

Scanning Tunneling Microscopy Studies of the Ge(111) Surface

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Abstract: This research project used a Scanning Tunneling Microscope (STM) to study the Ge(111) surface. The goals of this project were to obtain an atomically clean surface, dose it with Ag, and use the STM to obtain images of the phase transitions of Ag on Ge(111). However a clean surface was not obtained. The images revealed the surface was covered with contaminants and atomic resolution was not observed. Due to experimental difficulties the sample was scanned only four times. When a sample is maintained within the Ultra High Vacuum (UHV) system long enough to achieve an atomically clean surface the sample can then be dosed with Ag and scanned with the STM to observe the desired phenomenon.

Introduction: The Scanning Tunneling Microscope (STM) reveals a topographic image of a conducting or semi-conducting surface. It is capable of resolving individual atoms. The STM uses a very sharp tungsten wire (tip) that is brought within several Ångstroms of the sample. When a bias voltage is applied to the sample a quantum mechanical tunneling current is measured.¹ The tunneling current allows the tip to sense corrugations in the electron density of the surface that arise from the positions of the surface atoms.

The STM is used to probe the electronic properties of surfaces. It probes the charge density at the Fermi level rather than the total charge density. If a positive bias voltage is applied to the sample then electrons tunnel from the tip to the sample,

producing an image of the charge density of the lowest unoccupied states. If the sample is negatively biased, electrons tunnel from the sample to the tip thus producing an image of the charge density of the energetically highest occupied electron states on the surface.²

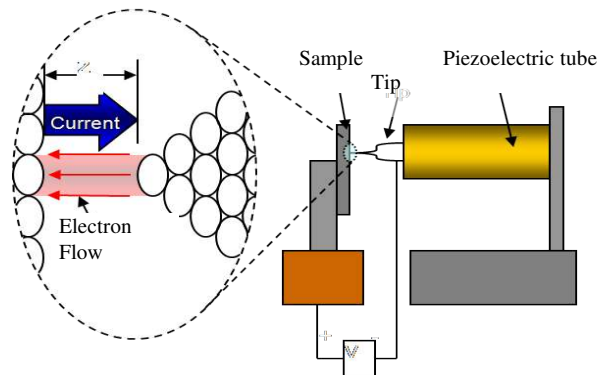


Figure 1. Schematic view of an STM. The tip is brought within a few Ångstroms of the sample. Tunneling junction is blown up to atomic scale.

The lateral resolution of an STM image depends upon the sharpness of the tip. The best resolution occurs when the tip is atomically sharp. Ideally the resolution obtained is 2 Å laterally and 0.01 Å vertically. The STM can operate in one of two modes: constant current mode or constant height mode. Figure 2 shows a schematic representation of each scanning mode.

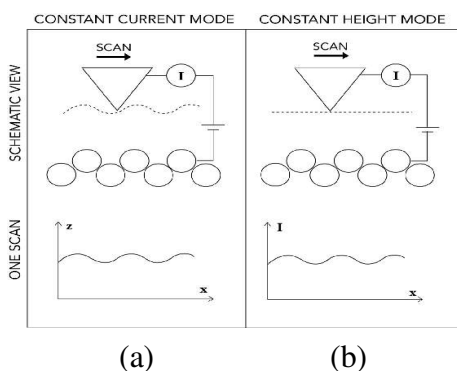


Figure 2. Schematic views of scanning a STM tip in (a) constant current mode and (b) constant height mode. An image consists of multiple scan lines.

In constant current mode the tip is scanned across the sample while the piezoelectric transducer, a ceramic material that expands or contracts in response to a change in the applied voltage (~ 100 Å/V), changes the height of the tip to maintain a constant current. The change in the applied voltage is controlled by a feedback loop. The distance between the tip and sample is kept nearly constant because the current varies exponentially with distance.¹ The z -position of the tip above the surface gives the sample topography.

In constant height mode, the tip is scanned across the sample at a nearly constant height and the current varies. In this mode the applied voltage across the piezoelectric transducer is held constant. This allows for a much faster scan rate of 1 kHz compared to the constant current mode

scan rate of ~ 10 Hz.¹ This method is used for atomically flat surfaces. The current variation is proportional to the sample topography.

