A Compact Dual-Tip STM Design

Weida Wu, Ayan Guha, Suenne Kim, and Alex de Lozanne

***Abstract*—A compact dual-tip scanning tunneling microscope (STM) design that achieves both rigidity and stability is presented. We constructed a prototype unit to perform tests in ambient conditions. The two STM tips were able to maintain a stable tunneling condition with the sample surface *simultaneously*. Topographic images of a fresh cleaved graphite were taken *simultaneously* from the two tips. A common feature found in both images indicates that the two tunneling spots are ∼800 nm apart.**

***Index Terms*—Scanning tunneling microscope (STM).**

I. INTRODUCTION

THE SCANNING tunneling microscope (STM) is a powerful tool to study surface electronic properties with atomic resolution. A conventional single-tip STM can provide rich information about local electronic properties. It has been proposed that a dual-tip STM, with two independent STM tips nearby on a microscopic scale, can obtain nonlocal information about surface states [1], [2]. For example, a dual-tip STM is likely to be the first tool able to measure the retarded Green functions directly, which is a problem of great fundamental interest.

Although the idea seems to be a simple integration of the STM setup, it is a great challenge to manipulate two STM tips independently in a well-controlled manner. As far as we know, only two groups [3], [4] have succeeded in demonstrating the capability of dual-tip STM. Here, we present a compact design of dual-tip STM ($\sim 1 \times 1 \times 5\ \text{in}^3$) to achieve both rigidity and stability. We demonstrate that we can reliably manipulate two tips and obtain stable junctions within a submicrometer distance.

II. STM DESIGN

Fig. 1(a) shows the schematic diagram of our dual-tip STM design. The two tips are held via friction inside two separate tip holders made from fine metal tubing . The center tip holder is glued on a four-quadrant piezo-tube (PZT-5H) with epoxy. The side tip holder is glued on an XY stage supported by another piezo-tube concentric with the center piezo-tube. The end of side tip holder is bent ∼ 45° to provide the incline angle. The center tip, which is the primary probe, is operated as a normal STM. The scanner tube is supported by a Z stage, which consists of a Macor cylinder with an inertial "kicker" attached to it [5]. Fig. 1(b) shows the stick-slip principle of the inertial motor [6]. The sudden contraction/extension of the piezo gives a large impulse to the moved object to overcome the stiction, i.e., to slip.

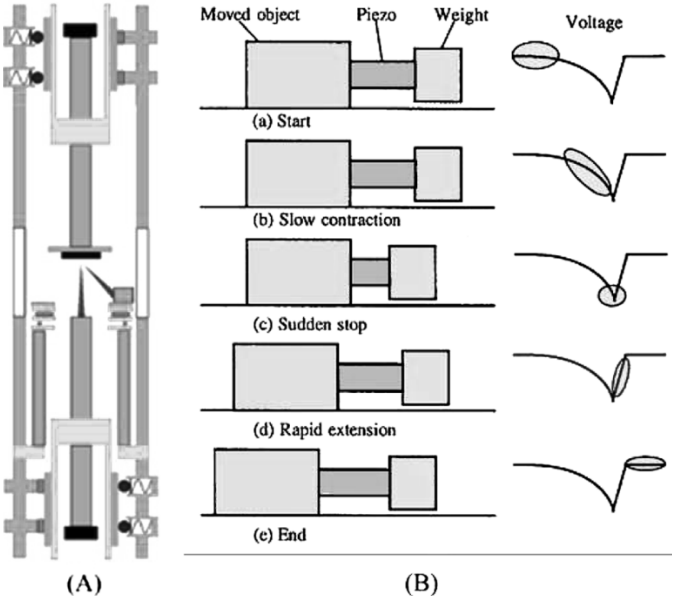

Fig. 1. (A) Schemetic diagram of the dual-tip STM design. See text for a detailed description. (B) The principle of an inertial motor. This mechanism is applied to both Z and XY stages in the current design.

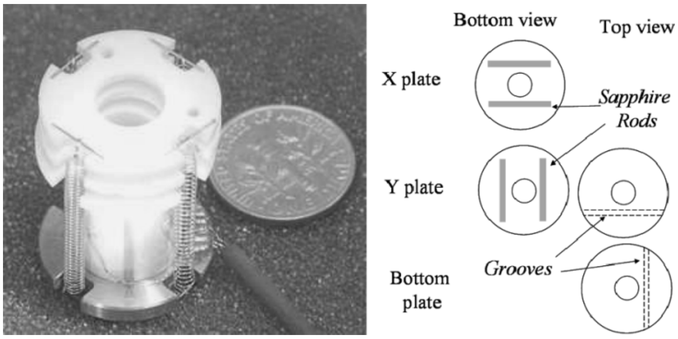

Fig. 2. Our XY inertial stage, which consists of three Macor plates. The $X(Y)$ stage is a Macor plate with two sapphire rods glued on the bottom along the $X(Y)$-direction. One of the two sapphire rods slides on a groove on the opposite plate to restrict the direction of the motion, while the other one slides on a flat surface to provide even support. Four soft springs are mounted between the side of the top plate and the base plate, which support the side tip piezo-tube. The springs provide the critical crimping force for stick slip to work.

