Home made Scanning Tunneling Microscope

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Abstract

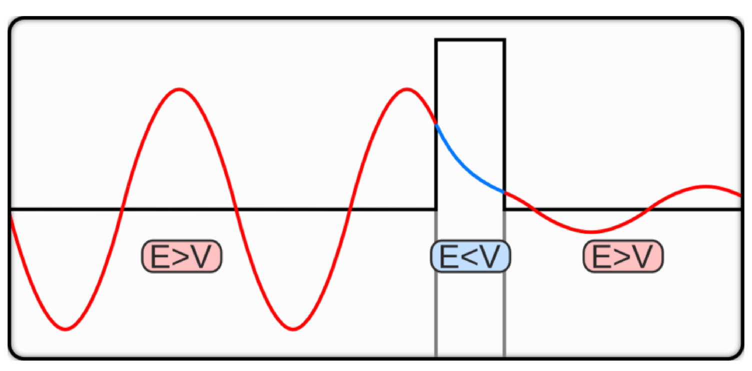
To realize measurement of tunneling effect, we build the setup to observe the tunneling current. Introduce tip etching to obtain a sharp top tip. Make the sample approach to the tip by piezoelectricity

Goal

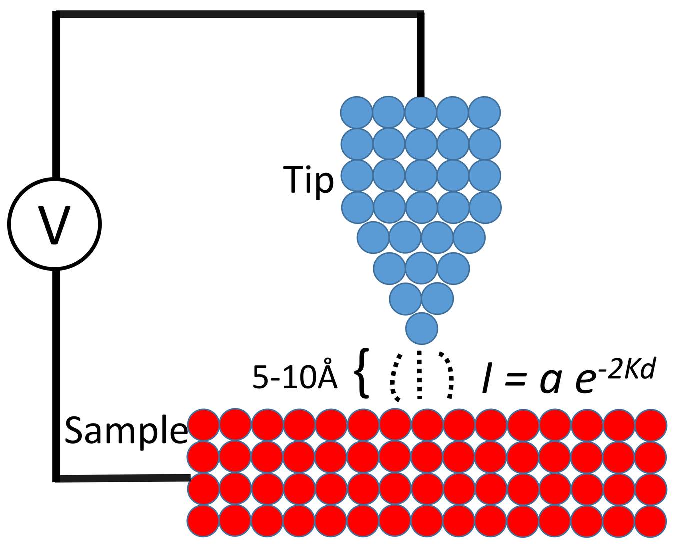
According to tunneling effect, the thickness of barrier will affect the tunneling current dramatically. We hope to observe the tunneling current and record the relation between tunneling current and the thickness of barrier. By controlling piezoelectricity to scan X-Y plane and to realize the observation of surface appearance of the sample.

Background

Scanning Tunneling Microscope (STM) is based on the concept of tunneling effect. In quantum scale, the tunneling effect occurs. A particle can pass through a barrier with energy higher than the particle. If the particles are electrons, tunneling current could be measured. After solving the Schrödinger equation, we ~~expected~~ tunneling current will exponentially decay as we move the tip away from the sample.



$$\frac{d^2\psi_{II}}{dx^2}+\frac{2m}{\hbar^2}(E-U)\psi_{II}=0 \qquad \psi_{II}=ae^{-2k_2x}$$



