ASYLUM RESEARCH
Atomic Force Microscopes

MicroAngelo
APP NOTE 01

MicroAngelo™ – Built-in Nanolithography and Nanomanipulation

Nanolithography and manipulation capabilities have actually been around for quite some time. Remember the famous 1990 IBM image of Xe atoms manipulated using STM?[1] Today's demanding applications require incredibly precise and flexible instrumentation. The MicroAngelo features built into Asylum's MFP-3D™ and Cypher™ AFM systems offer the most comprehensive capabilities and highest precision available for nanolithography and manipulation.

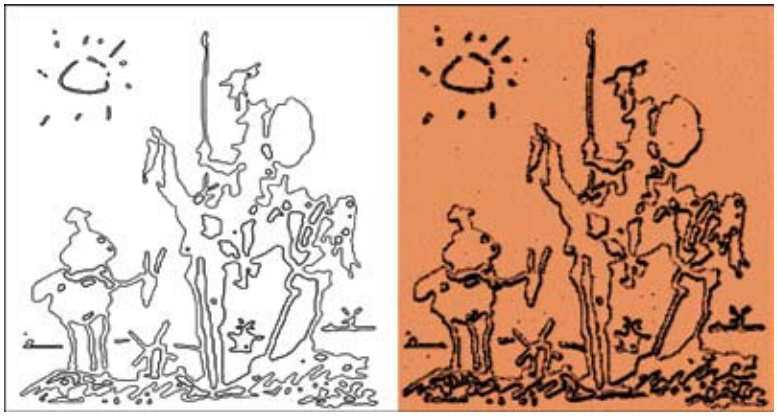

Figure 1: Coordinates of the imported JPEG line drawing (left) and AFM phase image (right) of nanolithographically etched polycarbonate, 5µm scan. The original JPEG scan is a copy of Pablo Picasso's "Don Quixote".

Quantum dot structure created on a GaAs wafer using oxidation lithography, 2.5µm scan. Image courtesy D. Graf and R. Shleser, Ensslin Group, ETH Zurich.

Built-in Capabilities Without Added Expense

With MicroAngelo, you can manipulate and modify samples and surfaces on the nanometer and picoNewton scale – even down to the level of single molecules. MicroAngelo comes standard with every MFP-3D and Cypher AFM – no additional hardware or software options need to be purchased to add nanolithography and manipulation functionality.

Closed Loop for Unequaled Repeatability

At the heart of MicroAngelo's precise operation is Asylum's patented nanopositioning system (NPS™). The NPS' sensored, closed loop operation in all three axes provides sub-nanometer resolution for the MFP-3D and sub-Angstrom resolution for Cypher over the entire scan range with the lowest sensor noise levels available today. This allows repeatable imaging, quantitative feature measurement, reliable and accurate imaging offsets, quantitative force curves, and quantitative positioning for manipulation and lithography.

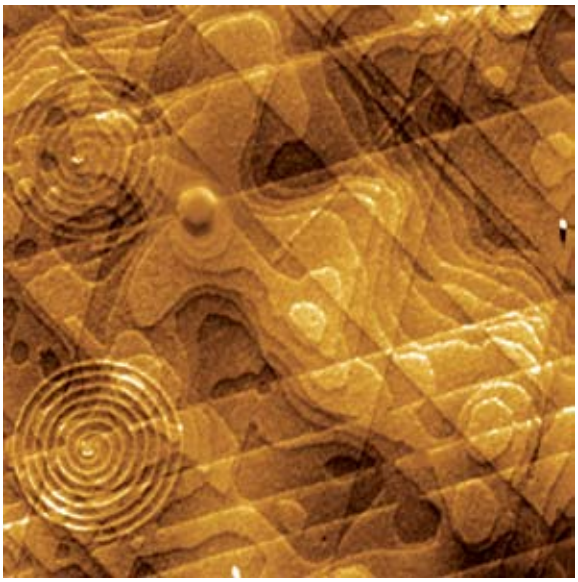

Figure 2: Nanografting of thiols on a Au(111) surface. 1.5µm scan. Sample courtesy M. Liu and G. Liu, University of California Davis.

Fully-Digital, Low Noise Controller for Flexibility

The all-digital ARC2™ controller provides users with the most sophisticated architecture available today. All-digital means that the signal is not corrupted by analog signal conditioning that is typical in other commercial units. In addition, new functionality can be added quickly and easily with software and firmware upgrades.

Incredibly Powerful IGOR Pro Software

Asylum's flexible, powerful, and open software is based on IGOR Pro and allows you virtually unlimited ability to modify routines and do custom experiments. Unlike proprietary software, if you don't find a feature you want, you can simply write your own.

Other powerful routines include nonlinear curve fitting to arbitrary user-defined functions, 2D FFTs, wavelet transformations, convolutions, line profiles, particle analysis, edge detection (eight methods, including Sobel), thresholding (five methods, including fuzzy entropy) and more.

Applications

MicroAngelo can be used for many nanolithography and manipulation applications including surface scratching and patterning, localized surface oxidation, nanotube, particle and molecular manipulation, single molecule experiments, nanoindenting, piezo-response force microscopy, and more.

