Creating an Automated Tip Fabrication Process for a Tunneling Microscope

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ABSTRACT

The research experience this summer focused around simplifying the tip fabrication process that is currently being used in the STM laboratory. Currently the process is doing completely by hand. The purpose of the research is to create an automated process that would allow for reproducible tips to help provide consistent results using the Scanning Tunneling Microscope.
INTRODUCTION/MOTIVATION

The true motivation for the research is provide better observation tools to study graphene. One of the instruments that the First group uses in studying graphene is STM. To provide consistent and usable results with the STM you need to conduct your scans with high quality sharp tips.
WHAT DOES THE CURRENT RESEARCH SAY?

- In doing my background research on the topic I discovered many other groups have worked on creating a consistent process for tip fabrication.
- I found that many groups had looked at the effect of molarities of the solution, cathode isolation, magnetic field, etching current and a host of other factors that can affect the etching process.
- For further information on the background please see the reference portion.
THEORY

The basic etch process is well known and has been thoroughly researched. Our goal was to take the results that other groups have found to be successful and combine it with a microcontroller (Arduino) and control the whole process electronically. We felt that at the very least we could increase the cut off by a large factor and thus increase the sharpness of the tips. By automating the process we will be able to produce consistent tips so the results from the STM will be much more comparable than before when using hand etched tips.
To begin with we started with a schematic that a previous group had used. I quickly realized that this setup was not going to work in our situation. We were using a different type of tip that required much more current to etch than their setup would allow.

Alternatively as a group a different etching setup was creating using an Apex PA 61 as a power source. This is a high power op amp that will allow as much etching current that is needed to flow. This was the first major obstacle that was overcome.
Once the larger more powerful op amp was setup I began to etch tips. For some reason the current was still being limited. Without the circuit the etching current was high, with the circuit the etching took an unreasonably long time because the etching current was so low. It was ultimately determined that a current limiting function of this op amp had been overlooked. Once addressed the etching current increase significantly but still not to the level expected. This was the second major hurdle that was overcome.
With the help of Lee we cannibalized a computer power supply. The positive rail on the computer power supply could produce a total of 12 amps. This would be more than enough to run the etching we needed. Although this solved one problem it created another one.
The Arduino can only output a positive voltage and if we sent the positive signal into the PA 61 it would come out negative and pull from the negative rail on the power supply which was limited.

So the solution was to use a smaller Op 27 op amp to invert the signal first and make it negative before it went into the big PA 61. On this first op amp we also put a low pass filter to give us voltage adjustability. The Arduino can only send a 5 volt signal. By using the pulse with modulator (PWM) we could pulse the 5 volts and with the low pass would be able to more control.
APPROACH CONTINUED

So my circuit at this point consisted of a small inverting op amp feeding into a larger inverting op amp which I put a gain of 2 on by making the feedback resister twice as large as my input resistor. This gave me a +10 volt source to drive the etching current. Our Arduino will only read a voltage so we have a non inverting op amp before it goes back to the Arduino to convert the current back into a voltage. We also had to created a current sensing circuit to aid in cutoff. A Zener diode was also utilized to protect the Arduino.
BASIC ETCHING SET-UP

- Anode (W wire) and cathode submerged in aqueous solution of KOH. Below the three ring cathode setup that was ultimately used is shown.
- W wire etches and breaks at the air/solution interface. The remaining wire is used as the tip. Below you can see the cathode that I created.
Actual circuit
TIP ETCHING SYSTEM

- Tip Etching System
- Electrochemical Cell
  - 1 mm polycrystalline tungsten wire
  - 500 mL 3 molar NaOH solution
  - three cathode arrangements isolated from the surface of the solution
- Etching Stand
- Arduino Control Circuit
Conclusions

- We concluded that for the large tungsten rods, previous research that 3 molar KOH is the ideal etching molarity.
- We also confirmed that cathode isolation was necessary to creating consistent tips.
- We also concluded that the etching time could be significantly reduced by slightly agitating the solution.
I need to thank all the people that made this incredible learning opportunity available. First and foremost I need to thank Leyla Conrad and Phil First. I have definitely gained valuable information that will help me do a better job of preparing my students for college. Also without the help of Lee, Britt and Kevin I am not sure if I would have made it through the summer.
Resources

On the electrochemical etching of tips for scanning tunneling microscopy
J. P. Ibe,a) P. P. Bey, Jr., S. L. Brandow, R. A. Brizzolara, N. A. Burnham, D. P. Dilella, K. P. Lee,b) C. R. K. Marrian,C) and R. J. Colton Sw:face Chemistry Branch search LaboratOl:V, Washington, DC 203 75-5000
A double lamellae dropoff etching procedure for tungsten tips attached
to tuning fork atomic force microscopyÖscanning tunneling
microscopy sensors M. Kulawik,a) M. Nowicki, G. Thielsch, L. Cramer,b) H.-P. Rust, and H.-J. Freund Fritz-Haber Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany
Title - Tools of the trade

Problem - Many of the tools used by Physicists are so far removed from the high school classroom that many students are unaware of what they are and how they work.