The side tip is supported by an XY inertial stage driven by the outer piezo-tube, which also provides feedback control for the side tip. The XY stage uses the same stick-slip principle. Fig. 2 shows a close look of our XY inertial stage, which consists of three Macor plates. Each of the upper two plates have two sapphire rods glued on the bottom to provide sliding surface. The two sets of sapphire rods are normal to each other. The top surface of the lower two plates have a groove aligned with the corresponding sapphire rod. The crimping force is provided by soft springs mounted on the side of the XY stage since the mass of

---

Manuscript received April 21, 2005; revised July 30, 2005. This work was supported by the Department of Energy under Grant FG03-94ER14465 and by the National Science Foundation under Grant DMR-0308575.

The authors are with the Department of Physics, University of Texas at Austin, Austin, TX 78712 USA.

Digital Object Identifier 10.1109/TNANO.2005.858592

the Macor plates is too small. The essential feature of our STM head design is the concentric arrangement of two piezo scanner tubes for the two tips. In other dual-tip STM designs, the two scanner tubes are normal to each other [3] or positioned side by side [4]. These designs complicate the scanning and feedback control mechanism since the two scanning planes do not match. The concentric design can minimize this effect and reduce the size of the STM head.

The sample holder is mounted on another scanner tube attached to another Z stage on the upper part of the STM head. The scanner tube on the sample side is important for tip alignment since it allows us to obtain topographic images from both tips simultaneously. The STM body is made of stainless steel. A highly ordered pyrolytic graphite (HOPG) sample is glued to the sample holder with silver paint. The center tip is grounded. The side tip and sample are biased at different voltages (V_{tip2} and V_{sample}). The STM probes are Pt–Ir tips made via electro-chemical etching. For detecting the tunneling current, we used two homemade two-stage current-to-voltage amplifiers with a total gain of 10^8 V/A. The feedback control of the two tips is provided by a Nanoscope IIIa controller and an analog PID controller (SIM960, Stanford Research Systems, Sunnyvale, CA). Data from both tips are recorded by the Nanoscope III electronics. To isolate the vibrations from the building, we used a homemade "air" table loaded with concrete patio blocks (70 lbs total) sitting on a bicycle inner tube. This provides a "quick-and-dirty" solution for STM operation in air. Since the vibration isolation is far from ideal, the STM head has to be rigid enough to be immune from external vibration. Our compact design greatly enhances the rigidity of the STM head so that a stable tunneling condition is obtained.

III. TIP ALIGNMENT

The coarse alignment of the two tips is achieved by viewing along the X- and Y-directions with two optical microscopes. The center tip is brought to the same height as the side tip. The side tip is then brought to the vicinity of the center tip by the XY stage so that the two tips are a few micrometers apart in the XY-plane. The fine Z alignment is achieved by bringing in the sample surface. The sample is lowered to approach the side tip by an automatic approach algorithm [7] until a tunneling current is detected. The center tip is then brought to the tunneling condition with the same algorithm. At this point, the two tips are aligned in Z and coarse aligned in the XY-plane. In order to further reduce the inter-tip distance, we scan the center tip while keeping the side tip a few nanometers above the sample plane. Therefore, there is no tunneling current from the side tip unless the distance between the two tips is the within tunneling distance. We then slowly increase the scan size to avoid a hard collision of the two tips so that we can determine whether the two tips are within the maximum scan range of the center tip scanner tube. When tunneling between two tips happens, a large tunneling current flows in both tips. If the distance between two tips is beyond the limit of scanner tube, we use the XY stage to move the side tip one step toward the center tip. Once the two tips are within the scan size of the center tip scanner, there will be a large current in the current amplifiers of both tips.

