Question 4	15	
Question 5	20	
Total	**80**	

The final mark is calculated proportionally on basis of the maximum score of 80

Final mark: _________

Question 1. Electron Microscopy and Electron Diffraction

a. Phase contrast imaging with an optical (light) microscope requires the insertion of a so-called phase plate. What position the phase plate has to be inserted and what is its function? Thus, explain briefly how the phase-plate works and why its function is important. (3 points)

b. Draw typical phase contrast transfer functions (PCTF) for a light microscope using phase contrast (i.e. with phase-plate inserted) and for a transmission electron microscope near optimum defocus; indicate in the latter the position corresponding to the point resolution of the TEM. (3 points)

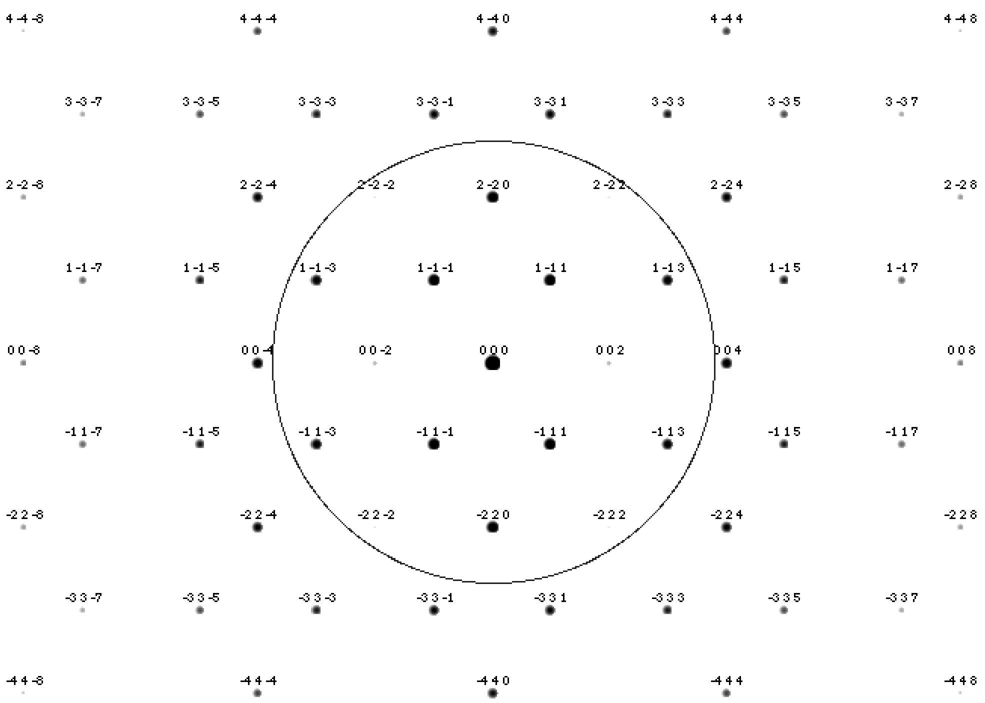
The electron diffraction pattern given below (see next page) holds for a thin crystal (4 nm) of silicon (having the cubic diamond structure). The circle indicates the objective diaphragm (aperture) used for High-Resolution TEM imaging (only the intensity in the diffraction pattern within the diaphragm contributes to the image intensity). This aperture has a radius of 0.7 reciprocal Ångstrom ($Å^{-1}$).

c. Along which zone axis of the crystal the diffraction pattern was recorded, i.e. which crystal direction was parallel to the incident electron beam? Explain how you derive your answer. (2 points)

d. Estimate the lattice constant of silicon (can even be done fairly accurate without using a ruler). Indicate clearly how you obtain your answer. (3 points)

e. In *fcc* crystals reflections like the 001 and the 110 are not present in diffraction patterns. Explain why these reflections are absent. (2 points)

f. On top, in crystals with diamond structure additional reflections, e.g. the 002, are forbidden. Nevertheless, a very weak 002 reflection/spot can be recognized for this 4 nm crystal and the relative intensity of this spot increases for increasing crystal thickness. Explain why the 002 reflection can appear in electron diffraction and will not appear in X-ray diffraction. (2 points)



