SURFACE PHYSICS EXAM

Please read all problems carefully before answering. Each problem is worth six points in total, with points for each sub-item given in the margin. Please remember to give numerical answers with the appropriate units.

PROBLEM I: Consider a crystal with FFC lattice structure, lattice constant d, and cohesion energy C.

a) Sketch the cubic unit cell of the FCC structure and highlight the (111) plane in it. *1 pt.*

b) Sketch the FCC(111) surface and mark the top, hollow site, and bridge high symmetry adsorption positions in it. *1 pt.*

c) What are the nearest neighbour distance and step height on the FCC(111) surface? *1 pt.*

d) In a different sketch, draw the $\sqrt{3} \times \sqrt{3}\,\mathrm{R}30°$ adsorption structure on the FCC(111) surface. *1 pt.*

e) Sketch the LEED pattern corresponding to the FCC(111) surface with a $\sqrt{3} \times \sqrt{3}\,\mathrm{R}30°$ adsorption structure. *1 pt.*

f) What is the formation energy for a surface vacancy on the FCC(111) surface? *1 pt.*

Total: 6 Points

PROBLEM II: Scanning tunnelling microscopy

a) Briefly explain the operating principle of scanning tunnelling microscopy and why the technique is surface sensitive. *1 pt.*

b) What quantity is measured by conductance spectroscopy? *1 pt.*

c) How does the density of states of nearly free electrons in two dimensions depend on energy? *1 pt.*

d) Sketch the tunnel conductance measured from the surface state of a Au(111) surface as a function of bias voltage. Au(111) hosts a surface state with a band onset 0.5 eV below the Fermi level. *1 pt.*

e) How does the tunnel current depend on the tip-sample distance? Give a formula. *1 pt.*

f) Model the tip as a close-packed cluster of four Copper atoms, one at the apex and three more in the second layer. What fraction of the tunnel current originates from the tip atom? Copper crystallises in the FCC structure with lattice constant 361 pm and has a work function of 4.7 eV. *1 pt.*

Total: 6 Points

PROBLEM III: You are working on a research project to synthesise and characterise thin films of a novel material. Which experimental techniques would you use to

a) Determine whether your samples have the desired chemical composition and are free of contamination? *2 pts.*

b) Ensure your samples are ordered and measure their crystal structure? *2 pts.*

c) Determine the band structure of your samples and measure the Fermi energy? *2 pts.*

In each case, explain your choice in a few sentences and describe how the technique you chose can answer these questions.

Total: 6 Points

PROBLEM IV: A photoelectron spectroscopy experiment on a Na(100) crystal with 100 eV beam energy yields the data shown in the figure below.

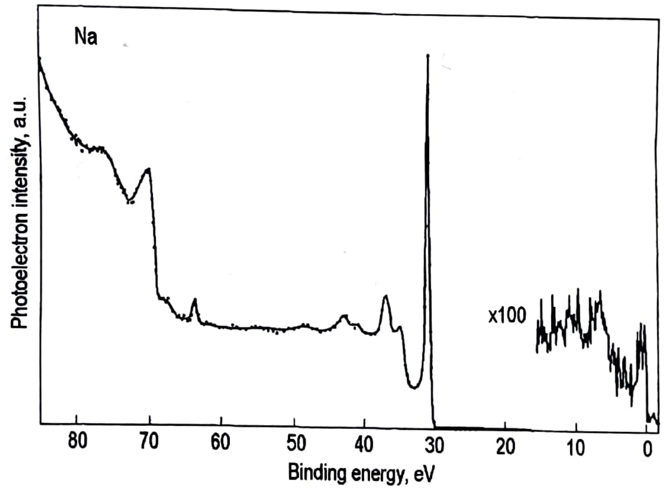

Figure 1: Photoelectron spectrum from a Na(100) sample.

a) What quantity is measured by the detector in a photoelectron spectroscopy experiment? *1 pt.*

b) How can the data be converted into electron binding energies? Give a formula. *1 pt.*

c) In a few words, explain how can you recognise which peaks correspond to electrons escaping the sample without losing energy in inelastic collisions. *1 pt.*

d) Mark the inelastic peaks in the spectrum above and write down the corresponding excitation processes. *1 pt.*

e) One of the peaks corresponds to an Auger transition. Mark it in the spectrum an write down the corresponding Auger process. *2 pt.*

Additional material for problem IV: Binding energies of Na valence electrons

Level	1s	2s	2p	3s
Energy	1075	63	31	1

Total: 6 Points

Problem V: You perform an ARPES experiment with 50 eV beam energy on a graphene sample. The band structure and first Brillouin zone of graphene are shown in the figure below. The K and K' points lie at $\vec{k}_{\|}^{K/K'} = \frac{4\pi}{\sqrt{3}a}\left(\frac{\sqrt{3}}{6}, \pm\frac{1}{2}, 0\right)$, where a is the lattice constant. The graphene lattice constant is 246 pm and the work function 4.6 eV.

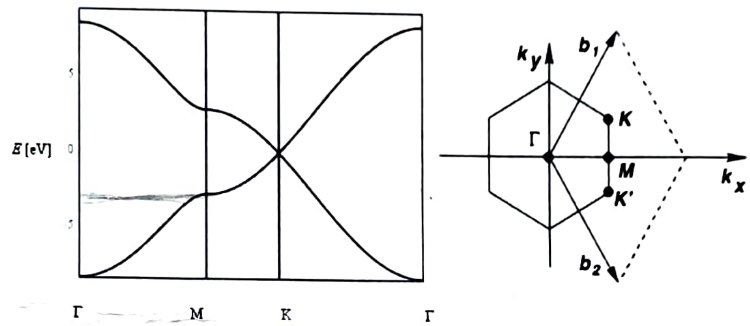

Figure 2: Graphene band structure and first Brillouin zone.

a) What will be the kinetic energy of electrons from the M-point? *1 pt.*

b) Under what angle do electrons from the Γ-point exit the sample? *1 pt.*

c) Under what angle to electrons from the K and K' points exit the sample? *2 pts.*

d) Sketch the ARPES signal (binding energy over $k_{\|}$) you expect to see for momenta close to the K point in a pristine sample. *1 pt.*

e) You dope the graphene by depositing a small amount of sodium on the sample. Sketch the ARPES signal for momenta close to the K-point on the doped sample. *1 pt.*

Total: 6 Points