EXPERIMENT III

SCANNING TUNNELLING MICROSCOPE (STM) **(Special hand-out)**

If you decide to perform this experiment, ask the instructor for a copy of the **burleigh**™ *Instructional Scanning Tunnelling Microscope* manual or download the manual from the course web site. The principle of operation of a STM and the details of the experimental procedures are fully described in the instrument manual (photocopy available from the course web site).

1. Safety

The experimental set-up itself does not present special hazards; just be aware that you are in a chemistry laboratory and that hazardous material may be handled around you. It is mandatory to wear safety goggles at all time in this setting.

2. Experiment

Perform the experiment described in section 4.1 of the STM manual, *Scan of a Holographic Gold Grating.*

* An image has to be loaded to activate the various menu items.
* Scan Configuration (Menu item: Collect -> Configure)
  First optimize the conditions (in particular the "Scan delay") to obtain a reasonably sharp images of the gold grating at a magnification of 76000x76000 Å; save this image. Then before disturbing the set-up obtain right away a series of scan at different magnifications simply by changing in the configuration menu the scan range (do not forget to save the picture after every new scan); suggested scan ranges are: 50000x50000 Å, 30000x30000 Å, 20000x20000 Å, 10000x10000 Å, 5000x5000 Å.
* Picture processing (process in turn each saved picture).

Note that the present software does not offer a print option; to export a picture appearing on the screen, use the "PrintScreen" *key to copy the "screen" to the Clipboard which can be pasted into a MS-Word document, then printed on the printer attached to the computer controlling the STM.; do include these pictures in your report.*

1) If the picture is unevenly lit (ie, one side of the picture is darker than the other side meaning that the sample as a whole is not resting horizontally), use the "Tilt removal" (Analysis -> Tilt removal). Print at least one sample image corresponding to each magnification.
2) You can see a 3D rendering of your pictures (Display -> 3-Dimension). Use the "Cross-Section" feature (Display -> Cross Section) to visualize the profile of the surface along a direction perpendicular to the orientation of the grating lines; depending on the regularity of the sample, you may want to obtain several "cross-sections" at different locations on the picture.

If these profiles are very noisy, you may want to process beforehand the picture to "smooth" out some of the noise; several "Filters" are available (Filter ->); you may have to try several of these to find which is the most suitable for your set of pictures. Get a printout of each of these cross-sections for later analysis.

* Before leaving, retract the tip and switch off the STM controlling unit. On the computer, exit the controlling software, exit window and switch the computer off.

3. Data Analysis and Discussion

Discuss the series of pictures obtained in term of the qualitative information they provide on the particular sample under observation.

On the printed out pictures, with a ruler measure (in mm) the line separation and the height (or depth) of the observed features; scale the measurements to obtain the real dimensions in Å. Indicate on the pictures where the measurements were taken. Tabulate clearly all these measurements obtained from each image to calculate the number of lines/mm on the grating and the depth of the grooves. Eventually merge all your measurements to report *one* set of final results (and the corresponding uncertainties); if you feel that some of the results need to be rejected or some of the images are unusable indicate clearly which ones and the reasons why.

Answer and discuss the following points:

1) Calculate the effective ohmic resistance of the tunnelling gap for the conditions used in your scans, then estimate the ohmic resistance in the situation of the tip touching the surface during a scan; knowing that the linear resistivity of gold is $10^{-8}\ \Omega\ cm^{-1}$; you'll need to make some assumptions about relevant dimensions (clearly state these assumptions). How do these two results compare and what do they tell you about the tunnelling process?
2) Usually the ohmic resistance of a metal increases with temperature; why? For a fixed applied voltage, what would be the net effect of a temperature rise on a current? What drives the electron flow in the case of tunnelling (see section 2 of STM manual)? Then, what would be the expected temperature dependence of this tunnelling current?
3) During adjustment, the tip approaches the surface until the preset tunnelling current is achieved. At this stage and before the scan is initiated, the tip is left stationary over the surface, at a fixed distance, maintaining the preset tunnelling current. Calculate the number of electrons/second which are flowing through the atoms involved in the tunnelling process between the tip and the surface. Compare this number to the number of atoms scanned at a particular magnification (one needs to assume the size of the atoms of the material scanned). What does it tell you about the tunnelling process?

4) The tunnelling current is proportional to the tunnelling transmission coefficient $T(E)$. The functional dependence of this transmission coefficient is:

$$T(E) \propto e^{-L\sqrt{2m\phi/\hbar^2}} \tag{1}$$

(see section 2 of the Burleigh STM manual) where L is the tunnelling gap, m is the electron mass, ϕ the work function (minimum energy to detach an electron from the metal surface) and $\hbar$ the Planck constant. Using eqn.(1), express the relative change of the transmission coefficient for a change dL of the tunnelling gap given by

$$\frac{1}{T(E)}\frac{dT(E)}{dL} \approx \frac{1}{T(E)}\frac{\Delta T(E)}{\Delta L} \tag{2}$$

From this, estimate the percent variation of the tunnelling current ($\Delta T/T$) for a change in L (ΔL) of 0.1 Å.; what does it tell you about the sensitivity of the technique?

5) The experiment is conducted in open air and the surface studied was not subjected to any special cleaning procedures. Consequently water vapour and other gases or contaminants may very likely be adsorbed on the surface (or on the tip). How can these molecules affect the tunnelling process? And, alternatively, can the tunnelling process change the distribution of the adsorbed species on the surface? Explain. How could this affect the aspect of STM scans?

6) In more general terms, can you think of applications for this technique? What is somewhat unique about the information provided by the STM, and are there other ways to get this information directly or indirectly?

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Chem 366W report check list

A report will not be accepted without all the items of this list checked. If a checked item is found missing in the report, the report will be automatically down-graded.

Student Name:____

Report: Scanning Tunnelling Microscope

Title page.

Correct title of the experiment .... ☐
Student Name & student ID .... ☐
Partner name (*if applicable*)____
Date of performance of experiment .... ☐
Abstract.. ☐
Introduction and theory .... ☐
Experimental
Changes from text description mentioned (*if applicable*).. ☐
Sample ID, ser no, stock solution …etc recorded (*if applicable*) .... ☐
Results
Results as Tables .... ☐
Graphs
 Size, at least ½ page .... ☐
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 Axis scales are sensible .... ☐
Only significant figures .... ☐
Uncertainties quoted .... ☐
Raw data provided (*electronic form, if applicable*) .... ☐
Calculations
Sample calculation provided .... ☐
Error analysis .... ☐
Sample error calculation provided .... ☐
Discussion
Comments on results .... ☐
Questions in text book and in manual answered .... ☐
Comparison with literature value(s) .... ☐
Conclusion.. ☐

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