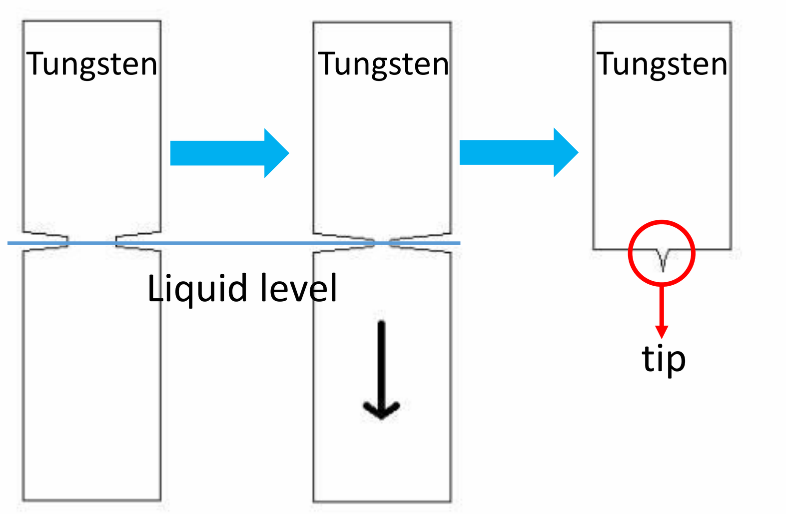
Tip etching

The tip can be made from Aurum(Au), Platinum(Pt), and Tungsten(W). Different materials needs different methods. We choose Tungsten(W) and use electrochemical etching to make the tips. Supply 7 Volt between the anode and the cathode. The electrolyte is 3M NaOH. By Reduction-Oxidation, the tungsten is oxidized, and dissolved in the electrolyte. The following is the Reaction equation.

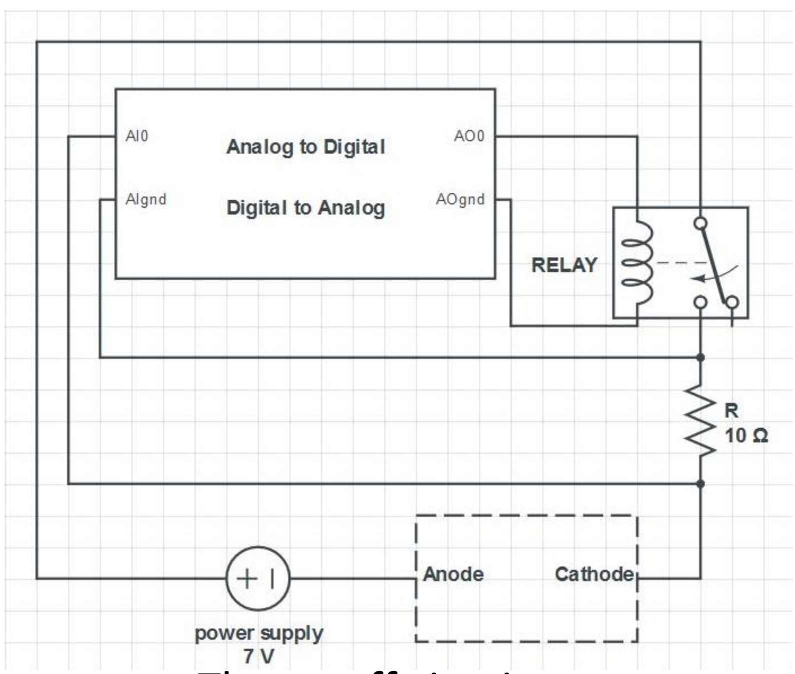
Anode $W+8OH^- \rightarrow WO_4{}^{2-}+H_2O+6e^-$

