Scanning Tunneling Microscopy of Metals on a Germanium Surface

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Abstract

Scanning Tunneling Microscopy (STM) was used to study the surface of Ge that was covered with a few atomic layers of Au, with additional experiments planned on adsorbed Ag and Ir. This was done by cleaning a clean Ge(111) surface, dosing it with the desired amount of Au, and then measuring STM images for further analysis. Low energy electron microscope (LEEM) imaging revealed that our Ge(111) sample dosed with 4.4 ML Au was not atomically clean and had many impact craters. STM data collected did not reveal atomic resolution images, but they did show atomic steps of the Au layers on Ge surface. Time constraints of the REU program did not allow me to be present for further data collection.

Introduction

Scanning Tunneling Microscopy (STM) is a method of surface analysis that allows us to image both conducting and semiconducting samples with atomic resolution. This process involves bringing an atomically sharp tungsten wire tip within a few Ångstroms of the sample surface. A voltage bias is then applied between the sample and the tungsten wire tip, allowing a quantum tunneling current to flow between the sample surface and the tip.

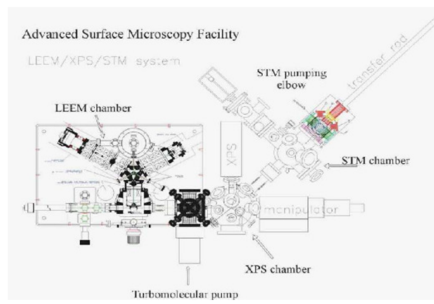

Figure 1: The advanced surface microscopy facility that is used in the lab. This system, which is operated in UHV, includes the LEEM, STM, and XPS chambers used for this project. [1]

The tunneling current drops off exponentially relative to the distance between the sample and the tip; by measuring the very small changes in tunneling current as the wire tip scans over the surface, computer software can reconstruct a topographical image of the charge density of the sample – a process that allows atomic resolution imaging.

Piezoelectric elements are used in the STM to control fine movements of the tip in three dimensional space. When a voltage bias is applied, a piezoelectric ceramic expands or contracts while preserving its volume. The tungsten tip is mounted onto a piezoelectric tube so that the user can control the tip in whichever direction is desired by simply placing the proper amount of voltage across it.

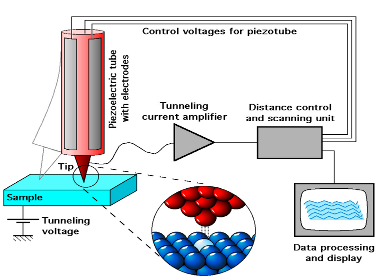

Figure 2: Diagram of an STM and mechanism of operation. The piezoelectric tube controls the precise movements of the scanning tip.
Figure: Michael Schmid, TU Wien

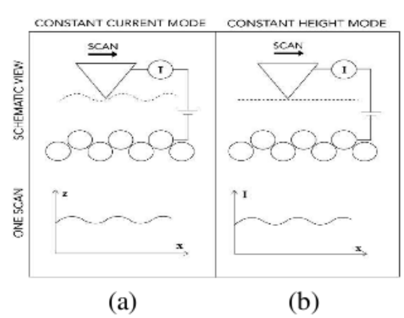

Figure 3: (a) Depiction of constant current mode of operation. Because the current is kept constant, the height must vary according to charge density. (b) Depiction of constant height mode. The scanner maintains the same height throughout the lateral scan, and the changes in tunneling current are recorded. [2]

When lateral scanning of the tip over the surface takes place, the z-direction (perpendicular to sample surface) is connected to an electronic feedback loop to maintain a constant current. The electronics then cause the tip to move up and down over the surface, keeping the distance between the tip and sample constant as the tip scans laterally over the surface. These variations of the z-position can then be measured and used to directly create a computer rendering of the topographical image of the surface. On a very flat surface, it is also possible to hold the tip at an approximately constant height and then to directly measure the variation of tunneling current with lateral position, which can be used to make an alternative rendering of the surface topography.

Experiment

The research this summer focused on measurements of transition metals dosed onto a Ge wafer sample, specifically Au on Ge(111), with plans also to study Ag on Ge(111) and Ir on Ge(001).

