Modifications to a Scanning Tunnelling Microscope

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Abstract

A scanning tunnelling microscope (STM), previously constructed as part of a PhD project, has been modified to improve its reliability and accessibility. Initially the aim was to obtain atomic resolution ($\sim 0.1\,\mathrm{nm}$) on a routine basis but for an unknown reason this has not been obtained and thus far we are limited to a resolution of about 1 nm.

Improvements to the device that converts the tunnelling current into a voltage were made resulting in a 1 pA resolution with a 17 nA range. This resolution is an order of magnitude better than previously obtained, while the bandwidth (5 kHz) is essentially unchanged.

A major aspect of this work was the fabrication of the sharp tungsten tips used as the STM probe. Careful control of the chemical etching process resulted in reproducibly shaped tips, with a radius of curvature of less than 20 nm in some cases.

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Introduction

1.1 Background of project

In 1995 a project to build a digitally controlled Scanning Tunnelling Microscope (STM) was begun. This task was undertaken as a PhD project by Henning Klank and was supervised by Dr. Blair Hall, Associate Professor Robert O'Driscoll and in the later years, Dr. Craig Eccles. The project was a challenging one, requiring knowledge of electronics, programming, control theory and hardware design.

As the project was started from scratch, and its implementers were inexperienced in this field, the STM was very much a prototype and was designed so that changes could be made easily. Each part was constructed so that it would work simply and reliably, with the hope that the microscope would function as a whole. This was achieved in 1998 when the first image of graphite was obtained with atomic resolution.

The STM was beginning to work. Images were recorded of 3 nm high terraces on graphite, a gold sputtered transmission electron microscope grating replica and graphite atoms. However, as with many prototypes, the STM was rather unreliable, images were difficult to reproduce and the software was not easy to handle. The results and shortcomings of the project were detailed in Henning Klank's PhD thesis *Design of Digital Instrumentation for Scanning Probe Microscopy.*

1.2 This project

Two critical parts of the microscope were left in the prototype stage and this masters project aims to replace and improve these thereby increasing the performance and reliability of the STM. The two components are the preamplifier, one of the most important parts of the STM electronics, and the STM probe, the most important and least understood piece of hardware in the STM. A third aspect of this work was the software interface that was tackled concurrently by Dr. Craig Eccles.

In some ways this thesis is a sequel to that of Dr. Klank's, but still with the goal of achieving atomic resolution on a regular basis. While the two major parts of this thesis should stand alone the driving motivation is to improve the STM.

1.3 Scanning Tunnelling Microscopy

A Scanning Tunnelling Microscope uses an imaging method similar to that used when reading braille. As a finger is scanned across a line, the various hillocks can be sensed by the finger tips and the words can be understood. In STM a very sharp metal probe, often called the tip, is scanned across a surface. However, instead of actually touching the surface to sense changes in height, a voltage between the tip and the sample is applied and a quantum mechanical effect called tunnelling occurs, in the form of a current. By measuring the tunnelling current the distance between the tip and the sample can be controlled. Many scans are performed to build up an image, similar to the pencil scans when making a pencil rubbing of an engraving.

1.4 The preamplifier

As in any instrumentation electronics, the performance of the first stage or preamplifier is critical in determining the overall noise and bandwidth of the system. In the STM the preamplifier is required to monitor the very small tunnelling current between the tip and the sample. This component is often referred to as a current-to-voltage converter.

A current-to-voltage converter for an STM has to amplify currents ranging from 10 pA to 10 nA. To convert very small currents such as these into reasonable voltages for analogue to digital conversion, a large gain is required.

Since high gain is essential this would usually require high valued feedback resistors. Because of this, small capacitances can have dramatic effects. Of particular importance is the reduction of the input capacitance, as this plays an important role in determining the final output noise. The most effective way of achieving this is to place the current-to-voltage converter as close as possible to the source. This creates its own challenges in STM.

1.5 STM tips

The tip in an STM is the very front end of the system, since it is the tip that determines the spatial resolution of the system and often the noise performance. Unfortunately the tip is easily damaged and therefore cheap, reliable tips have to be easy to manufacture.

It is now common place to achieve atomic resolution with such an instrument. To do this the tip must be *incredibly* sharp. The success of the STM as a tool relies on the nature of the tunnelling current. The tunnelling current decays exponentially with distance and it is this fact that is exploited to achieve high resolution. With a sharp tip and a flat surface the current is mostly contained within an area smaller than the surface area of the tip.

1.5.1 Fabrication of tips

Tips have to be constructed with a very small end radius, preferably less than 100 nm. This may seem like an almost impossible task and one requiring very specialised machining tools. However, this is far from the truth and although the manufacture of tips is still difficult, the process by which they are formed is relatively simple.

One starts with a simple wire, and electrochemically etches it until it breaks in two and hopefully a sharp tip remains. However some parameters can be varied to produce consistently good tips.

Good, reliable tips can dramatically improve the performance of a STM, not only in terms of resolution but also the signal to noise ratio.