A Platform Technology for High-throughput Atomically Precise Manufacturing: Mechatronics at the Atomic Scale

Award Number EE0008322

UT Dallas, Zyvex Labs and NIST

04/01/2018 – 03/31/2021

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Overview Slide

Timeline

- Award issued April 2018
- Projected End date March 2021
- Project will be started as soon as funds are made available

Challenges

- High-throughput Atomic Precision Lithography
- High-speed imaging for lithography
- Parallel operation of probes
- Atomic precision positioning

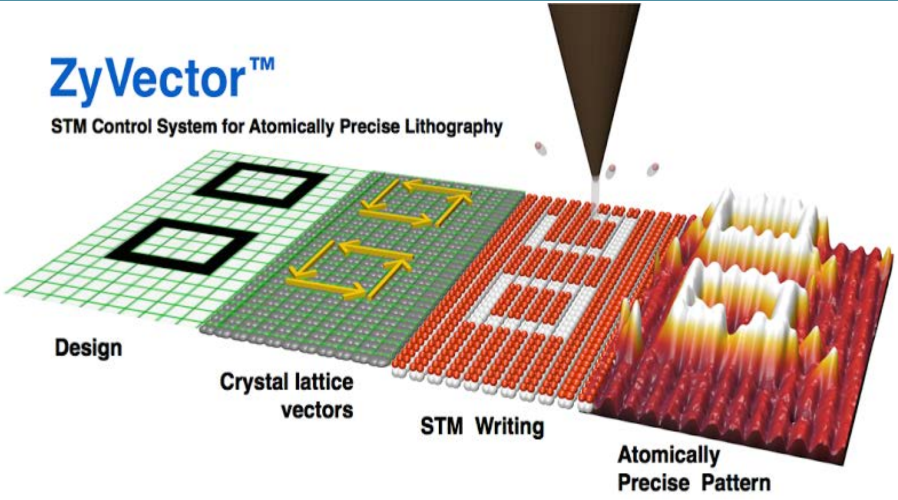
Budget

	BP 1 4/1/2018 – 9/30/2019	BP2 10/1/2019 – 3/30/2021	Total Planned Funding (FY 18-FY 20)
DOE Funded	$1,230K	$1,118K	$2,417K
Project Cost Share	$358K	$247K	$605K

Partners

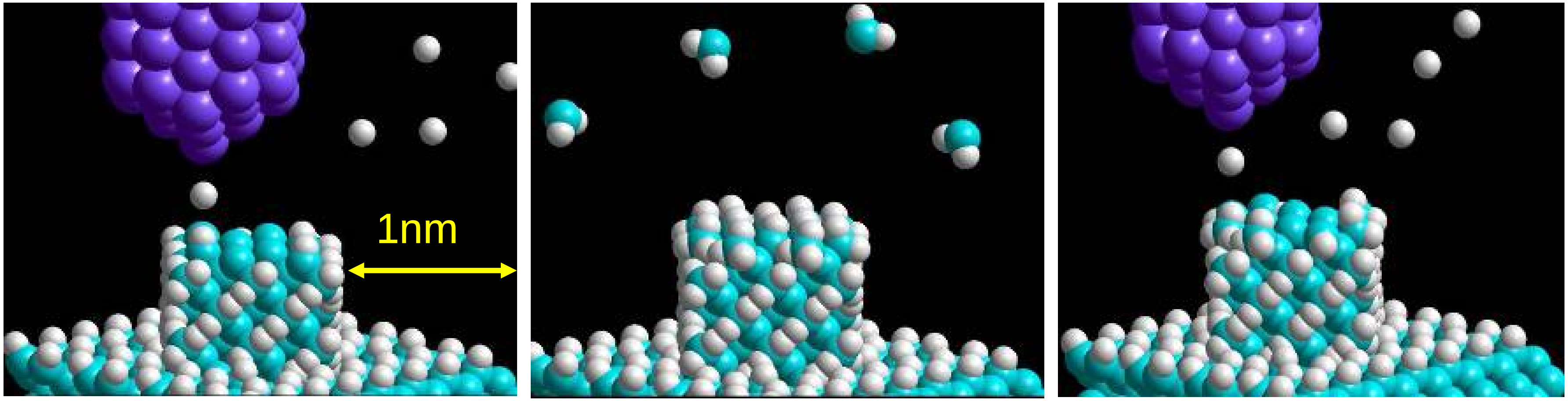
- UT Dallas Laboratory for Dynamics and Control of Nanosystems collaborates with Zyvex Labs and NIST.
- NIST will participate in design and fabrication of MEMS STMs.
- Zyvex Labs will integrate the developed systems into existing STMs and perform validation experiments.

