Self-tuning PI Control for STM Tip Protection

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Tip-sample crash is a major failure in Scanning Tunneling Microscope (STM) operation. The effect of such failure can be more devastating when STMs are operated in Hydrogen Depassivation Lithography (HDL) where preserving the tip shape is vitally important. Given the sub-nanometer separation between the tip and sample, performance of the closed-loop control system has an important role in preventing such crashes.

We have established that there is a direct link between the Local Barrier Height (LBH) and the STM feedback stability [1]. The loop gain of the feedback control system is affected by the LBH, and since the closed-loop stability depends on the loop gain, LBH variations can severely affect the stability. We proposed a self-tuning PI controller that measures the LBH and continuously adjusts the PI gains to deal with the LBH variations and prevent instability [1].

In this work we investigate the effect of the proposed self-tuning PI controller on the STM tip durability. We successively scanned a Si(100)-(H) surface while the PI gains and scanning speed were normal, and the tuning algorithm was operating. After collecting 64 images each in 5 minutes, we turned off the tuning algorithm and continued the successive scanning with the same parameters. Results (Figure 1) show that while the tuning algorithm was active, the tip changes did not result in major crash. However, when we turned the tuning off, tip changes resulted in formation of an undesired HDL pattern on the surface. The growth of the formed pattern in the next scans and the final tip crash can be due to the variation of the LBH caused by the tip changes and by the formed patterns.

We also report on the effect of the self-tuning PI controller on the STM operation in lithography mode. Figure 2 shows the STM image and the tunneling current recorded while performing the HDL with and without the tuning algorithm. The sharp spikes in the current are due to sudden change of the LBH when hydrogens are depassivated. Our results show that the self-tuning controller lowers the height of the current spikes and reduces the chance of current pre-amplifier saturation that can be a reason for control malfunction during the lithography. The success of this technique for stabilizing imaging and HDL on Si(100)-H should extend to any surface investigated by STM, reducing instability and enhancing tip lifetime.

[1] F.Tajaddodianfar, *et al, Rev. Sci. Ins. 89 (1), 013701 (2018)*

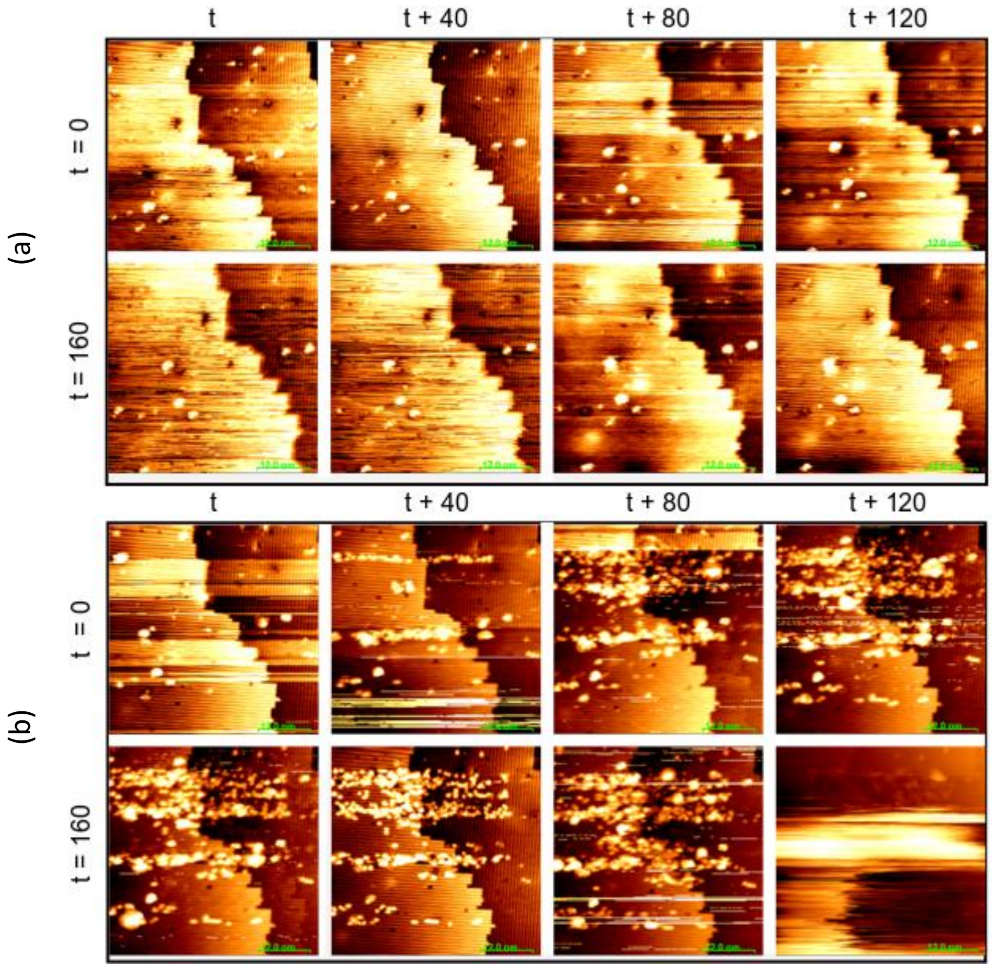

Figure 1: Successive STM imaging of H-terminated Si surface, a) with and b) without the PI tuning algorithm. Times are given in minutes relative to the image in the top left corner. PI gains are normal and scanning speed is 150nm/s. One out of eight captured images are shown and group (b) is taken immediately after group (a) with the same parameters. Tip changes in group (b) result in formation of an undesired pattern in the surface that is due to feedback instability caused by LBH variation, and tip dies eventually. The same tip survives in (a).

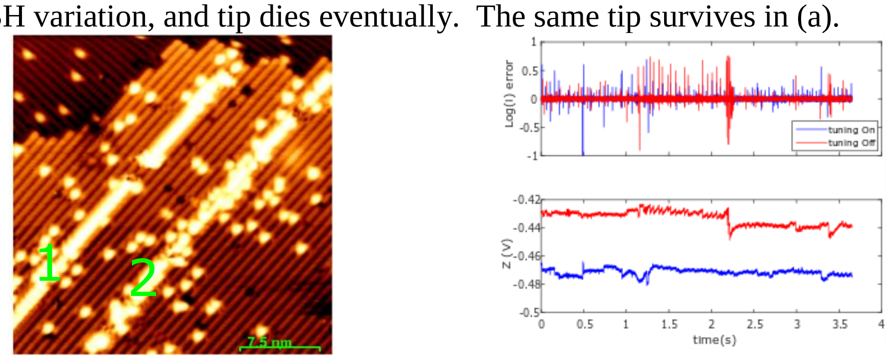

Figure 2: Left) STM image showing two HDL patterns drawn with (1) and without (2) PI tuning algorithm. Right) The feedback error signal (top) and controller command (bottom) during the HDL.