A TEM STUDY OF ELECTRON TUNNELING IN BIOLOGICAL MACROMOLECULES

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Tunneling is a ubiquitous phenomenon. Alpha particle disintegration, the Stark effect, superconductivity in thin films, field-emission, and field-ionization are examples of electron tunneling phenomena. In the scanning tunneling microscope (STM) electron tunneling is used as an imaging modality. STM images of flat surfaces show structure at the atomic level. However, STM images of large biological species deposited onto flat surfaces are disappointing. For example, unstained virus particles imaged in the STM do not resemble their TEM counterparts.

It is not clear how an STM image of a biological species is formed. Most biological species are large compared to the nominal electrode separation of ~1nm that is required for electron tunneling. To form an image of a biological species, the tunneling electrodes must be separated by a distance that would normally be too large for a tunneling current to be observed. Furthermore, the tunneling current depends exponentially on the product of two quantities: the electrode separation, and the effective work function within the tunneling region. If a biological species caused the work function to vary within the tunneling region, the change in work function could be incorrectly interpreted as a change in the morphology of the species. To understand what an STM image actually records, the tunneling characteristics of biological species must be measured in an independent and unambiguous manner. A one-dimensional tunneling apparatus (used in conjunction with TEM imaging) has been designed and constructed for this purpose. In addition to a tunneling current, three essential parameters can be determined: (1) the actual separation of the tunneling electrodes, (2) the number of species within the tunneling area, and (3) the size, and the shape, of each species involved in the tunneling process.

Figure 1A shows a prototype tunneling apparatus mounted in the side-entry goniometer stage of a TEM. The electrode gap is uniquely defined between the highly curved apices of two field-emitter tips (Tip C and Tip A) whose separation is controlled by a PZT ceramic translator used to support one of them. This type of piezoelectric device is also used to control the separation of the tunneling electrodes in an STM. Figure 1B and Figure 1C are TEM images of two tungsten field-emitter tips that were prepared by conventional methods (the tip with the smallest apex radius of curvature defines the tunneling area). Figure 1D and Figure 1E show how the size, the shape, and the number of biological species within the tunneling area can be directly determined from a TEM image. Any biological species can be placed on a field-emitter tip from aqueous solution using a simple deposition technique.

References

FIG. 1.--An electron tunneling apparatus mounted in the side entry goniometer stage of a TEM (A); a TEM image showing the apex of a clean tungsten field-emitter tip with a large apex radius of curvature (B), and a clean tip with a small apex radius of curvature (C); a TEM image of a ferritin monolayer (D) and virus particles (E) on large radius tungsten tips. Note: marker refers to images (B)-(E).