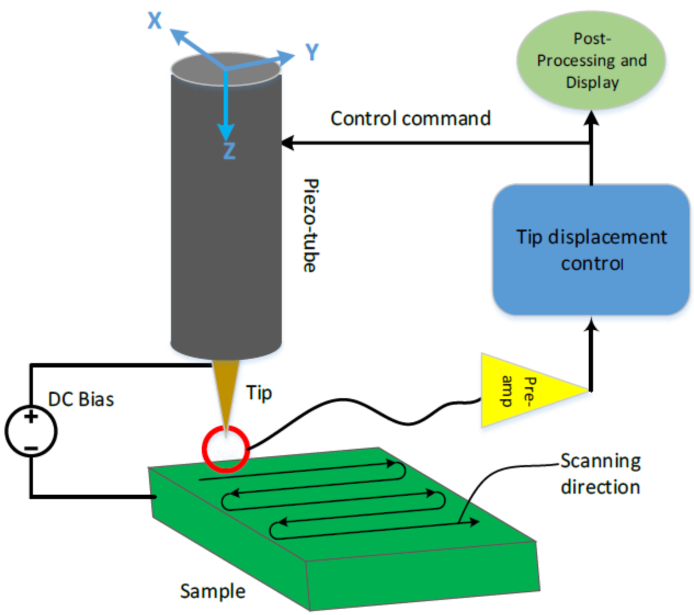
Project Objectives



- The key objective is to build a platform technology for high-throughput Atomically Precise Manufacturing (APM) based on Hydrogen Depassivation Lithography.
- The envisioned system will enable atomically precise lithography at speeds and throughputs 2-3 orders of magnitude beyond what is feasible with today's technology.
- It will facilitate programmable atomic-scale position control for the commercially viable fabrication of the smallest building blocks and the positional assembly of these building blocks into atomically precise systems and sub-systems to create electronic devices and systems of minimal size, and thus, of the highest energy efficiency.
- APM will offer the ultimate in miniaturization and energy efficiency.
- The project is aligned with AMO's mission of creating "*foundational energy-related advanced manufacturing technologies*".

Technical Innovation





- HD lithography is done today using a Scanning Tunneling Microscope (STM). The STM was invented over 35 years ago and has changed little ever since. Its primary use is imaging material surfaces with atomic resolution.
- STMs use a piezoelectric actuator to move an atomically sharp tip over a surface, while a feedback control system maintains a tunnelling current constant.