With MicroAngelo, users can easily import curves from a variety of other programs or generate them within the MFP-3D or Cypher software environment. As shown in Figure 1, an original JPEG image was imported into the software and converted to a list of coordinates to create the lithography pattern. These coordinates were then used to manipulate the AFM tip which created the scanned image.

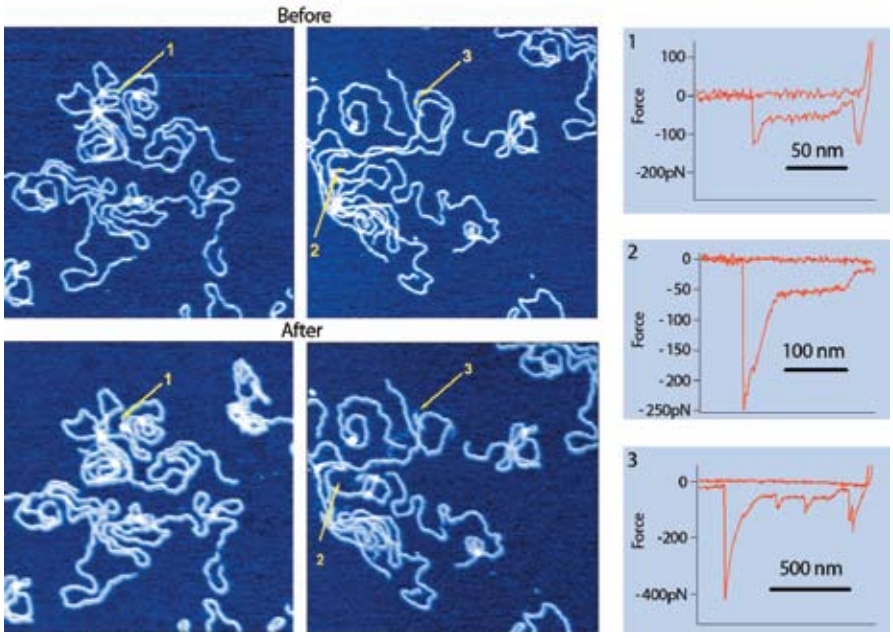

Figure 3: Lambda digest DNA, 1µm scan, with force curves taken at three different, mouse-selected points (right). Different portions of the B-S transition are visible in the force curves.[2]

Figure 2 shows nanografting of thiols. The nanografting was performed on a gold surface onto which a self-assembled monolayer (SAM) of decanethiol had been adsorbed. Imaging and lithography were done in contact mode in an aqueous solution containing octadecanethiol, whose tail is eight carbon atoms longer than decanethiol. At low forces, the AFM simply imaged the SAM. However, when higher forces were applied during lithography, the AFM displaced the original SAM molecules. The longer-tailed molecules then diffused in to heal the SAM resulting in a raised surface. The spirals are 620nm in diameter,

with average line spacings of 40nm, average line-widths (FWHM) of 15nm, and average heights of 0.15nm. Mono-atomic steps of (111) gold are shown in the background.

Figure 3 shows before and after scans on Lambda digest DNA in fluid. Force curves were made at user-selected sites 1, 2 and 3 ("before" image). The DNA appears wider on the "after" images because the tip has picked up contaminants (presumably DNA) while performing the force curves. The force curves show the characteristic B-S transition of stretched DNA.[2]

Figure 4 illustrates a rolling experiment using a bundle of single-walled carbon nanotubes. The initial image shows a single isolated nanotube bundle running from lower left to upper right, which is manipulated in the subsequent images (a larger bundle is also visible to the right of the smaller bundle and an atomic step is also visible). Images A, C, E and G show the cantilever tip paths (yellow) followed using the MicroAngelo interface. Figures B, D, F and H show the effects on the manipulated nanotube. In Figures A, B, the upper-right section is rolled to the right while the lower section is rolled to the left, bifurcating the nanotube bundle. Additional manipulations shown in Figures C through H realign the nanotube sections. During the manipulation, the normal loading force was set to 90nN. The nominal velocity of the cantilever tip was 1µm/second in all of the images, and the vertical scale was 15nm.

Figure 5: Pitts Model 12 biplane lithography on a sol-gel PZT thin film. Piezoresponse force microscopy (PFM) amplitude is painted on top of the rendered topography. 14.5µm scan, bitmapped lithography.

