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## DESIGN NOTE

# A compact inertial slider STM

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**Abstract.** A compact, less than 0.3 $cm^3$, scanning tunnelling microscope (STM) based on a new inertial slider design is presented. The STM is built of two concentric piezoelectric tubes, the inner one for scanning the tip and the outer one for inertial sliding of the sample to and from the tip. The coarse approach is made by inertial sliding of the sample along a plane that is non-perpendicular to the tip, while the sample surface is kept perpendicular to the tip throughout inertial sliding and image acquisitions. The compact design ensures a mechanical noise level of less than 0.1 Å.

The scanning tunnelling microscope (STM) yields images of surfaces at atomic level by the use of a sharp tip close to the surface. The mechanical parts of the STM consist mainly of a piezo scanner for fine motion and a mechanism for coarse approach. The piezo scanner usually has a scan range of only a few micrometres and it is therefore necessary to use a coarse approach mechanism to reduce the probe–sample distance to fall within the range of the piezo scanner. It is also convenient to be able to move the sample laterally to a new scan region. While the piezo scanner is usually small, the need for a coarse approach mechanism adds to the size of the STM head and the choice of this mechanism greatly affects the performance of the final STM. Because of the mechanical nature of these microscopes and the small distances measured, the mechanical stability must be very high. The usual way to accomplish a low-noise microscope is to design the STM head with as high a resonance frequency as possible so that it becomes vibrationally isolated from the low-frequency noise present in the experimental set-up. In order to obtain a high-resonance frequency the mechanical parts defining the tip–sample distance should be kept small, i.e. the 'mechanical loop' between the sample and tip should be as short as possible.

A number of coarse approach mechanisms have been reported [1–3], for example inertial sliders [4–8]. This mechanism has been increasingly used in UHV and at helium temperatures [9, 10], resulting in compact designs. In the inertial slider the moving object, a stage, is placed on a supporting table which is connected to a piezo. A sawtooth electrical waveform is applied to the piezo. During the slow ramp of the sawtooth, the stage follows the motion of the support. At the step in the sawtooth waveform, inertial forces due to the large acceleration exceed the static friction limit. The support slides under the stage in this phase and the result is a net motion of the stage with respect to the support.

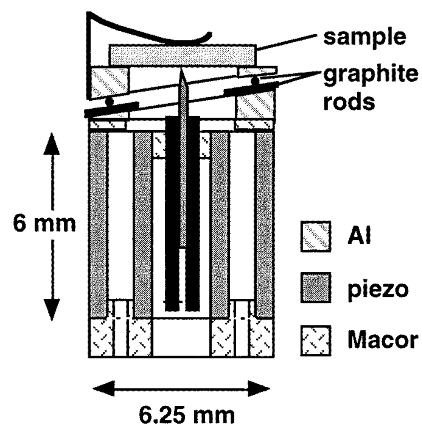


**Figure 1.** Schematic drawing of a cut through the STM head. The sample is inertially slided down a non-perpendicular plane to reduce the tip–sample distance.

We report here a new and very compact inertial slider design that enabled us to reduce the size of the STM head to a total volume of less than 0.3 $cm^3$. We found that this very compact design reduces the mechanical noise level to less than 0.1 Å.

Our design is based on two concentric tube scanners (figure 1). The outer one is used for inertial sliding while the inner one is for scanning the tip. The idea is to slide the sample along a plane that is non-perpendicular to the tip, so that the tip–sample distance is easily varied by sliding the sample up and down this inclined plane. This also enabled an increased resolution in tip–sample

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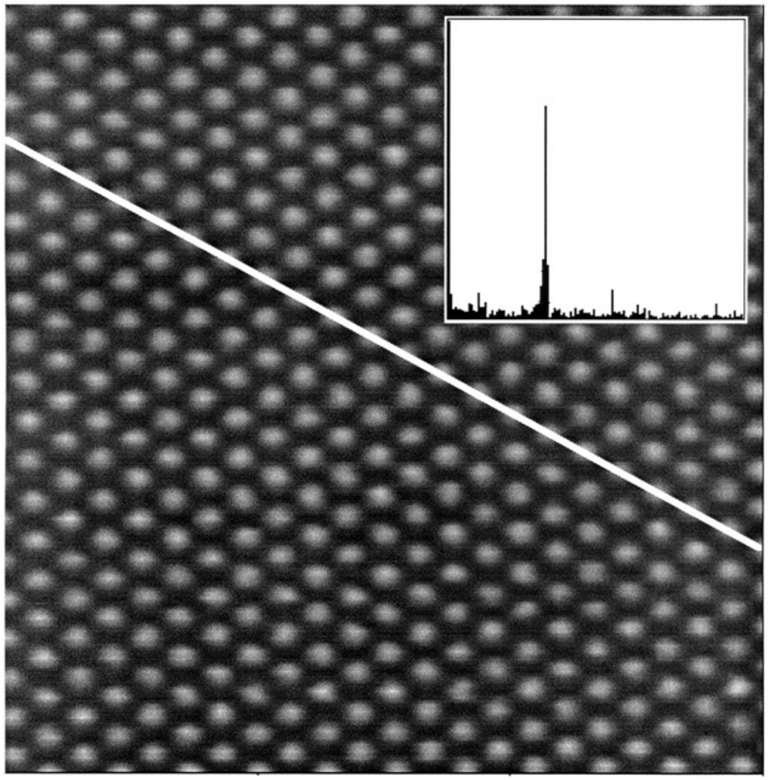

