Digital Atomic-Scale Tip Based Nano Fabrication

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Zyvex Labs has been developing Hydrogen Depassivation Lithography (HDL) as a digital process. HDL is carried out with modified Scanning Tunneling Microscope (STM) instrumentation and uses electron stimulated desorption of H atoms from a Si (100) 2x1 H passivated surface. In this sense, it is a form of e-beam lithography. The process inherently has some digital aspects: 1) the resist (the H atoms) have a digital response, the Si-H bond is either broken or it is not. 2) The resist distribution is quantized with on H atom per surface Si atom in the beautifully ordered Si surface lattice. 3) There are distinct imaging (reading) and lithography (writing) modes. We have embraced the digital nature of this process to capitalize on the many advantages of digital processes. We align our exposures to the Si surface lattice to allow us to read and write on a digital grid. Like any good digital process we can take advantage of working within tip position tolerances and still get the perfect digital response we desire. There is even some tolerance in the pattern transfer methods that we use. This paper will describe our current state of the art with is sub-nm resolution, sub-nm critical dimension control, and ~1nm pattern placement over modest areas. To improve on this performance, we are working on creep and hysteresis correction and improved control systems to produce unprecedented tip position control in scanning probe instruments.

We are also working to expand the pattern transfer technologies used with our STM lithography. We have already demonstrated: Atomic Layer Epitaxy growth of Si and Ge, Atomic Layer Deposition of TiO_2, and the deposition and epitaxial overgrowth of phosphorous donor dopants. These processes and the all have digital fabrication aspects. We are working to exploit the digital nature of these fabrication processes and new ones that we plan to develop.

We believe that there is a spectacular opportunity to learn from the tactics employed in information technology by Richard Hamming and many others that learned to deal with the inevitable errors in computation, transmission, and storage. This was accomplished by a host of error detection and error correction schemes. The current and rapidly evolving IT systems are incredibly complex and yet extremely reliable. In nanofabrication, the digital events are the making and breaking of chemical bonds. Digital processes are designed so that there are adequate tolerances to minimize errors. We plan to develop additional fabrication methods that can either detect the chemical bond events, or at least be able to detect their completion. This will allow us to develop fabrication-error detection and correction processes. We believe that by embracing and developing digital tactics with our nanofabrication processes, similarly impressive nanosystems that are not restricted to information processing will emerge.

Our ultimate goal is the development of Atomically Precise Manufacturing where inevitable fabrication errors are detected and corrected. This technology will provide the nano-foundries required to produce the large array of nanotechnology products that have been promised but not yet delivered. An interesting analogy could be made between the state of nanotechnology today and information technology when it was still in its largely analog implementation. The vast majority of the growth of that industry and the benefits that it has provided, were enabled by implementing digital information theory in electronics, communication, and storage. **It is time for nanofabrication to go digital.**