

Proposal

Design of a Scanning Tunneling Microscope

Submitted to

The Engineering Honors Committee

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Abstract

This proposal discusses design of a scanning tunneling microscope (STM) with the ultimate goal of resolving near-atomic scales. Challenges include vibration isolation, precision adjustment, and tip mounting and actuation, while minimizing cost. Imaging of a gold foil will be undertaken first, followed by imaging of a thin film of nickel on silicon, and bundle of single-walled carbon nanotubes (SWCNT) and fibers comprising SWCNTs.

Introduction

Electrons are normally confined within a solid by a potential barrier at the surface of that solid. One way to liberate electrons is to bring a sharp tip near the surface of a sample and apply a small voltage between tip and sample. The resulting electric field causes some of the electrons trapped within the metal tip to flow, i.e. tunnel, through the potential barrier to the sample surface.

An STM uses this principle of tunneling to image the sample surface at near-atomic scales. The probe tip is at a negative potential with respect to the sample, and when connected to an external circuit results in a tunneling current. The probe tip is adjusted vertically in order to maintain the tunneling current as the probe tip is scanned laterally. The probe tip's variation of vertical position relative to a datum then provides information regarding the local height or surface topology of the sample.

The essential components of a STM include a probe tip, a sample stage, a control system, and a detector to measure the tunneling current. The probe tip supplies the tunneling current, which passes through the conducting sample and is monitored by the detector. As the tip translates laterally across the sample surface, the control system moves the tip vertically to ensure that the tunneling current is maintained. This vertical motion can be monitored and

represents the surface height variation since the local distance between the tip and the sample surface is held constant by maintaining the tunneling current. In the proposed research project, a simpler design will be followed for constructing the STM as reported in ref. [8].

Objectives

The specific goals of this project are:

- To design and construct an inexpensive STM capable of imaging with near-atomic scale resolution, and based on a modification of an existing design in ref. [8].
- To explore several scanner concepts based on the inexpensive unimorph piezoelectric disks, in order to maximize the resolution.
- To image the surface topology of a metal thin film.
- To investigate the ultimate resolution of the inexpensive STM by imaging the surface of a bundle of single-walled carbon nanotubes and fiber composed of these bundles.

Methodology

The basis for the proposed project is the design reported in ref. [8]. The proposed work and the design of ref. [8] are similar in their use of piezoelectric actuators, and in the use of proportional and integral feedback control for adjusting the probe tip height. In the proposed work, however, microprocessor controlled coarse adjustments and independent mobility of the probe tip will be utilized.

The sample and STM apparatus will be mounted on a vibration isolation table. Vibration isolation will be accomplished using air-filled rubber inner tubes as shock absorbers. Inner tubes such as those used for model airplane tires are commercially available and relatively inexpensive. This approach to vibration isolation is an improvement over that of ref. [8] but considerably cheaper than mounting the sample on an optical table with either pneumatic or

hydraulic legs. Vibration can dramatically alter the successful operation of the STM if the amplitude of the vibration-induced motion exceeds the extremely small distance that must be maintained between probe tip and sample surface in order to draw a tunneling current.

Two microprocessor controlled stages [see Fig. 1] will be used to position the sample specimen to the desired location. These stages (Velmex MA601) can translate with controlled increments of 2.5 microns/step, and will provide the coarse adjustment for the microscope. The piezoelectric actuators, on which the probe tip is mounted, will be used for fine control. The combination of coarse and fine control will be used to adjust the distance between sample and probe tip until a tunneling current is detected in the external circuit.

Once a tunneling current is detected, the control strategy consists of proportional-integral (PI) control of the scanning motion of the probe tip based on the design of ref. [8]. The control circuit will first convert the tunneling current into a voltage signal that will be used to maintain the tip-surface distance using a piezoelectric actuator in the vertical direction. These actuators deflect in a manner directly proportional to the voltage applied, which will be recorded in order to determine the topology of the sample. The recorded voltage profile will be fed into MATLAB and translated into an easily interpreted image of the surface since lateral and vertical displacement voltages are proportional to local displacements.

The piezoelectric actuators assembly (i.e. scanners) will also be employed to control the scanning motion of the probe tip and to maintain its constant tunneling current (see Figs. 2-4). These piezoelectric actuators will be obtained from commercially available inexpensive buzzers. The probe tip will translate rectilinearly, depending on the configuration of the disks as shown in Figs. 2 and 3. These scanner designs differ from ref. [8] where the probe tip swings through an arc in two perpendicular directions (see Fig. 4). These three forms of mounting the probe tip will

first be used initially to image a gold foil. Subsequently, a sputtered thin film of nickel will be imaged. Finally, the STM will be used to image bundles of SWCNTs and continuous fibers comprising SWCNTs.

The proposed project represents an ambitious and somewhat risky effort. However, the available information in ref. [1-5 and 8] should be sufficient to develop a working STM prototype. The challenges are namely the quality of vibration isolation, the precision in the coarse adjustment and fine adjustment, and the design of a sensitive scanner. If external vibration is not isolated, ambient vibration noise will cloud the image or result in the tunneling current not being detected. If precise adjustments cannot be maintained the tip can crash into the sample or a tunneling current may not be acquired, resulting in no image. The scanners must be constructed in ways that are sensitive to displacements on the near-atomic scale or else atomic resolution cannot be achieved. Nevertheless, potential solutions to these problems have been outlined in this proposal.