Cathode $6H_2O+6e^- \rightarrow 3H_2+6OH^-$

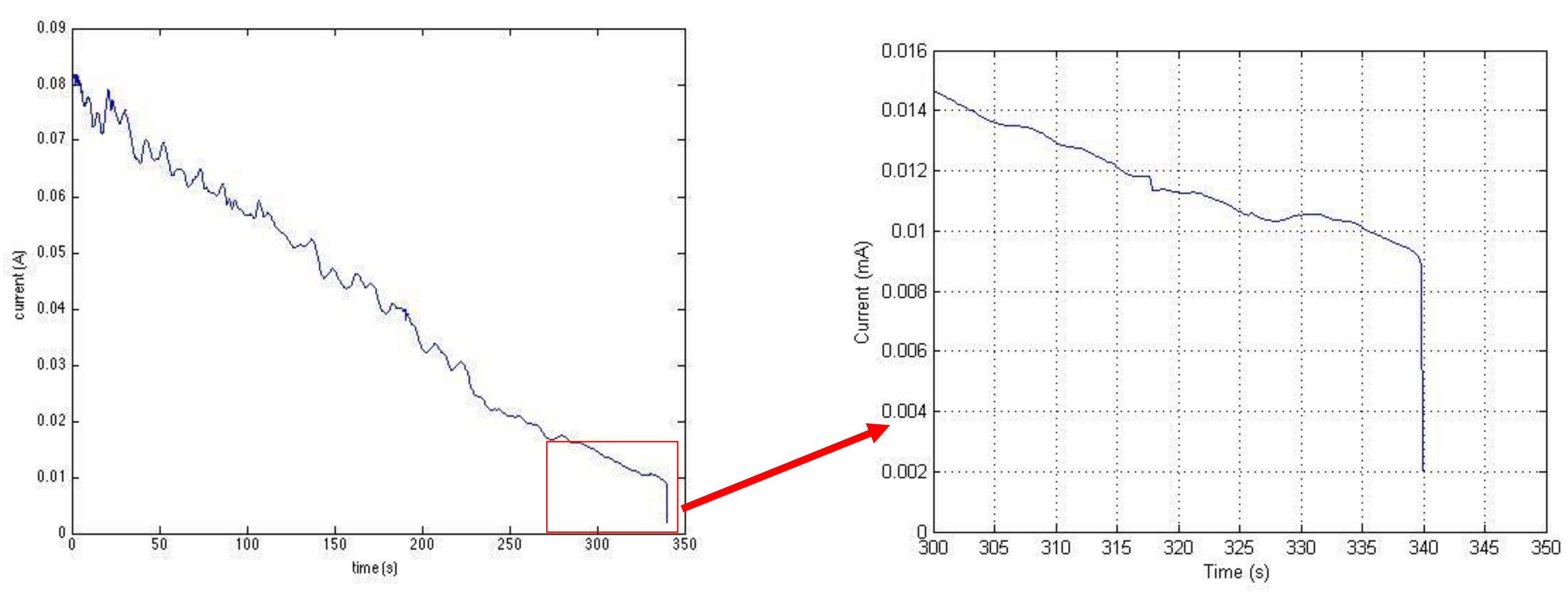
We can discover that $WO_4{}^{2-}$ accrete on the tungsten. The reaction rate is slow down, because the contact area became smaller. However, $WO_4{}^{2-}$ does not exist on the level. The Reduction-Oxidation happen continuously on the level. Before the tip finish, the weight under the liquid surface is enough to snap the tungsten. At this time we have to cut off the power supply, or the tip will be etch again. We use the relay and the AD/DA card to control the power supply, the following is the schematic diagram of the power cut.



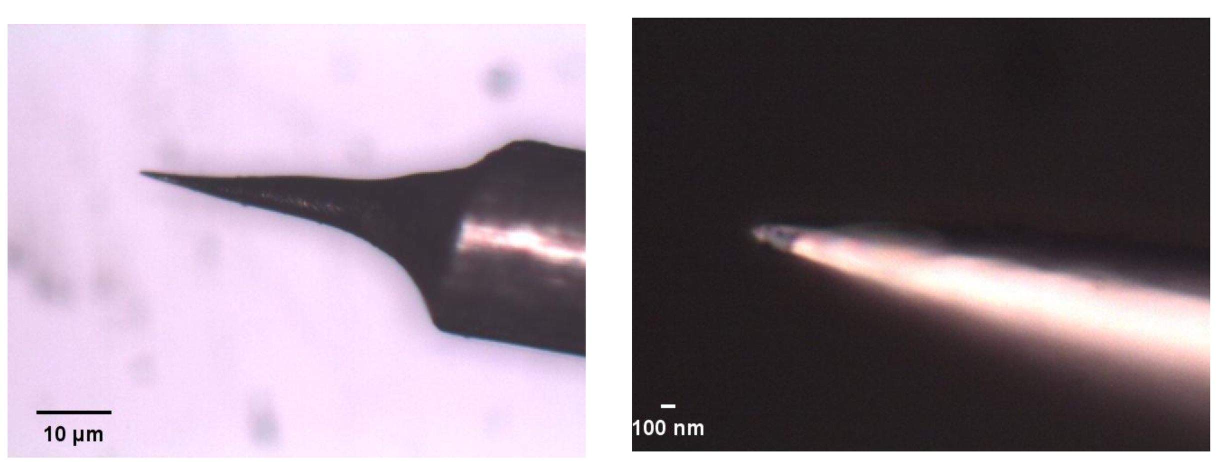
The tungsten(W) in the process of etching.



