

# **Construction of a Low Temperature Scanning Tunneling Microscope**

**Jacob Tosado**

**July 22, 2004**

This paper discusses work I have done with the construction of a low temperature scanning tunneling microscope (LTSTM) and the operation of a scanning tunneling microscope (STM). A brief description to why a LTSTM is used and the background concerning that description, is covered. Mainly methods in STM imaging are described giving insight into two possible sources of imaging deformation.

---

## **I. Introduction**

The variation of the density of states of ferromagnetic manganite thin films as a function of temperature and its spatial variation is currently a topic of great interest. Tunneling spectroscopy and surface imaging via scanning tunneling microscopy (STM) is an excellent technique for studying such properties and has promoted the use of low temperature scanning tunneling microscopy (LTSTM). In this field it has been observed that at the curie temperature manganites such as  $\text{LaPrCaMnO}_3$  exhibit steep drops in resistivity (also the metal insulator transition point) where the isolated creation of ferromagnetic domains begin to merge. Our plan is to study the behavior of these domains as a function of temperature using LTSTM.

A manganite is an insulating solid at room temperature. As temperature is decreased to its Curie temperature the material's resistivity peaks after which there occurs a steep decrease of resistivity into a metallic state. The transition from insulating to metallic states is characterized by the behavior of magnetic domains throughout the manganite. A large drop in resistivity also occurs when a magnetic field  $\sim 10$  Tesla is applied and this phenomenon is called colossal magnetoresistance (CMR). These domains will initially occur in isolated areas then spread until the manganite reaches saturation magnetization. Depending on the composition of the manganite, the nature of magnetic field saturation can be changed. Utilizing the angstrom scale resolving power of a LTSTM, it is possible to make real time analysis of these phase transitions. Our goal is to image these transitions at temperatures of around 10 Kelvin in fields of nine Tesla.

Theories concerning charge ordering, the "Hunds coupling" energy, and the Jahn-Teller effect go very far in explaining the mechanics behind manganite behavior [7]. Any measurements that may confirm or disprove these theories could make a profound impact in understanding the behavior of manganites. An LTSTM provides an experimental way to make these measurements. In this paper I will describe our progress towards the construction of a LTSTM over the course of this REU project.

## **II. Background**

Several concepts concerning STM should be clarified. STM technology was initiated by G. Binnig and H. Rohrer in 1981 culminating over a decade of technology and

humanity's desire to see the atom [1]. Seven years later perovskite type crystals became noted for their CMR properties, namely manganites. Extensive LTSTM research of manganites finally culminated in the mid to late 90's revealing the effectiveness of LTSTM in imaging CMR effects [5].

Atomically resolved imaging with an STM involves positioning a tip of some material at a distance of about five angstroms from another material which is the sample. At this separation the electrons are able to tunnel across the potential barrier created by the gap. A tunnel current is produced and can be measured to create an image.

Often images will be displayed showing neat rows and columns of atoms. However, STM images are actually a measure of the electron density over the surface. Bright colors illustrate the maxima and dark the minima. The atomic structure can be studied in detail though Fourier transform.

Our scan area ranges from two to ten nanometers square at a frequency range of 20 to 40 hertz. Maintaining the five-angstrom tunnel gap while in scan is achieved with a piezo-electric control system. This system utilizes piezo-electric material, which deforms by only a few angstroms on application of a few volts (10-100Å/V).

Movement in the direction normal to a sample's surface is required for coarse approach of the tip towards the sample. Hence, the tip is not rigidly connected to the sample. Instead friction of the piezo material along an adjacent surface holds the tip in place where

periodic voltage jerks to the piezos move the tip towards the sample. Our current system operates at one kilohertz where previous systems work at 60 hertz [6]. The higher frequency is an advantage since the coarse approach is done manually and can take up a lot of time .