MicroAngelo can also be used in conjunction with Piezoresponse Force Microscopy (PFM). PFM can be used to modify ferroelectric polarization through the application of a bias. When the applied field is large enough (i.e. greater than the local coercive field), it can induce ferroelectric polarization reversal. This technique can be used to 'write' single domains, domain arrays, and complex patterns, as shown in Figure 5 in which an image of an airplane has been patterned into a ferroelectric film via ferroelectric lithography. The patterns are written without changing the surface topography. The ultimate limit for this writing process is determined by the material properties and the sharpness of the tip. Under optimal conditions,

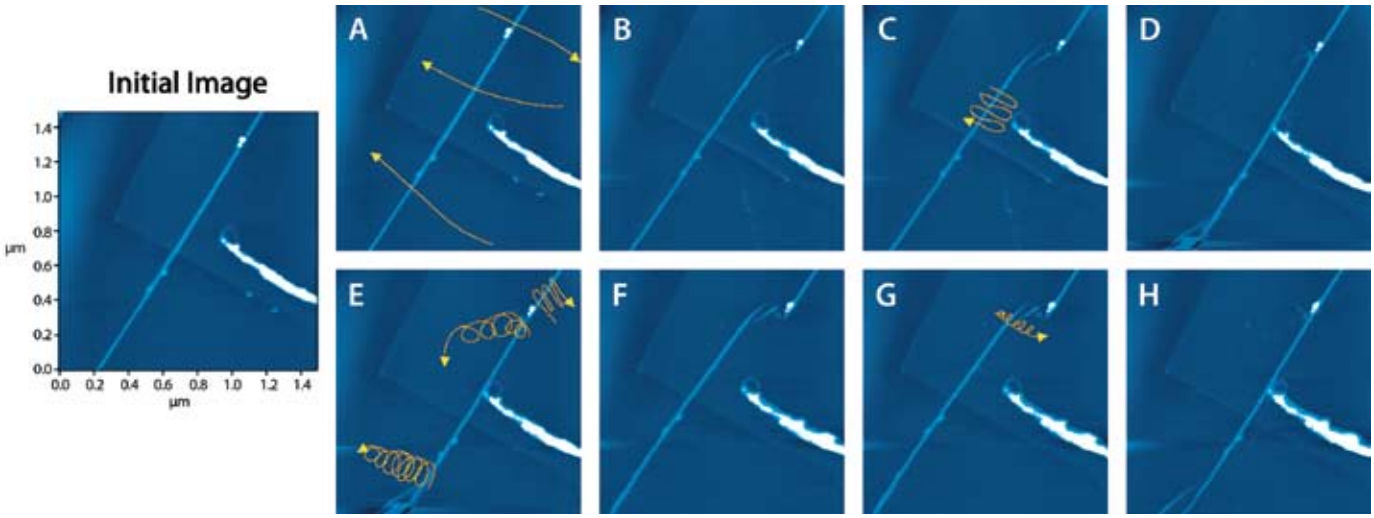

Figure 4: Rolling bundle of single-walled carbon nanotubes. The yellow lines show the user's manipulation. "B" shows that the upper section of the tube rolled right based on the commands in "A". Next, the lower section of the tube was rolled to the right (C, D), left (E, F), and then right again (G, H). 1.45µm scan, vertical scale 15nm.

reliable fabrication of 5-8nm features (bit size for information storage) has been demonstrated.[3] Notably, surface polarization controls chemical reactivity of the surface in the acid dissolution and metal photodeposition processes, providing a pathway to transform the polarization pattern into a topographic or deposited metal pattern.

Figure 6 shows anodic oxidation lithography on a silicon surface. The pattern was first imported into the software as a JPEG and then written with a -10V bias on a conductive cantilever tip at 20nm/s. The AR logo was written in AC mode.

MicroAngelo also enables quantitative measurements for tribological applications using the Asylum Research MFP NanoIndenter. Figure 7 shows a scratch and indent performed on polyurethane (*For additional information on nanoindenting, see our MFP NanoIndenter data sheet).*

Power and Flexibility in One Complete System

You'll find all the power and flexibility of MicroAngelo built into each Asylum SPM system. Contact us today or send us your samples to see why Asylum Research is the right choice for nanolithography and nanomanipulation.

References

1. D.M. Eigler, E.K. Schweizer. Nature 344, 524-526, 1990.
2. M. Rief, H. Clausen Schaumann, H. Gaub. Nature Structural Biology, vol. 6, 346, 1999.
3. Y. Cho, S. Hashimoto, N. Odagawa, K. Tanaka, Y. Hiranaga, Nanotechnology 17, S137, 2006.

MicroAngelo Features/Benefits

- Lowest noise and highest precision with closed loop position control in all three axes.
- Customizable IGOR Pro Software – sophisticated graphics loading, interpretation and analysis software allows you to load external graphics files, make freehand and geometrical sketches, or even plot user-defined mathematical functions. Advanced ARgyle™ 3D rendering and real-time scanning are built-in capabilities in the system software.
- No latency greater than 65ms between points.

Figure 6: Anodic oxidation lithography on silicon, written in AC mode, 1µm scan.

Figure 7: Indent and scratch on polyurethane, 17µm scan.

- Lithography can be operated in either vector based or bit-mapped modes.
- Groups of points are sent to the controller and processed at the natural controller interrupt rate. Complex patterns that are typical in anodic oxidation applications are easily drawn.
- All data types are available for plotting during lithography, including deflection, lateral force, amplitude, phase and all user-available analog-to-digital converters (ADCs) and digital-to-analog converters (DACs).
- Lithographic contrast can be controlled by modulating cantilever set-point (both contact and AC modes), cantilever drive voltage, cantilever potential and/or any other channel including the user-available DACs.

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