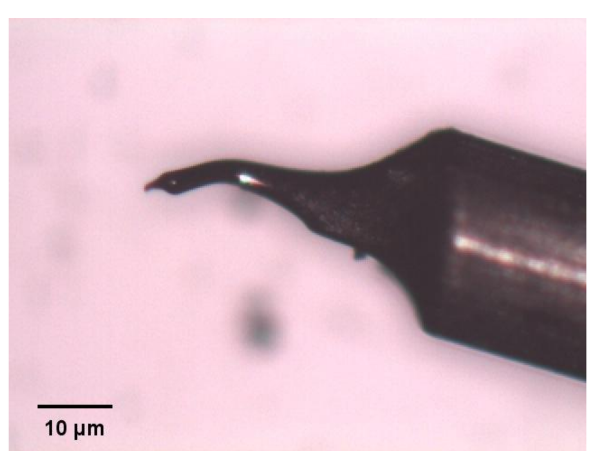
The cutoff circuit



Set the cutoff current 0.006mV. As soon as tip etching off, the current drops dramatically.



The tip etched by using cutoff circuit.



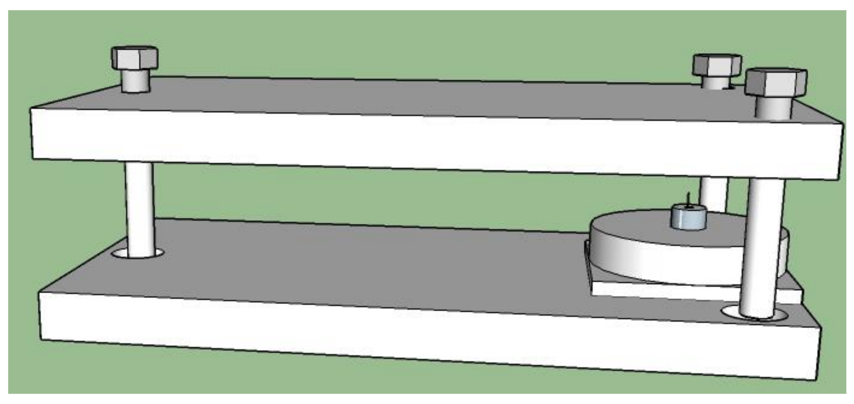
The damaged tip.

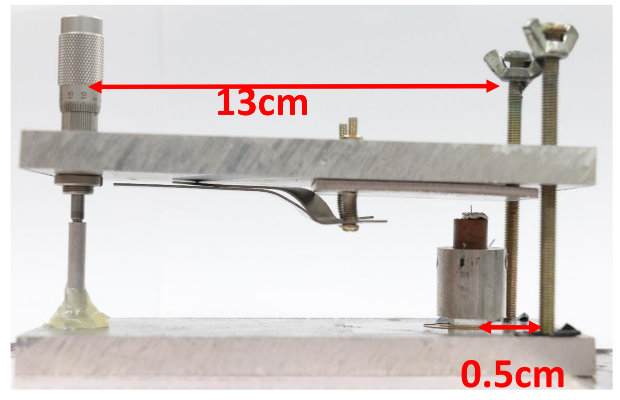
Reference

- Introduction to Scanning Tunneling Microscope, Julian Chen (1993)
- Design of green and research type scanning tunneling microscope, Wu-Jing Fan

Experimental setup

Typically, the distance between sample and the tip has to be about 5-10Å to make tunneling effect happen.

