High Current Pulse Generation for Thermal Surface Modification using Standard STM

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Scanning tunneling microscopy (STM) has been extensively used to both image at the nanoscale as well as modify surfaces with atomic resolution[1]. One modification method is thermal heating of the substrate below the STM tip using field emission/tunneling current[2]. Unfortunately, thermal heating of conductive materials, such as metals, requires large currents in comparison to typical tunneling currents used for metrology (1-10 µA vs. 0.1-1 nA). Such large currents cannot be supported by the high-gain transimpedance amplifiers (TIA) used in precision STM system. In this work, however, we demonstrate that 1) high currents *can* be produced if the duration of the current is sufficiently short, i.e. a short pulse, and 2) that the pulse duration can be significantly longer than the thermal time constant of many conductive substrates, suggesting that surface heating can be accomplished with these short pulses.

Our approach to generating high currents is to utilize the parasitic capacitance of an STM tip (38 pF in an RHK ATM 350 Ambient STM), rather than the TIA to supply the current. The TIA is not able to supply currents above 100 nA nor is it able to respond on time scales much less than the time constant of the TIA ($R=10^8\ \Omega$, C=38 pF, τ=3.8 ms). The parasitic capacitance, however, is able to support currents of 1-10 µA for durations of 10+ µs with minimal deviation of tip voltage (nominally 0 V).

To explicitly demonstrate this, we fabricated a custom, high-speed current measurement amplifier which measures the current into the *sample* stage. It was necessary to measure the sample stage current rather than tip current so as to not disturb the STM tip parasitic capacitance we wished to investigate. We set the sample at +2 V for nominal tip-distance biasing of 0.5 nA and pulsed the substrate (Au) to a voltage between 3 and 9 V, using 1 µs and 4 µs durations, at different substrate locations.

Fig. 1 shows the resulting current measurements with a 0.5 nA steady-state bias set point. The variation is due to differing substrate locations and tunneling conditions in ambient conditions. Currents as high as 20 µA can be achieved for at least 4 µs. Fig. 2 shows current measurement for long pulses; a clear decline in the current can be seen after 25 µs. It is believed this is due to the charge accumulation of the parasitic capacitance and also possibly to the servo loop of the STM beginning to pull the tip away, thus reducing current. It is clear that sub 25 µs pulses can be sustained. Fig. 3 is a COMSOL thermal simulation of electron beam under a paraboloidal STM tip on Au(100 nm)/Ti(5 nm)/Si(1µm). Currents of 4 µA produced localized heating above 1000 C in a radius of 2 nm in < 1 ns, which should be sufficient to modify the surface[2,3].

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[1] Randall, J. N.; Lyding et al, Journal of Vacuum Science & Technology B **27,** 2764 (2009).

[2] U. Staufer, R.Wiesendanger et al, Appl. Phys. Lett. **51**, 244(1987).

[3] F. Flores, P. M. Echenique, and R. H. Ritchie, Phy. Rev. B **34**, 2899 (1986).

[4] J. G. Simmons, J. Appl. Phys. 34, 1793 (1963).

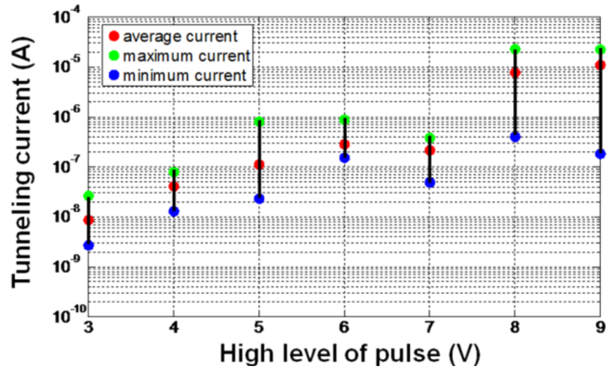

Fig. 1 Tunneling current as a function of high level of pulse. Data taken for 1 μs and 4 μs pulses, with both showing similar rages of current for the same pulse voltage.

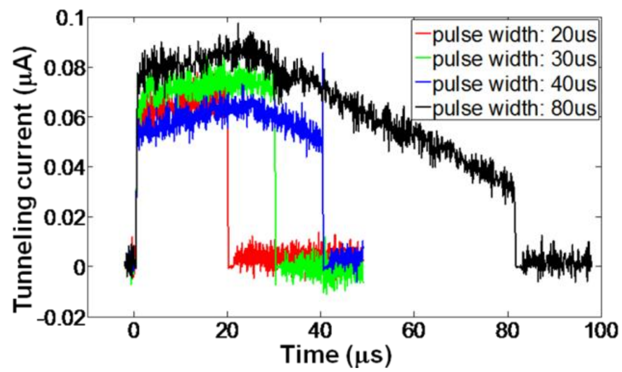

Fig. 2 Tunneling current caused by pulse with different pulse widths. The pulses are square wave pulses with low level of 2 V and high level of 5 V.

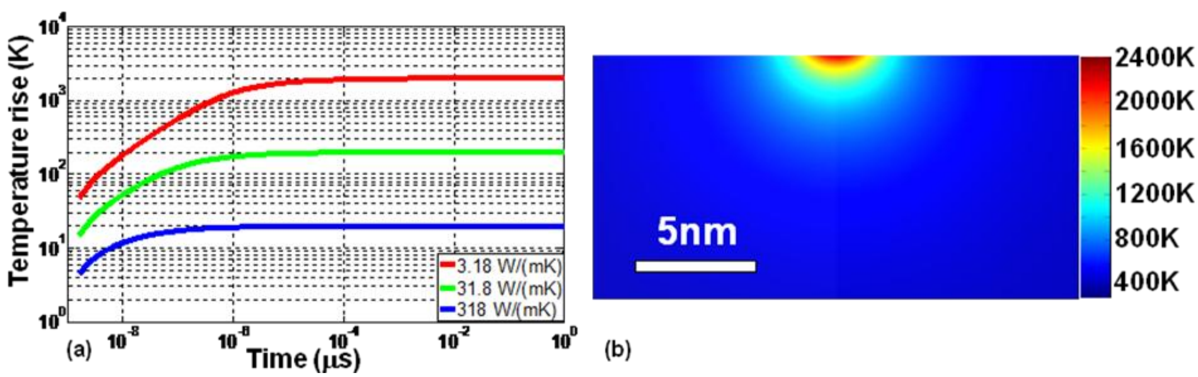

Fig. 3 COMSOL thermal simulation of electron beam under a paraboloidal STM tip on Au(100 nm)/Ti(5 nm)/Si(1μm). In the simulation, the tip radius of curvature is chosen as 10 nm and an 8 V (high level) pulse is applied to the sample while the separation between tip and sample is set as 0.7 nm, which corresponds to 4 μA tunneling current calculated using J. G. Simmons' tunneling model[4]. (a) The temperature rise at the center using different thermal conductivities of the gold layer[3] (bulk, bulk/10 and bulk/100) to simulate nanoscale effects while the heat capacity was kept at the bulk heat value. (b) Heat profile of the locally heated region.