Abstract - This lesson plan focuses on the major tools that physicists use to conduct their research. The teacher will use a power point presentation to instruct the students on the basic components, operation and uses of the scanning tunneling microscope. In addition several web based java applets will be used to simulate the use of the microscopes. This will be the introduction phase of the project. The second stage will involve the students working in collaborative groups where they will research and prepare presentation on other important scientific tools. The final phase will involve the students presenting to the class what they discovered. The presentation will be assessed via a rubric.
Objectives – Georgia state standards
SCSh4. Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.
SCSh7. Students will analyze how scientific knowledge is developed.

Anticipated learner outcomes -
The learner will be able to know and explain how the major tools that physicists are used.

Background - The only background information that would be needed is the initial power point that goes over the STM. This power point is used as an exemplar to show the students what is expected from their presentations.

Materials/ Supplies - Access to a projector and the to computer lab will be the only supplies needed.
Plan

Day one – Teacher will go over the power point with the students. Afterwards students will use the java applet modeling the STM. The teacher will go over the rubric to ensure students understand what is expected from their presentations.

Day two and three – Students will begin research on their assigned scientific tool.

Days 4 and 5 – Students will present their presentations to the rest of the group. Presentation will include a power point as well as a flier describing their tool.
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organizational</strong></td>
<td>Presentation was highly organized. Student demonstrated great control over ideas which facilitated the listener's ability to follow the presenter's progression of thoughts with no difficulty.</td>
<td>Presentation was well organized. Student demonstrated strong control over ideas. The listener had little difficulty in following the presenter's progression of thoughts.</td>
<td>Presentation was sufficiently organized. Student demonstrated control over ideas. The listener had difficulty following parts of the presenter's progression of thoughts.</td>
<td>Presentation was limited in organization. Student demonstrated limited control over ideas. The listener had difficulty following most of the presenter's progression of thoughts.</td>
<td>Presentation was not organized. Student demonstrated very little control over ideas. The listener could not follow the presenter's progression of thoughts without great effort.</td>
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<tr>
<td><strong>Illustrative Examples</strong></td>
<td>Multiple examples included in the presentation were thoughtful, relevant and insightful. All of the examples gave the listener greater understanding of the presentation.</td>
<td>Some examples included in the presentation were thoughtful, relevant or insightful. Some examples gave the listener an improved understanding of the presentation.</td>
<td>Examples were included in the presentation but the relevance to the presentation was unclear at times.</td>
<td>An example was included in the presentation but the relevance to the presentation was limited.</td>
<td>Examples were not included in the presentation and/or irrelevant to the presentation.</td>
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<td><strong>Content Knowledge</strong></td>
<td>Student demonstrated great understanding of the content of the presentation evidenced by the inclusion of several relevant and accurate facts, which facilitated the listener's understanding of the presentation. Student responded to all questions correctly and/or provided clarifying examples / explanations without consulting notes.</td>
<td>Student demonstrated strong understanding of the content of the presentation. Some relevant and accurate facts were included and facilitated the listener's understanding. Student could respond to most questions correctly and/or provide clarifying examples / explanations without consulting notes.</td>
<td>Student demonstrated limited understanding of the content of the presentation. General facts were included but the facts did not provide depth of understanding for the listener. Student could respond to some questions correctly and/or provide clarifying examples / explanations without consulting notes.</td>
<td>Student demonstrated very limited understanding of the content of the presentation. Facts, when included, were overly general and/or inaccurate, and the facts did not help the listener's understanding of the presentation. Student could not respond to questions correctly nor provide clarifying examples / explanations.</td>
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<td><strong>Audience Interaction</strong></td>
<td>Student demonstrated consistent poise and control during the presentation. Presenter interacted with the audience extremely well by effectively using eye-contact, an appropriate speaking volume and controlling the rate of speech.</td>
<td>Student demonstrated poise and control during most of the presentation. Presenter interacted with the audience well. Student used eye-contact, an appropriate speaking volume and used an appropriate rate of speech.</td>
<td>Student demonstrated limited poise and control during some of the presentation. Presenter interacted with the audience inconsistently. There was some use of eye-contact. At times, there was an appropriate speaking volume and/or there was consistently appropriate rate of speech.</td>
<td>Student demonstrated very limited poise and control during of the presentation. Presenter interacted with the audience poorly. There was very little use of eye-contact, little, if any, control of speaking volume or little, if any control of the rate of speech.</td>
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