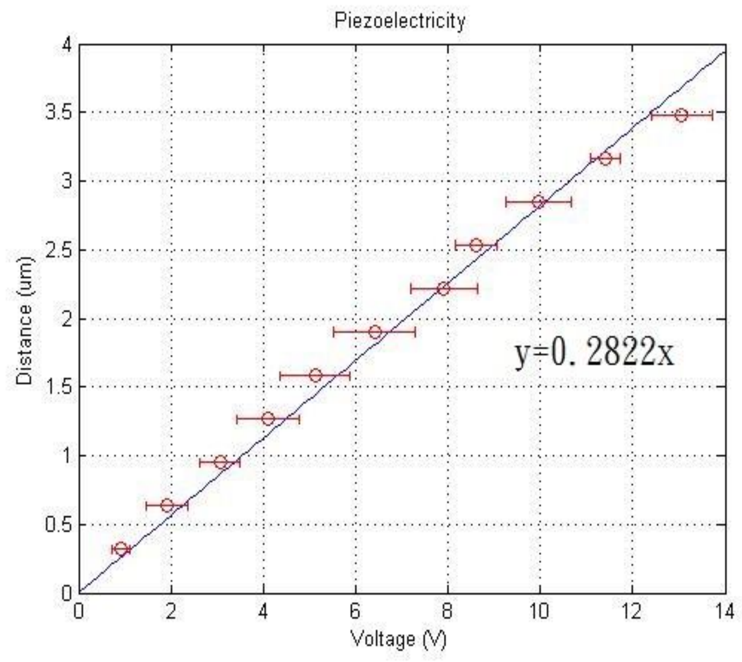


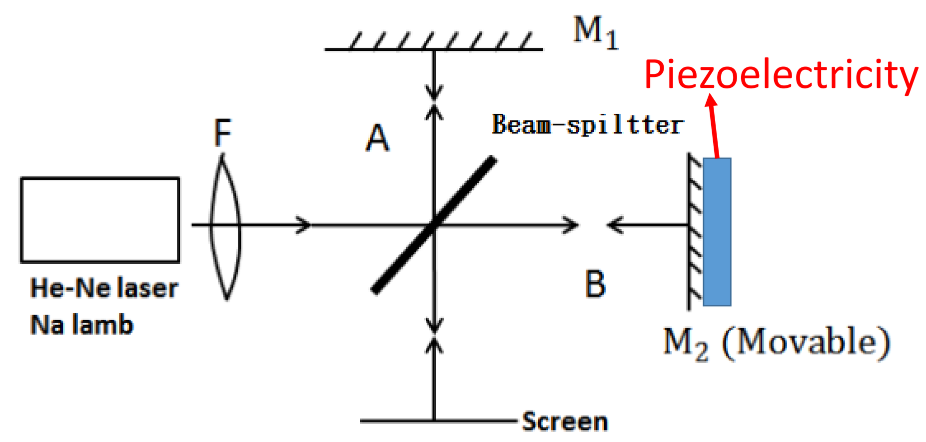


It's the stepper device to forward the tip to sample. The screws closer to the tip stage are coarse adjustment knob and its screw pitch is 1.8mm. The farther screw is fine adjustment knob. Its screw pitch is 0.5mm. Use applied lever principle can have the space resolution 120nm. We can control manually and make the sample move to tip 120nm each step.

Piezoelectricity

We use "Michelson interferometer" to get the relation between the applied voltage and expansion. The result is forward 0.28nm/1mV.





Optical path difference = 2A-2B = $2\Delta D=\Delta m * \lambda$ $\lambda = 632.8nm$

Using adder circuit to supply 0.1V and 0.001V for piezoelectricity, we need two kinds of voltage scale to control piezoelectricity.