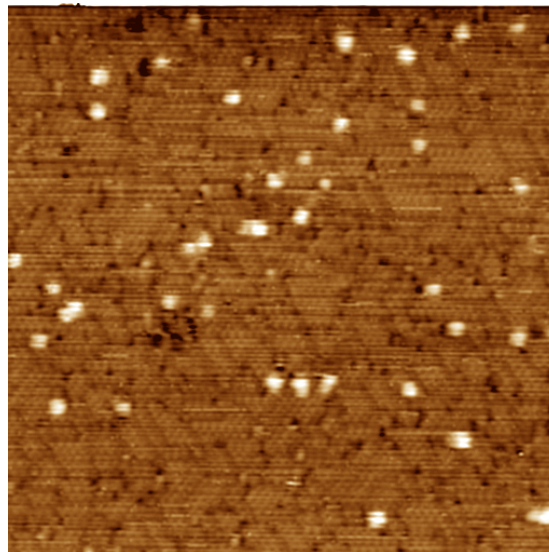


Figure 3. STM image of clean Ge(111) surface. Image taken by Cory Mullet. Size: 500 Å square. White spots are defects and contaminants and dark spots are vacancies. In this image you are able to see the individual Ge atoms. Brightness of image is proportional to height of tip above sample and therefore proportional to image topography.

Experiment: The research project involved preparing and scanning a Ge(111) sample. The goal was to obtain a clean sample and dose it with Ag to study the phase transitions of Ag on Ge(111). The sample was placed in an Ultra High Vacuum (UHV) system that contained an STM, X-ray Photoemission Spectrometer (XPS), and Low Energy Electron Microscope (LEEM) as shown in Figure 4. The cleaning of the sample took place in the XPS chamber and the scanning took place in the STM chamber. It was necessary to place the sample in a UHV system with a pressure of $\sim 10^{-10} - 10^{-11}$ Torr to keep the sample free of contaminants while conducting an experiment.

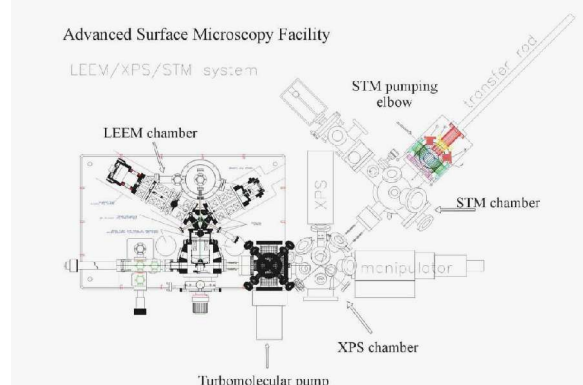


Figure 4. The UHV system in which the Ge(111) sample was prepared and scanned.

After the sample was placed in the UHV system the next step was to obtain an atomically clean surface. It was first degassed (heated) to remove adsorbed molecules. The degassing of the sample was done in the XPS chamber, where the sample was heated *in situ* for several hours. Degassing of the sample was only necessary when the sample was first introduced to the UHV system. Next, the sample underwent several cleaning cycles. Each cycle consists of sputtering the sample with Ar⁺ ions for 15 minutes and then annealing the sample for 10 minutes.

Ion bombardment with Ar⁺ ions removes more stubborn contaminants such as carbon, oxygen, and sulfur; but it can leave the surface disordered. The sample was sputtered with 250 eV Ar⁺ ions. Annealing the sample by electron beam bombardment reorders the surface but also causes contaminants within the bulk of the sample to diffuse to the surface. Multiple cycles of sputtering and annealing were required to create a depletion region near the surface that is free of contaminants. Annealing the sample reorders the surface to a c(2 x 8) crystal structure.

