From STM to Lithography Tool

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Abstract: Since its invention, Hydrogen Depassivation Lithography (HDL) has been primarily carried out using Scanning Tunneling Microscopes (STMs)[1].

STMs are wonderful research tools which are able to explore the topography, chemistry, and electronic states of surfaces with atomic precision and HDL has significantly better resolution and precision than the best e-beam lithography tools[2]. However, STMs are also: difficult to use; have creep and hysteresis that results in image distortions, tip position instability, and difficult navigation; are painfully slow; and unreliable because they are prone to frequent tip crashes.

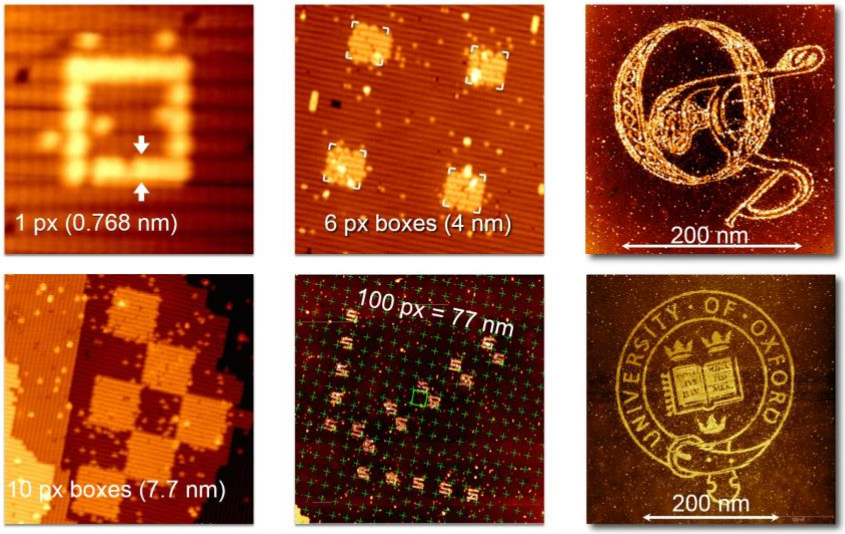
Surface scientists put up with these problems because there are no alternatives to STM as an atomic resolution tool that can provide such a wealth of information on surfaces, but they are unacceptable for lithography tools. Therefore, Zyvex Labs has been evolving the instrumentation of Scanning Tunneling Microscopes, to make the practical patterning tools that carry out automated atomic precision HDL.

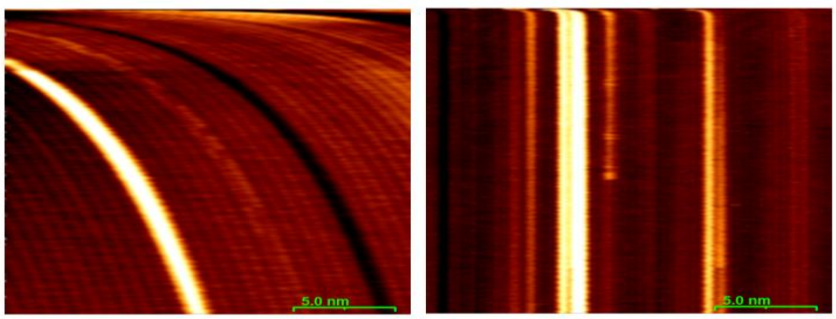
We started by using basic STM instrumentation, a piezo-tube scanner and a PI loop to control the tip height while scanning using a control system that was designed for imaging. We have developed ZyVector^{TM}[3], a powerful, 20-bit, low-latency, low-noise control system designed to develop and execute automated lithography. We have implemented creep and hysteresis correction for far more accurate tip positioning for imaging and lithography. We developed an automated, vector-scan, variable spot-size, lithography process that automatically aligns to the surface Si lattice to carry out digital lithography with sub-nm pixels that are four surface Si atoms[3]. We have software that automatically fractures CAD data into different sections and generates tip vectors to carry out the exposure with the atomic precision tunneling mode and the higher throughput, nm-spot-size field emission mode. We have also developed an adaptable PI loop that constantly measures the local barrier height which affects the gain of the system and automatically adjusts the PI parameters to keep the control system in a stable region, significantly reducing tip crashes[4]. We are also using machine learning to optimize and improve the automation of the lithography system.

Most exciting is our recent success in developing MEMS actuators for the nanopositioning of the tip. Using a Z-axis electrostatic drive we have demonstrated scan rates 10 times that possible with a piezo actuator while maintaining dimer row resolution imaging on Si(001):H. We are currently developing an XYZ MEMS scanner which will be even faster with no creep or hysteresis. This will lead to a massively parallel tip technology that will dramatically increase throughput[5].

References

1. Lyding, J. W. (1994). Nanometer scale patterning and oxidation of silicon surfaces with an ultrahigh vacuum scanning tunneling microscope. *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures*, *12*(6), 3735. https://doi.org/10.1116/1.587433
2. Randall, J. N., Owen, J. H. G., Lake, J. & Fuchs, E. Next generation of extreme-resolution electron beam lithography. *J. Vac. Sci. Technol. B* **37**, 061605 (2019). doi: 10.1116/1.5119392
3. https://www.zyvexlabs.com/apm/products/zyvector/
4. Tajaddodianfar, F., Moheimani, S. O. R., & Randall, J. N. (2018). Scanning Tunneling Microscope Control: A Self-Tuning PI Controller Based on Online Local Barrier Height Estimation*. *IEEE Transactions on Control Systems Technology*, 1–12. https://doi.org/10.1109/TCST.2018.2844781
5. Randall, J. N., Owen, J. H. G., Lake, J., Saini, R., Fuchs, E., Mahdavi, M., … Schaefer, B. C. (2018). Highly parallel scanning tunneling microscope based hydrogen depassivation lithography. *Journal of Vacuum Science & Technology B*, *36*, 6–10. https://doi.org/10.1116/1.5047939





Uncorrected creep after 500 nm jump

500 nm jump with creep correction