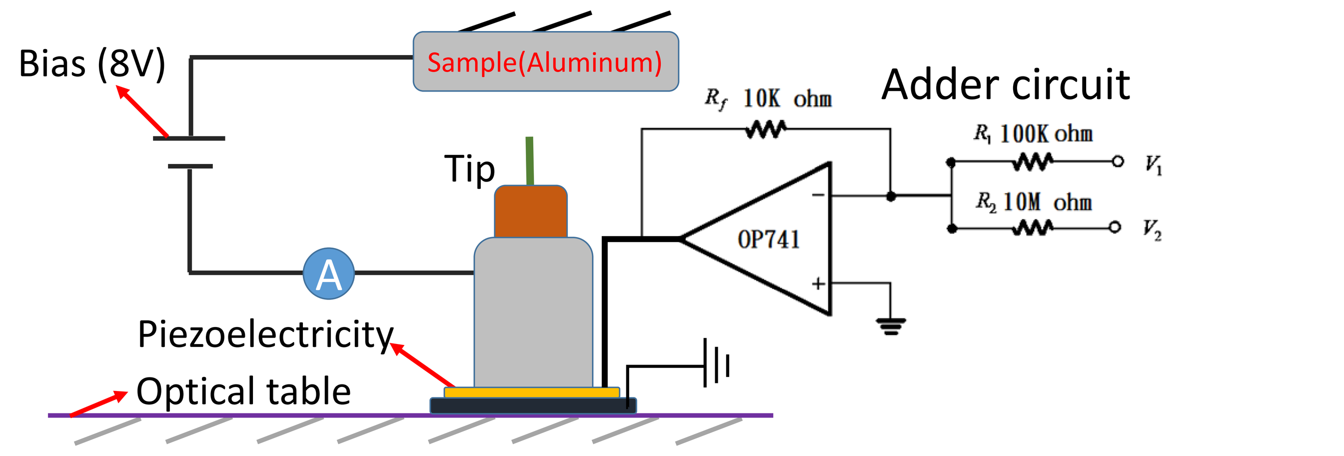
Discussion

Tunneling current

The tunneling current would happen in a tiny gap and our setup most forwards 120nm. As long as we adjust the fine adjustment knob, it is easy to miss the interval which can happen the tunneling effect. That is the scope of work of piezoelectricity. However, all of our existing piezoelectricity are broken because the piezoelectricity can not afford oversized voltages (exceed 15V). Therefore, we can not work in this gap. The range of tunneling current scale in this gap is 0.1um-1mm.

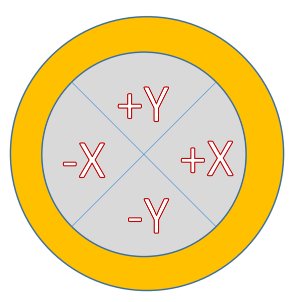
STM operation

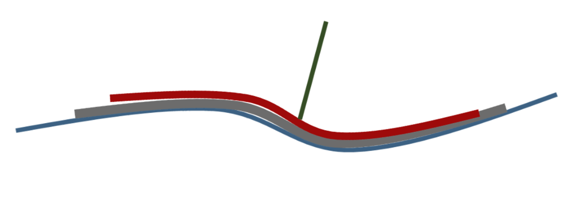
The tunneling currents $I = a\,e^{-2Kd}$, a is the bias between tip and sample, d is the distance between sample and tip , K is the constant relative to the material of tip and sample.(The applied bias voltage is 8V.) After supplying the bias and using the piezoelectricity to forward, we can measure the tunneling currents. However, currents is so too small to measure and we series connect current amplifier to record the currents. The region where tunneling effect happening is so small so it can not afford any vibration. The vibration will result in breaking the tip and unstable currents. Therefore, we select the optical table to isolate vibration.



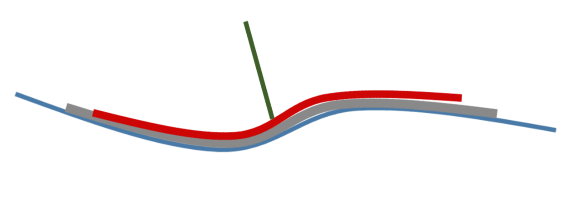
X-Y scanning

We cut the piezoelectricity into four blocks. We supply the voltage for four of one and the tip would scan the direction of it. Use this phenomenon, we can scan the x-y plane. According the effect of piezoelectricity, we estimate the x-y scanning range would reach 5um X 5um.





Supply the voltage for -X.



Supply the voltage for +X.

Summary

1. The stepper device can move the tip toward the region where the tunneling current could be measured.
2. We have learned how to make a tip with sharp top. The shape of sharp tip will decide the resolution of the scanning image.

Ongoing work

- To Solve the problem of piezoelectricity.
- To Do the vibration isolation
- To Record the relation between the distance and tunneling current.
- To Scan the surface appearance of Aluminum.