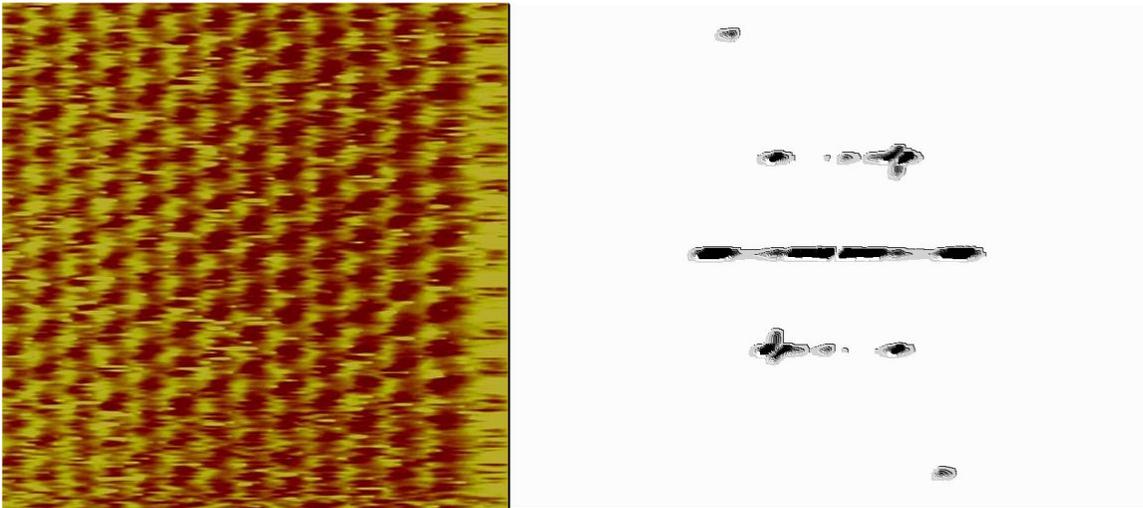
While in tunneling range (fine approach) the STM is subjected to inertial vibrations, which could potentially destroy imaging and image quality. Various types of vibration isolation systems are employed. Our systems use a tripodal air spring system, similar to those in optical research.

### **III. STM**

The most delicate part of the STM is the STM tip. Many advances in this area have been made. In principal the sharper a tip the better; however, for our purposes, a simple platinum rhodium wire is used which produces good atomically resolved images.

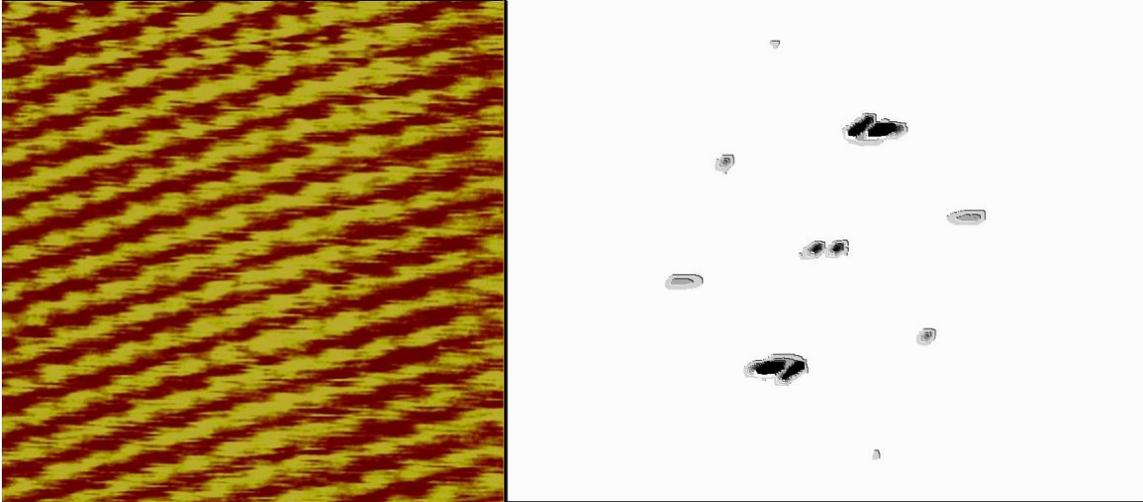
We use a 0.25mm diameter platinum-rhodium wire cut to about one tenth of an inch. The platinum-rhodium alloy is used for its brittle structure. Since the cutting tool can be a pair of sheers or wire snips, the actual cut, if looked at up close, can be quite jagged and rough. For platinum-rhodium, a cut will tend to be a fracture leaving exposed atomic sized sharp edges, all potentially tips where ideally only a single maximum tip will participate in tunneling.