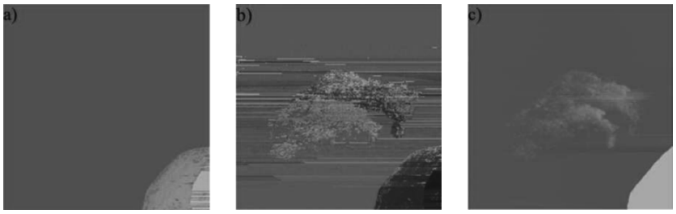

Fig. 3. In this measurement, the side tip is held approximately 10 nm above the sample surface. The center tip is scanned over the sample surface. The scan size is approximately 500 nm. (a) Tunneling current image from the side tip. (b) Tunneling current image from the center tip. (c) Topographic images obtained from the center tip. Tunneling conditions: $V_{\mathrm{sample}} = 0.5$ V, $V_{\mathrm{tip2}} = 1.0$ V, $I = 2$ nA.

Fig. 3 shows a typical situation when the two tips are nearby. In this experiment, the side tip is held approximately 10 nm above the sample surface with its feedback off. The scanning voltages were applied to the center tip scanner. Fig. 3(a) is a measure of the tunneling current from the side tip as a function of the center tip position. Fig. 3(b) is the current image from the center tip. The side tip sees no tunneling current until the center tip is close by, which happens at the bottom right corner of the scanning area. The currents have opposite sign due to the current flows from one tip to the other. At the same time, the topographic image [see Fig. 3(c)] shows that the center tip saw a big "mountain."

We offset the scanning area of the center tip carefully so that the "co-tunneling" boundary is always at the corner or edge of the scanning area. This will prevent hard contact between the two STM tips. By mapping out the boundary of the co-tunneling current between the two tips, we can find out the "image" of the side tip, which is convoluted with the shape of the center tip. If the side tip apex is beyond the limit of the scanner tube, we stop scanning and use the XY stage to move the side toward the center tip. From the convoluted "image," we estimate the tip radius is approximately a few hundred nanometers.

IV. RESULTS OF APPROACH

Once the two tips are microscopically nearby, we scan the sample in XY only while keeping the two tips tunneling to the sample with independent feedback loops controlling only their Z position. Fig. 4(a) and (b) shows the topographic images obtained *simultaneously* from two tips by scanning the sample scanner tube in ambient conditions. Only the respective feedback voltages were supplied to the scanner tube of each tip. The scan size is approximately 1.8 μm. The dashed rectangles in each image highlight the same area of the sample surface. The offset of this common area indicates that the tunneling apexes of each tip are approximately 800 nm apart. In previous studies [3], [4], the two probes are brought to the same area separately. Our images demonstrate that we are able to manipulate two STM probes reliably and form stable tunneling junctions simultaneously on a microscopic scale. This is the basic requirement for the measurement of electrical transport properties. Fig. 4(c) is the same area (slightly smaller) of the surface obtained with the center tip scanner tube after withdrawing the side tip to avoid a tip–tip crash. Some surface damage was found, probably produced during the withdrawal of the side tip. Fig. 4(c) shows

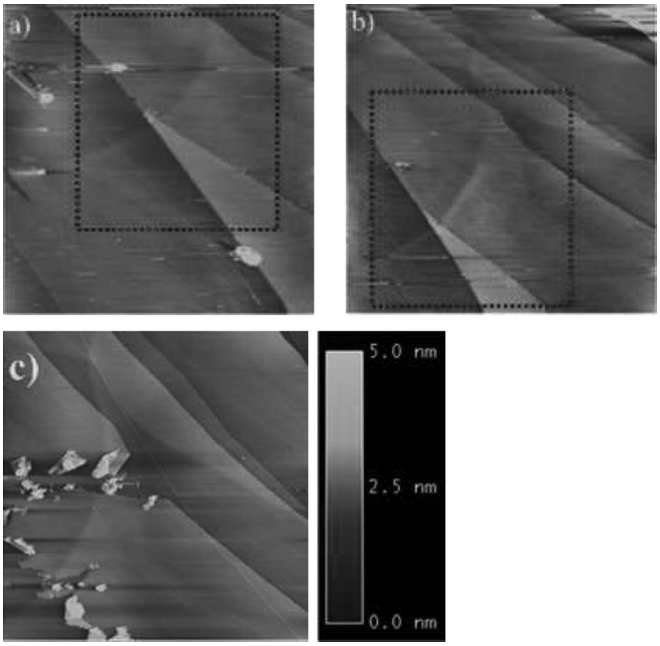

Fig. 4. STM topographic images obtained simultaneously from: (a) the center tip and (b) the side tip (scan size: $\sim 1.8~\mu\text{m}$). (c) STM image obtained by scanning the center tip after withdrawing the side tip (scan size: $\sim 1~\mu\text{m}$) Tunneling conditions: $V_{\text{sample}} = 0.5$ V, $V_{\text{tip2}} = 1.0$ V, $I = 2$ nA.

that the center tip can be positioned around the side tip with its scanner tube. This is another basic requirement for dual-tip STM experiments.