After the sample was properly prepared it was ready to scan. The sample was mounted

onto the STM stage and the tip was placed over the sample. The STM was operated in constant current mode. The bias voltage applied to the sample was -2.0 V. The piezoelectric transducers changes the height of the tip with respect to the sample until a tunneling current of ~ 0.500 nA is reached.

Results/Discussion: The sample was scanned multiple times before attempting to dose it with Ag. However the images obtained from the STM showed that the sample was still contaminated. Since the sample appeared dirty it was not dosed with Ag because it would be difficult to identify which structures in the image were Ag and which structures were contaminants.

The image resolution obtained was poor. Atomic resolution was not seen in any of the images. Morphological features such as monatomic steps and terraces were not seen in the majority of the images. However, large areas of contaminants were observed.

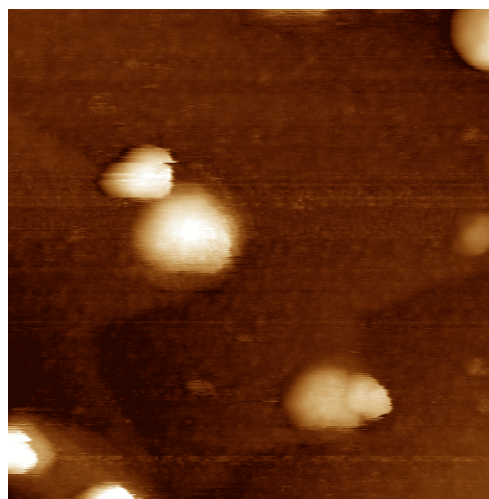


Figure 5. STM image of clean Ge(111) surface. Size: 1000 Å square. Monatomic steps are observed. White spots are contaminants.

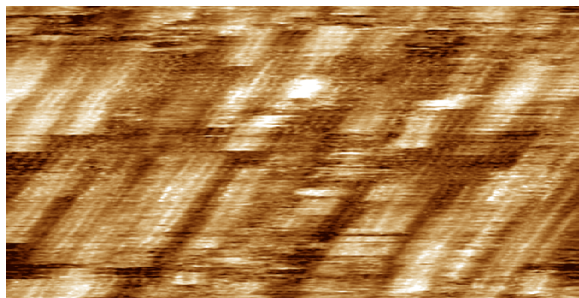


Figure 6. STM image of clean Ge(111) surface. Size: $400 \text{ \AA} \times 200 \text{ \AA}$. Rows seen in image appear to be rows of Ge atoms. Individual atoms are not resolved.

Several experimental difficulties were encountered during this project. The Ge (111) sample is very thin ($\sim 0.5 \text{ mm}$ thick) and cracks very easily. Throughout this project six samples cracked in the UHV system. Of these samples: two cracked when transferring the sample from the load lock to the STM transfer bar and three samples cracked when the sample was transferred from the STM transfer bar to the STM stage. To help prevent the sample from cracking when transferring it from the load lock to the STM transfer bar, stainless steel nuts were added to the sample holder screws to stabilize the top plate relative to the base plate as seen in figure 7.



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Figure 7. Sample holder, Stainless steel nuts were added to screws to prevent the sample from cracking.

Difficulty also arose with the sample holder parts. After the last recorded scan one

of the sample holder's feet became bent and was replaced. The sample cracked when it was placed in the STM stage and a new sample was put in.

The sample was scanned last on July 26, 2007. The images were lost when the STM software closed unexpectedly. However, good large-scale images were obtained. The images showed monatomic steps and terraces but individual atoms were not resolved.

No other scans were taken because the samples continued to crack and had to be replaced and prepared.

Conclusions/Future Work: Difficulties arose in maintaining a sample long enough in the UHV system that it could be cleaned sufficiently to achieve an atomically clean surface. Difficulties included cracked samples and damaged sample holder parts. When a sample does appear to be clean it can be dosed with Ag and then rescanned to study the phase transitions of Ag on Ge (111).

This experiment will continue with a clean and undamaged sample. In order to maintain a sample long enough in the UHV system more solutions are needed to prevent the sample from cracking.

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R1- R23 (1986).

² M. Herz, F. J. Giessibl,, and J. Mannhart,
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