A sample of Ge(111) was cut from a wafer and placed in a special sample holder. The experiment relies on operating in ultrahigh vacuum (UHV ~10^{-10} Torr,) so that the sample surface can stay clean throughout the entire experiment. The sample holder is placed in the x-ray photoemission spectroscopy (XPS) chamber of the UHV system for cleaning cycles. The cleaning procedure consists of bombarding the sample with Ar+ ions, ~ 0.4 keV, for 15 minutes and then annealing the sample at 830°C for 15 minutes. The ion bombardment energizes surface contaminants via collisions, ejecting them from the Ge surface. However, the energized ions will often leave impact craters on the surface of the sample, which is an undesirable feature. To counter this, the surface is subsequently annealed at high temperatures so that the surface recrystallizes into an ordered structure. This cycle is repeated until the experimenter is satisfied with the level of cleanliness – a factor that depends on whether or not the Ge sample had previously been dosed with metal atoms.

Figure 4: The sample holder that allows us to move the germanium sample from chamber to chamber within the UHV system. The sample sits under the circular opening of the top plate of the holder.

After the cleaning cycles, the sample is placed in the Low Energy Electron Microscope (LEEM) to inspect it for large scale surface defects. The sample is dosed with the desired amount of metal and then analyzed in the LEEM again. This time, the sample is checked both for large scale defects and also to make sure that the metal was deposited correctly. At this point, the Low Energy Electron Diffraction (LEED) pattern can also be analyzed to verify that the appearance of expected ordered surface structures from the proper metal.

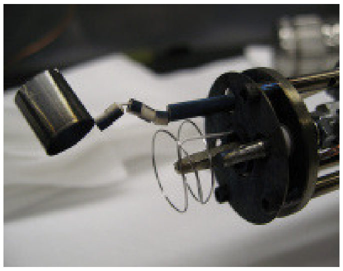

Figure 5: The electron beam-evaporator mechanism which doses the sample with metal. In the center is a rod composed of the metal to be dosed or a tungsten rod with a layer of that metal wrapped around it. The circular tungsten filament provides electrons when heated. Those electrons are accelerated by an attractive voltage onto the metal to be dosed, causing it to vaporize and hit the germanium sample. When placed in front of the rod, the cylindrical foil is used to measure the amount of metal that is being evaporated

The next step is then to place the sample in the STM chamber. The sample holder is mounted onto the STM stage, and the tip is brought close to the sample. A voltage bias of 2 V is applied between the sample and the tip, and a tunneling current of 0.5 nA is maintained by the feedback loop.

Discussion

The LEEM imaging of our Au on Ge(111) sample showed that many large scale defects were present on the surface of the Ge sample. This could likely be an effect of the multiple sputtering cycles in which the ion bombardment was energetic enough to greatly disorder the surface. STM imaging of the Au on Ge(111) showed large scale atomic steps, but atomic resolution of the surface was not achieved before the end of the REU program.

Difficulties that impeded the experimental operations included equipment that needed constant adjustment and working with the UHV system. Working in UHV is by far the biggest limitation to the speed at which data can be collected. Whenever the equipment is opened to atmosphere, it must be pumped down, baked to release water and other contaminants from the interior surfaces, and then finally pumped down to UHV pressures. This is a time intensive procedure, usually taking a few days. Couple this with the fact that the equipment is delicate and prone to malfunction, and it becomes clear why troubleshooting is one of the more common activities that occurs in the laboratory.

Future Work

The Au on Ge(111) experimental data will be analyzed by graduate student Cory Mullet. If he decides that atomic resolution images are needed, he will continue with the STM measurements. It is possible that the surface might be too defective at this point to achieve atomic resolution. Additional sample cleaning and dosing, or perhaps even replacement of the Ge sample, would then be necessary,.

The Ir on Ge(001) experiment was not carried out during my stay for the REU program, mainly due to the problem of not having some necessary parts to assemble a second sample holder. With the proper materials, that experiment will still be performed.

Acknowledgments

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References

[1] Devlin, C. L. H., D. N. Futaba, A. Loui, J. D. Shine, and S. Chiang, Mat. Sci. Engin. B, 96, 215-220 (2002).

[2] P. K. Hansma and J. Tersoff, J. Appl. Phys. 61, R1 (1987).