The ideal case of a single tip being the sole producer of the tunneling current is not always true. Quite often there occurs multi-tip phenomenon as described by Mizes et al., [2] which will cause the image to look foggy creating an ambiguity between one maxima and the next. For instance, a normal graphite image of singly spaced maxima is constructed with three sine waves of different phases and equal amplitudes as shown in Fig.1. If the value of one of these amplitudes dominates the other two, rows of maxima occur (Fig. 2). If two amplitudes dominate the third, a triangular array of ellipses occur [2].



**FIGURE 1. (left) Single-spaced maxima. (right) Fourier transform revealing the triangular symmetry of graphite.**

Aside from the multi-tip phenomenon there is also the explanation given by Kobayashi and Tsukada [3] for a particular image deformation resulting in linear chains or rows of maxima. This phenomenon calls to the existence of the tip possessing different electronic levels [4]. One of the defining characteristics in constructing the anomalous rows of maxima required that the three-fold-symmetry axis of the tip be tilted by 7.5 degrees.



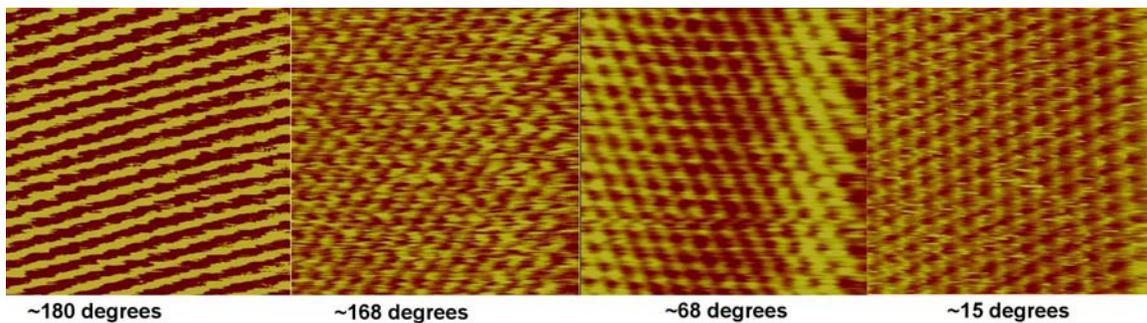
**FIGURE 2. (left) Rows of maxima. (right) Fourier transform where the amplitudes of one axis dominates the other two.**

Images as in Fig. 2 depicting linear chains of maxima are a common recording on our systems. These images usually occur just before acquiring individual atomic resolution. In some instances these images are the only ones recorded.

On analysis I made a rough comparison of the electron density surface to a corrugated surface whose maxima correspond to the maxima of the electron density. I noticed that if one looks directly at the corrugated surface, with the general plane of the surface perpendicular to the line of sight, then rotates this plane slightly, so that one edge is further away and the other edge is closer, one sees a silhouette of rows. Each of these silhouettes designate rows of maxima equidistance from the observer. If I now rotated this corrugated surface about an axis parallel to the line of sight, the appearance of continuous silhouettes become periodic. This allows the observer at certain angles to view silhouettes of single maxima.

Drawing the analogy of the corrugated surface to the surface of electron density I took note of three ideas. Primarily, the spatial configuration of the corrugated surface and the electron surface has little correlation. Second, the appearance of rows can be characterized as maxima of equal denomination. Third, rotation of the surface along an axis parallel to the line of sight can be analogous to the rotation in the direction of scan across the surface electron density.