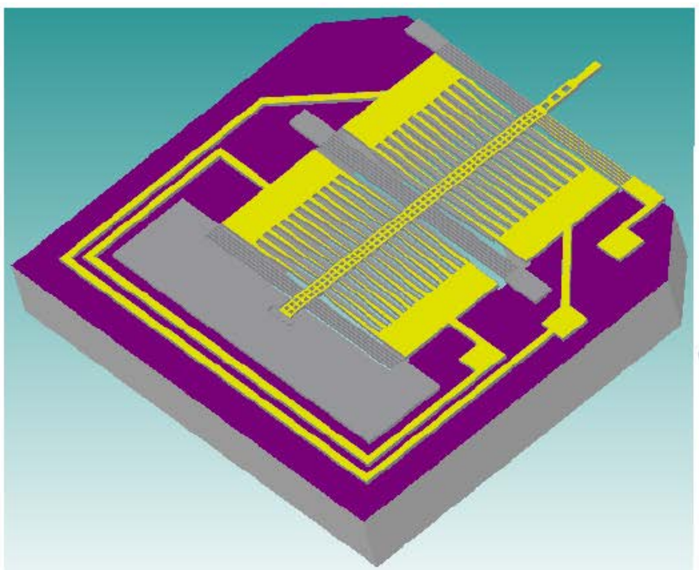
Technical Innovation

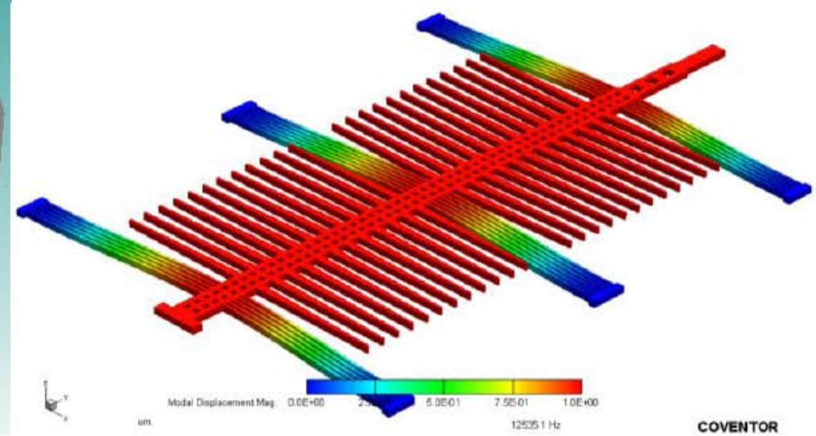
- Use of STM for HD-Lithography is complicated by a number of issues:
  - Piezoelectric actuators are highly resonant systems which require a low-bandwidth controller to function properly – *this sets a hard limit on their speed*.
  - Piezoelectric actuators suffer from hysteresis and creep – *these limit their positioning precision*.
  - STMs perform lithography with a single tip – *this limits their throughput*.
- *Speed, throughput and accuracy* are the issues that we will attempt to resolve in order to make this technology commercially viable.

- We will build a parallel array of actuators to increase throughput of the system by enabling a large number of tips to perform lithography simultaneously.
- This is a multidisciplinary project that will combine innovations in mechatronic system design, feedback control, high-precision engineering and microfabrication technologies to enable atomically precise manufacturing.

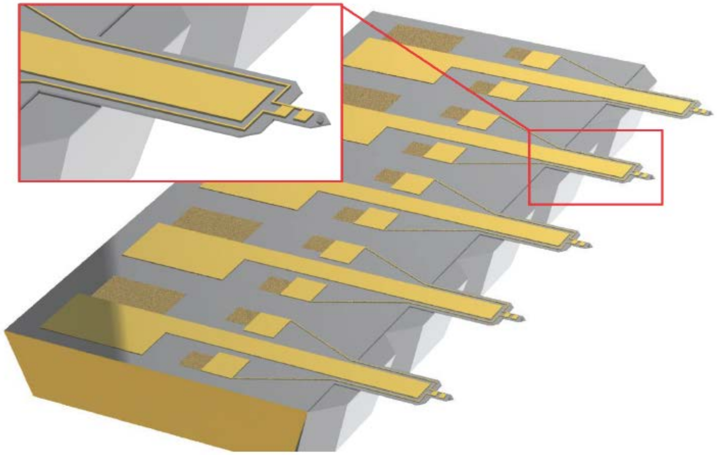
Technical Approach

- During this program we intend to progressively move away from using piezoelectric actuators in STM, ultimately replacing them with MEMS nanopositioners. Electrostatic actuation used in MEMS is far more suitable for atomic precision positioning than piezoelectric actuation.
- Using MEMS enables us to build a compact array of STM tips that operate in parallel, thus increasing the throughput of the system for both lithography and imaging.
- We will design the MEMS STM nanopositioners to have a faster response compared with piezos, thus enabling a faster operation compared with today STMs.





Technical Approach



- Imaging is an important capability in atomically precise lithography.
- We will design and build an array of active micro-cantilevers for high-throughput non-contact atomic force microscopy.
- We will develop non-raster scanning methods for high-speed AFM and STM.

The Team:

- The project is led by Reza Moheimani (UT Dallas), and will involve close collaborations with Jason Gorman (NIST) and the Zyvex Labs team led by John Randall. This is a multidisciplinary team with a history of close collaboration on complex projects.