V. SUMMARY

In summary, we have demonstrated that our compact dual-tip STM design is capable of reliable manipulations of two independent STM probes on a microscopic scale. Both tips can make stable tunneling junctions with the sample surface simultaneously. We show that the two tunneling junctions are approximately 800 nm from each other by topographic images taken simultaneously with the two tips. However, in order to perform a more useful two-tip experiment, one has to go to a low-temperature (LT) and ultra-high vacuum (UHV) environment. The vibration isolation will be achieved by hanging the STM head with soft springs inside the UHV chamber. We are building such a LT-UHV chamber and STM for further tests.

REFERENCES

[1] Q. Niu, M. Chang, and C. Shih, "Double-tip scanning tunneling microscope for surface analysis," *Phys. Rev. B, Condens. Matter*, vol. 51, pp. 5502–5505, 1995.

[2] J. M. Byers and M. E. Flatté, "Probing spatial correlations with nanoscale two-contact tunneling," *Phys. Rev. Lett.*, vol. 74, pp. 306–309, 1995.

[3] H. Grube, B. C. Harrison, J. Jia, and J. J. Boland, "Stability, resolution, and tip–tip imaging by a dual-probe scanning tunneling microscope," *Rev. Sci. Inst.*, vol. 72, pp. 4388–4392, 2001.

[4] H. Okamoto and D. Chen, "An ultrahigh vacuum dual-tip scanning tunneling microscope operating at 4.2 K," *Rev. Sci. Inst.*, vol. 72, pp. 4398–4403, 2001.

[5] A. Guha, S. Kim, and A. L. de Lozanne, "Novel frictionless approach mechanism for a scanning tunneling microscope," *Rev. Sci. Inst.*, vol. 74, pp. 4384–4388, 2003.

[6] D. W. Pohl, "Dynamic piezoelectric translation devices," *Rev. Sci. Inst.*, vol. 58, pp. 54–57, 1987.

[7] E. W. Hudson, "Investigating high-t_c superconductivity on the atomic scale by scanning tunneling microscopy," Ph.D. dissertation, Dept. Phys., Univ. California at Berkeley, Berkeley, CA, 1999.

Weida Wu received the B.Sc. degree in physics from the University of Science and Technology of China, Hefei, China, in 1998, the M.Sc. degree from Northwestern University, Evanston, IL, in 1999, and the Ph.D. degree from Princeton University, Princeton, NJ, in 2004. His doctoral dissertation was entitled "Magnetic Field Induced Commensurability and Correlation Effects in Organic Conductors."

In 2004, he joined the Department of Physics, University of Texas at Austin, as a Post-Doctoral Fellow. His current research interests include studies of strongly correlated electronic systems (organic conductors, manganites, etc.) with transports and STM and magnetic force microscope (MFM).

Dr. Wu is a member of American Physical Society since 2000.

Ayan Guha received the B.Sc. degree (with honors) in physics from the Indian Institute of Technology, Kharagpur, India, in 1992, and the Ph.D. degree from the Indian Institute of Science, Bangalore, India, in 2001. His doctoral research concerned transport noise properties and scanning tunneling spectroscopy studies on colossal magnetoresistance oxides.

In 2001, he began his post-doctoral research in building a two-tip STM at the University of Texas at Austin.

Suenne Kim received the B.Sc. degree and M.Sc. degree in physics from Ewha Womans University, Seoul, Korea, in 1998 and 2000, respectively, and is currently working toward the Ph.D. degree in materials science and engineering at the University of Texas at Austin. Her masters research concerned Raman spectroscopic studies of phase transition in PZN-xPT ferroelectric relaxors of morphotropic phase boundary. Her doctoral research concerns an LT dual-tip STM with the two STM tips as electrodes and mechanical manipulators.

Alex de Lozanne received the Bachelor's degree (with highest distinction) from Purdue University, West Lafayette, IN, in 1975, and the Ph.D. degree from Stanford University, Stanford, CA, in 1982.

He is currently a Full Professor with the Department of Physics, University of Texas at Austin, where he has been a faculty member since 1985. He previously held a junior faculty position with the Department of Applied Physics, Stanford University. He is interested in applying scanning probe techniques to the study of nanostructures, superconductivity, and magnetism. He has authored or coauthored 104 refereed papers and book chapters. He holds two patents.

Dr. de Lozanne was the recipient of several fellowships and a 1986 Presidential Young Investigator Award.