Expected Contributions

The goal of this research is to provide a method for high-resolution imaging of surfaces at minimal cost. STMs are commercially available, but are quite expensive. Moreover, commercially available STMs cannot be used in-situ, as part of other experiments. This instrument would be very beneficial because it would save both time and money since samples would not need to be shipped to facilities elsewhere on campus or outside the university. For the near future, this project could help examine the structure of SWCNT bundles and fibers easily and inexpensively. It is anticipated that imaging SWCNTs could help determine the chirality of the tubes which influences their properties.

Schedule and Budget

| TASKS AND SCHEDULE | Spring 2006 | Summer 2006 | Autumn 2006 | Winter 2006 | Spring 2006 |
|-----------------------------|-------------|-------------|-------------|-------------|-------------|
| Initial Construction of STM | <-----> | | | | |
| Trouble Shooting of STM | | | <-----> | | |
| Additional Probe Tip Design | | | <-----> | | |
| Testing Scanners | <-----> | | <-----> | | |
| Literature Search | <-----> | | | | |
| Writing of Thesis | | <-----> | | <-----> | |
| Gathering Images | | | <-----> | | |
| imaging gold foil | <-----> | | | | |
| imaging sputtered thin film | | | <-----> | | |
| imaging SWCNTs | | | | <-----> | |
| Analysis of Data | | | <-----> | | |
| Imaging Software Design | | | <-----> | | |
| Internship | | <-----> | | | |

| BUDGET | Cost |
|--|------------|
| Computer and Oscilloscope (Provided by ME Department) | N/A |
| Data Acquisition Board | \$500.00 |
| Electronic Components (Capacitors, Op-Amps, Piezoelectric Disks, etc.) | \$200.00 |
| Vibration Isolation (Rubber Tubes and Supports) | \$100.00 |
| Power Supplies and Signal Generators | \$50.00 |
| Gold Foil, STM probe tips | \$100.00 |
| Mechanical Components (Materials and Machining) | \$100.00 |
| Total | \$1,050.00 |

Capabilities

I have followed the development of inexpensive STM for years, and I believe that I have finally acquired enough knowledge to design and construct my own STM. I have taken ME H610 which introduced me to circuit design and the underlying principles of quantum mechanics, which is relevant for understanding tunneling. Also, I currently am taking ME H680 which will help with data acquisition and signal processing. This course will provide me with additional knowledge to interpret the STM signals. The necessary equipment to build and image the microscope is available in the Applied Physics Laboratory (APL). Dr Vish Subramaniam and Dr. Joseph Heremans will jointly co-advise me during this project. Additional assistance with electronic components will be provided by the ME Electronics Shop Supervisor, Mr. Joe West, and additional expertise in design of experiments will be provide by graduate students in the APL.

Fig. 1: STM Coarse Adjustment Stage, illustrating an alternative approach to ref. [8].

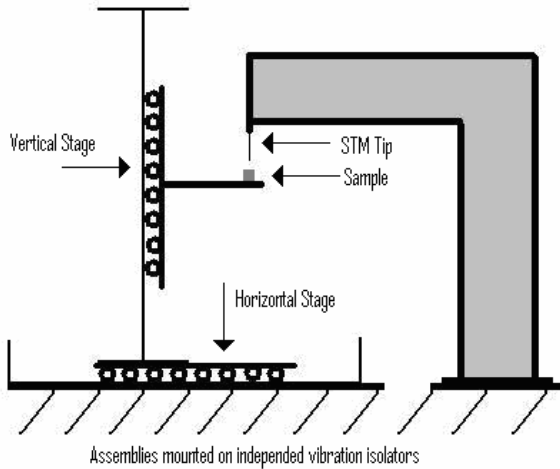


Fig. 2: Piezoelectric Actuators Schematic, affording three independent degrees of freedom and requiring two unimorph disks.

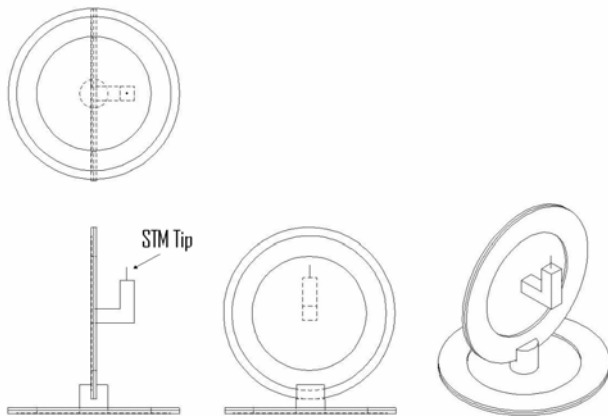


Fig. 3: Alternative Piezoelectric Actuators Schematic, affording three independent degrees of freedom and requiring three unimorph disks.

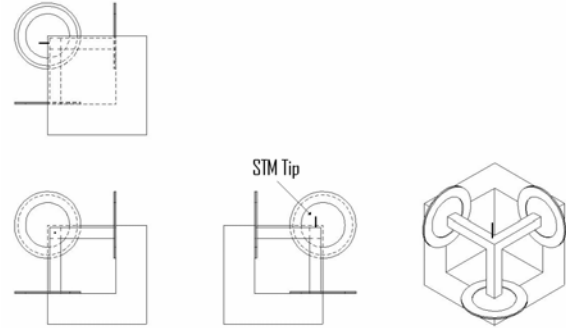


Fig. 4: Single Unimorph Design, illustrating the probe tip mount in ref. [8].



References

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