Question 2. Surface Techniques

Auger electron spectroscopy and X-ray photoelectron spectroscopy

a. Explain the basic physical principles of AES and XPS. (3 points)

b. How does the experiment work for each case and what can one learn from them? (3 points)

c. Why is in AES the intensity shown as a function of kinetic energy and in XPS as a function of binding energy and what are the advantages in doing so? How are the two scales converted into each other? (3 points)

Scanning tunneling microscopy and atomic force microscopy

d. What is the reason that adsorbates can appear as depressions in STM images? (2 point)

e. Comparing STM and AFM: which type of information can you obtain from STM but not from AFM and vice versa? (2 point)

f. What are the advantages/disadvantages of the constant height mode over the constant current mode? (2 points)

Question 3. Vibrational and vibronic molecular transitions

a. Sketch potential energy curves for a diatomic molecule in its ground electronic state and an excited electronic state, consistent with the following observation: (i) both potentials have identical shapes, and (ii) the strongest absorption band is 0 (ground state) -> 2' (excited state) (3 points).

b. Depict the strongest fluorescence transition (2 points).

c. Depict two vibrational transitions (2 points).

d. Formulate gross, specific (in harmonic approximation), and population selection rules for IR transition to be active (4 points)

e. Depict schematically Raman Stokes and anti-Stokes transitions (2 points)

f. Formulate the rule of mutual exclusion (2 points).

Question 4. X-ray diffraction measurements on a powder sample of iron metal

a. The unit cell of iron is cubic and contains atoms at the coordinates (0,0,0) and (½,½,½). Show that the condition for an *hkl* peak to have non-zero intensity is $h+k+l = 2n$. (3 points)

b. Do the 110 and 220 peaks of iron have the same intensity? Explain your answer. (2 points)

c. When a diffraction pattern of iron powder is measured using Cu $K\alpha_1$ radiation ($\lambda = 1.5406$ Å), the first peak is observed at $2\theta = 44.35°$. Determine the lattice parameter. (3 points)

d. Cesium chloride (CsCl) is also cubic with atoms at the same coordinates as iron: Cl at (0,0,0) and Cs at (½,½,½). However, the 210 peak of CsCl is observed whereas the 210 peak of iron is absent. Explain why. (2 points)

e. Mention two ways in which the powder diffraction pattern of iron (and also the diffraction pattern of most other materials) will change as the sample is heated above room temperature. (2 points)

f. When iron is exposed to an intense femtosecond laser pulse, a shock-induced phase transition to a hexagonal close-packed structure occurs. Briefly describe a possible X-ray diffraction experiment that could follow the structural changes on the picosecond time-scale. (3 points)

Question 5. You have made films of different materials and want to characterize their properties.

a. You have grown an Au film with lateral dimensions of 5mm × 5mm of approximate thickness 30 nm on a Si wafer, and you would like to verify its thickness. Describe two such techniques that are suitable for this task, explain their working principles, and list their advantages and disadvantages. (5 points)

b. You have a free-standing polymer film with lateral dimensions of 5mm × 5mm and a thickness of 10 µm, and want to obtain structural information from the entire volume of the film. Describe technique(s) that are suitable for this analysis. Explain briefly why. (5 points)

c. The structure of a film with a thickness of 10 nm has to be analyzed locally. Which techniques are suitable when the lateral structure needs to be determined on (i) the tens of nm length scale, (ii) the sub-nm length scale? Explain briefly why and describe the working principle of the suitable technique(s). (5 points)

d. Now you want to characterize a surface of the sample. Which technique(s) allow(s) the structure of a conducting / of an insulating substrate surface to be obtained with atomic resolution in real space? Explain briefly why. (5 points)