A High-Speed Z-Axis MEMS STM Nanopositioner

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Scanning tunneling microscope (STM) is a powerful and versatile tool, not only capable of obtaining topographic information at atomic levels from a conductive surface, but also suited for patterning, manipulation and other applications, all with unprecedented precision. A typical STM's operation relies on the quantum tunneling phenomenon. Providing a few angstroms of tip-sample separation, and a bias voltage between the two, a tunneling current (TC) is established. The tunneling current is logarithmically proportional to the tip sample separation[1]. During imaging, a three degree of freedom (DOF) piezotube is employed to scan the tip over the surface, while a PI controller drives the Z axis in order to maintain the tunneling current at the set value. Therefore, an image of the sample surface can be constructed using the Z axis controller output, along with the corresponding X, and Y coordinates from the piezotube.

Despite its well-established use in high precision applications, the achievable scan speed of the conventional STM has remained limited since its advent. One of the main reasons limiting the achievable scan speed is the relatively low operation bandwidth of the bulky piezotube Z-axis positioner, which is typically less than 1 kHz in conventional systems[2]. This limitation correspondingly hinders the ability of the Z-axis controller to rapidly respond to the changes in the topography during the scan.

To address this limitation, we design, build and characterize a high-bandwidth, 1-DOF nanopositioner with an electrostatic parallel plate actuation mechanism and a conductive tip, to replace the Z axis of the currently available STM piezotubes (Figure 1). The device is microfabricated using an SOI wafer with two device layers, where the top-most layer is designated for the tunneling current sensing, and contains the conductive tip realized by FIB induced deposition. The bottom device layer, on the other hand, comprises the actuation mechanism along with the shuttle and mechanical flexures, that provides 2-µm displacement range in one direction, comparable to a typical STM piezoelectric tube scanner. Importantly, the nanopositioner is structurally designed to have a -3dB bandwidth of 15.6 kHz, increasing the STM positioners' Z axis bandwidth more than an order of magnitude as experimentally shown in Figure 2. Using this system we were able to demonstrate that tunneling current can be successfully established on an HOPG sample in air and successfully maintained for over two minutes (Figures 3-4).

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[1] Lang, N. D. "Apparent barrier height in scanning tunneling icroscopy." *Physical Review B* 37.17 (1988): 10395.

[2] Tajaddodianfar, Farid, et al. "A self-tuning controller for high-performance scanning tunneling microscopy." Control Technology and Applications (CCTA), 2017 IEEE Conference on. IEEE, 2017.

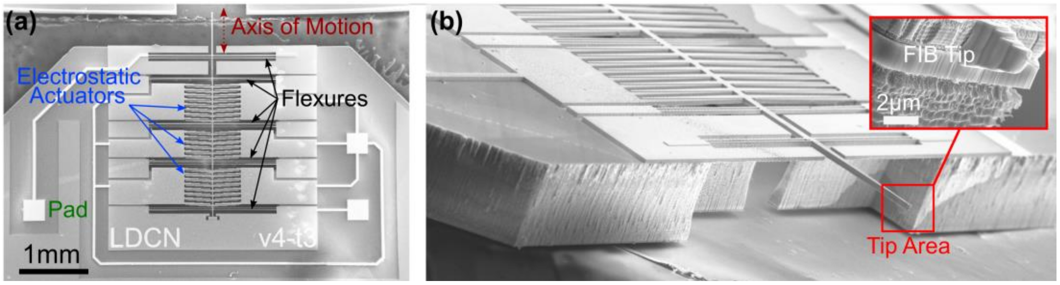

Figure 1: SEM photomicrographs of the MEMS nanopositioner in top view (a), and in isometric view. Inset shows a close-up view of the Pt tip.

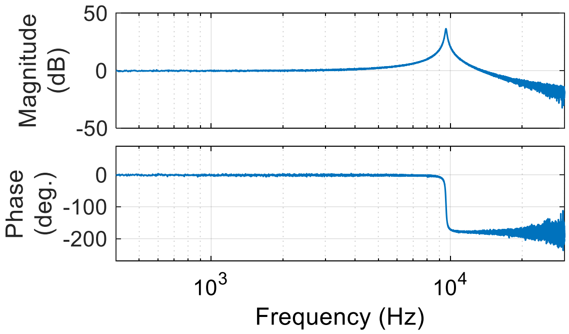

Figure 2: Frequency response of the nanopositioner.

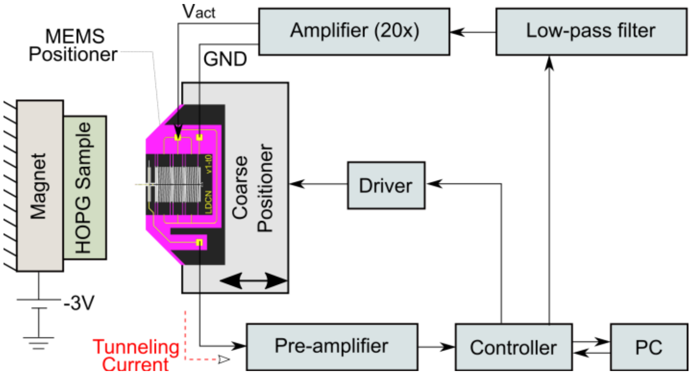

Figure 3: Schematic of the experiment apparatus.

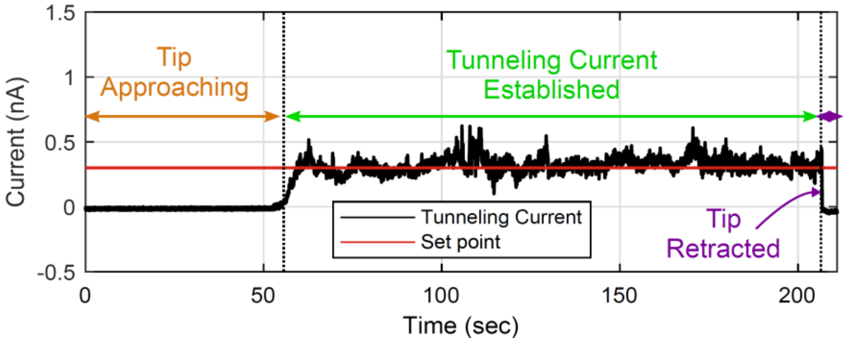

Figure 4: Tunneling current established on HOPG sample.