From these three ideas I predicted that a scan depicting rows of maxima might be rotated a certain number of degrees to where it gives single maxima and that this effect is periodic. The scans shown in Fig. 3 demonstrate this phenomenon.



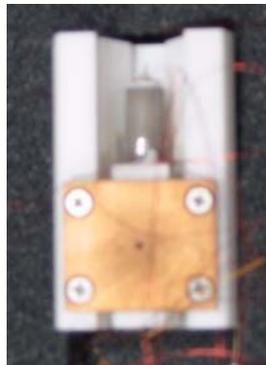
**FIGURE 3. Various graphite scans where the approximate scan direction is labeled.**

Mizes et al. and Kobayashi and Tsukada [2][3] explain the appearance of rows of maxima each giving defining characteristics to its cause. A Fourier transform of an image with maxima rows shows that one of the three amplitudes dominate (Fig. 2, right). This dominance is consistent with multi-tip phenomenon. However, if the periodicity of rows when the scan direction is rotated correlates to the spatial configuration of the surface of electron density, then it is possible that the rows are due to a slight tilt between the axis of

the electron surface and the three-fold-symmetry of the tip resulting in maxima of equal denomination which is consistent with the tip possessing various electronic levels.

#### IV. LTSTM

Our LTSTM in contrast to our STM will be subject to extreme low temperatures and high magnetic fields. These conditions necessitate the use of appropriate materials for its construction. Macor<sup>®</sup>, a white machinable glass ceramic with a coefficient of expansion of  $93 \times 10^{-7}/^{\circ}\text{C}$ , is suitable since it does not deform greatly at low temperatures. The LTSTM, as shown in Fig. 4, uses Macor<sup>®</sup> as the main structure. Other materials include copper and stainless steel for conductivity and strength respectively. The LTSTM probe, made from stainless steel is attached to the LTSTM allowing it to be placed in and removed from the Dewar (Fig. 5).



**FIGURE 4. White structure is made form Macor<sup>®</sup>**

The vibration isolation system required for the operation of the LTSTM are a set of three nitrogen filled air springs on a tripod base. The Dewar in which the LTSTM will be cooled and subjected to high magnetic fields is suspended form an aluminum platform

resting on the air springs, as shown in Fig. 5. Lead is added to the platform to increase its mass dampening any inertial oscillations in the structure.



**Figure 5. Vibration isolation system**

## **V. Summary**

As of now the LTSTM, LTSTM probe, Dewar and vibration isolation system have been completed. Plans are under way to have the LTSTM operating by the end of August 2004. Preliminary calibrations of the LTSTM have been successful. Final scan calibrations of the LTSTM will be done using a graphite sample. Further tests will involve gold thin films. Once operational, tests of various manganites will commence.

Thanks to:

Dr. Amlan Biswas  
Tara Dhakal  
Yun Sunghee

- 
- [1] G. Binnig and H. Rohrer, Nobel lecture, December 8, 1986.
  - [2] H.A. Mizes, Sang-il Park, W.A. Harrison: *Phys.Rev.* **B36**, 4491 (1987).
  - [3] K. Kobayashi, and M. Tsukada: *J. Vac Sci. Technol.* **A8**, 300 (1988).
  - [4] H.-J. Guntherodt, R.Wiesendanger Scanning Tunneling Microscopy I, edited by G. Ertl, R. Gomer, and D.L.Mills (Springer-Verlag Berlin Heidelberg, 1992), Vol.20, Chap. 6.1, pp 131-140.
  - [5] A. Biswas *et al.*, *Phys. Rev.* **B59**, 5368 (1999).
  - [6] S.H. Pan, E.W. Hudson, and J.C. Davis, *Rev. Sci. Instrum.* **70**, 1459 (1999).
  - [7] A.J. Millis Colossal Magnetoresistive Oxides, edited by D.D. Sarma, G. Kotliar and Y. Tokura (Gordon and Breach Science Publishers, Amsterdam, The Netherlands, 2000), Vol 2, Chap. 2, pp 53-86.