**Figure 2.** A typical unfiltered constant current STM image of graphite. Bias voltage 2 mV, tunnelling current 6 nA, and scan frequency 10 Hz. The grey scale is 2 Å. The inset shows the Fourier transform along the white line in the STM image. The large-amplitude peak corresponds to an atomic corrugation of about 1 Å. The spectrum shows that the noise level is about ten times lower than the atomic corrugation.

distance, since a step along the plane should be scaled with the inclination angle. This increased resolution was essential since the inner piezo, holding the tip, was rather short and had a limited scan range. We chose an angle of 84° between sample and tip so that an inertial sliding step along the plane was scaled down by a factor of ten when considering the tip–sample distance. In order to minimize the sensitivity to mechanical noise and also to simplify the mounting of the sample, electrical connections to the sample or sample holder placed on top of the inclined plane were undesirable. Instead the current was transmitted through the contact between the inclined plane and sample holder. This contact was preferably defined by three point contacts and for simplicity we used polished graphite rods (0.3 mm diameter) on both the inclined plane and the sample holder. By placing three graphite rods on the inclined plane and three rods on the sample holder, perpendicular to those on the inclined plane, three point-like electrically conducting contacts were achieved. We found that this arrangement generally works very well, but with the short outer piezo used here fast electronics are needed in order to gain enough acceleration to overcome the static friction. In these initial tests of the STM head we used commercial drive electronics (Nanoscope III, Digital Instruments, Santa Barbara, California) and the fall times of the sawtooth waveform were quite limited. The required fall time in order to make an inertial slider motion can be estimated by

$$\Delta t = \sqrt{\frac{2\Delta s}{\bar{a}}} < \sqrt{\frac{2\Delta s}{g\mu_s}} \qquad (1)$$

where $\mu_s$ is the static coefficient of friction, $g$ the acceleration due to gravity and $\Delta s$ is the lateral scan range of the outer piezo given by [11]

$$\Delta s = 2\sqrt{2}\frac{d_{31}VL^2}{\pi Dh} \qquad (2)$$

where $d_{31}$ is the piezoelectric coefficient, $V$ the applied voltage, $L$ the length, $D$ the diameter and $h$ the wall thickness of the piezo tube. With our short outer piezo a lateral scan range of $\approx$0.6 $\mu$m was achieved when using both sides of the piezo. The static friction coefficient of the graphite rods was $\approx$0.25 and we thus required a fall time of less than 1 ms—right on the limit of the drive electronics used in our set-up. A possible solution to this problem is to use faster low-voltage electronics but that will also substantially reduce the range of the piezo.

To test the STM we used mechanically cut Pt/Ir tips and a standard test sample: highly oriented pyrolytic graphite. We easily detected individual atoms of the graphite surface, as shown in figure 2. The image shown was not filtered in any way and was taken with a low bias applied to the sample as is usual in order to increase the observed corrugation. Evidently both the mechanical and electrical noise levels are very low although simple vibrational damping was used (three rubber bands stretched by 10 cm, corresponding to a resonance frequency below 2 Hz).

Another advantage with this design is that it is automatically thermally compensated because the same materials are used in the outer and inner piezos. The small volume of the STM also makes it easy to cool the whole STM head to cryogenic temperatures. To increase the scan range, the outer piezo could also be driven out of phase with the inner one. If the same piezo material is used for both the inner and outer piezos, the $z$-range is doubled and the $x$–$y$ scan range would be increased by a factor (less than two) that depends on the ratio of the tube diameters (see equation 2). In our case the $x$–$y$ scan range was increased by 50%.

The STM design that most resembles the present one is the beetle type described by Besocke and co-workers [7, 8] although that design was larger. Our outer tube corresponds to three thinner tubes in the beetle type. Three tubes will lead to a higher mechanical noise level since the resonance frequency is proportional to $d/l^2$ where $d$ is the diameter and $l$ the length of the object. One advantage of the beetle type STM is the ability to make coarse adjustments in both lateral directions, while in our design only one lateral direction is available in addition to the $z$-direction, however, for many applications this is sufficient.

In conclusion we have presented a very small STM head (about 0.3 $cm^3$) suitable for high-resolution measurements and with a low mechanical noise level of less than 0.1 Å. The inertial mechanism permits coarse adjustments in the $z$-direction and one lateral direction. The symmetrical design (both from a material and geometrical point of view) yields a small thermal drift.

## Acknowledgment

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