Participant roles:

- UTD will design and fabricate 1DOF MEMS STMs, a 3DOF flexure-guided nanopositioner, feedback control algorithms for MEMS STM and an active cantilever array.
- NIST will design and fabricate a 3DOF MEMS STM.
- Zyvex Labs will participate in the overall design process and will integrate the developed systems in a UHV STM system to experimentally demonstrate their functionalities.

Results and Accomplishments

- This is a new project.
- It consists of eight tasks, each involving several sub-tasks.
- The project will be performed over two funding periods.
- It will involve significant collaborations between the three involved organizations.
- In the GANTT Chart:
  - U – UT Dallas
  - Z – Zyvex Labs
  - N – NIST

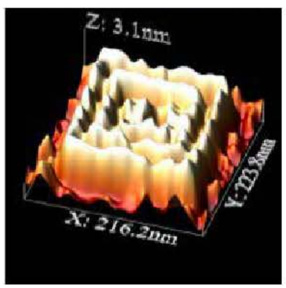
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1. High-speed scanner													
1.1	Design & modeling	UZ											
1.2	Machining & mech. tests		U										
1.3	Assembly & test				UZ								
2. 1DOF MEMS-STM													
2.1	Design & FEA		UZ										
2.2	Fabrication			UZ									
2.3	Characterization					UZ							
2.4	UHV tests						UZ						
3. 3DOF MEMS-STM													
3.1	Design & simulations			All									
3.2	Fabrication				N								
3.3	Characterization						All						
4. AFM cantilever array													
4.1	Design & Fab	UZ											
4.2	Characterization		UZ										
4.3	Modeling & sysid				UZ								
5. Control of high-speed scanner													
5.1	Controller design							UZ					
5.2	Controller implementation								UZ				
6. Imaging & Litho - 1DOF STM													
6.1	Q-control							All					
6.2	High-speed imaging									UZ			
6.3	Parallel imaging & litho											UZ	
6.4	Pattern generation												UZ
7. Imaging & Litho - 3DOF STM													
7.1	UHV tests							NZ					
7.2	Q-control design									NU			
7.3	High-speed imaging											NZ	
7.4	HD lithography												NU
8. AFM cantilever array													
8.1	Control design for the array							UZ					
8.2	High-speed imaging									UZ			

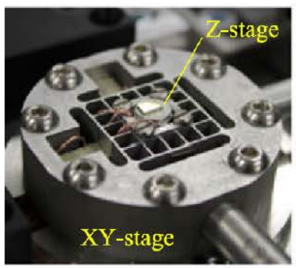
Table 1: Program Gantt Chart; U=UT-Dallas, Z=Zyvex Labs, N=NIST

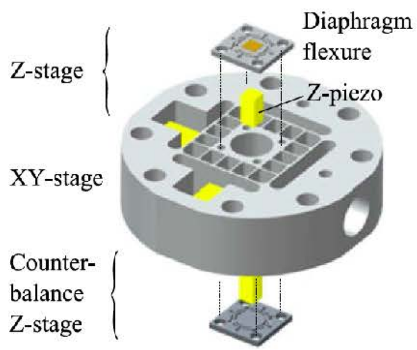
Transition (beyond DOE assistance)

- This is an ambitious project that aims to design a platform for atomically precise manufacturing, *for the first time*, by developing technologies that when combined will result in a viable APM platform. Successful execution of this project will complete the first step to making APM commercially viable.
- In long term, the technologies to be developed offer a path to developing active nano-mechanical systems. Zyvex Labs has already demonstrated pattern transfer into Si by HDL, selective ALD, and dry etching. Pattern transfer into Si is the Basis of MEMS/NEMS. The NEMS decedents made possible by the MEMS HDL scanners we propose will be quite flexible in their production capabilities and thus able to produce robust material products.
- In short term, there will be the scope to commercialize individual technologies developed throughout this project. We believe there is a market for MEMS STM and AFM. A possible path for commercialization is that Zyvex Labs will license the MEMS STM scanner technology from UT Dallas. Zyvex has successfully commercialized a number of complex systems in the past.

Questions?


Z: 3.1nm
X: 216.2nm
Y: 223.8nm


Z-stage
XY-stage


Diaphragm
flexure
Z-stage
Z-piezo
XY-stage
Counter-
balance
Z-stage