Massively Parallel Positioning of Dip-Pen Lithography Arrays

Introduction

The purpose of this three-year project is to create the positioning equipment that will enable the OSU NSEC to conduct a Dip-Pen Nanolithography (DPN) process wherein an array of 1x1cm^2 silicon chips, each with 55,000 AFM tips, are used to conduct massively parallel writing on DNA strands. The focus of this work is the creation of the core meso- and micromechanical instrumentation, and the integration of electronics software, that are required to manipulate the chips with Angstrom-level resolution. The arrayed positioners are to work with the arrays of DNA molecules, to be fabricated by OSU. Figure 1 shows an example array that OSU has created (left) and a schematic of how a DPN tip from the array will interact with DNA strands (right). The equipment must be cost-appropriate for research and fabrication tasks.

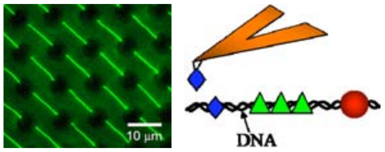

Figure 1. DNA array (left) and AFM-DNA interaction (right)

Project timeline

- Year 1: Model, design and fabricate open-loop prototype nanopositioners.
- Year 2: Equip the nanopositioners with a six-axis sensing system and closed loop control.
- Year 3: Finalize the control-actuation-sensing-calibration and demonstrate parallel DPN processing.

We are in the first $^1/_3$ of year 2. The open-loop (Year 1) and closed loop (Year 2) prototypes are shown in Figure 2.

Figure 2. DNA array (left) and AFM-DNA interaction (right)

Figure 3 shows a close up of the Year 2 prototype.

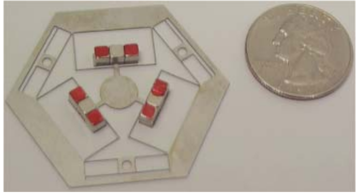

Figure 3. Beta prototype HexFlex with magnet arrays that are used to actuate the nanopositioner.

Nanofabrication system design

The prototypes are to be set in an array of 10, as shown in Figure 4. A probe array is attached to the central stage of each nanopositioner. The nanopositioners and probe arrays plug into a monolithic structure that aligns them to the corresponding samples that they process.

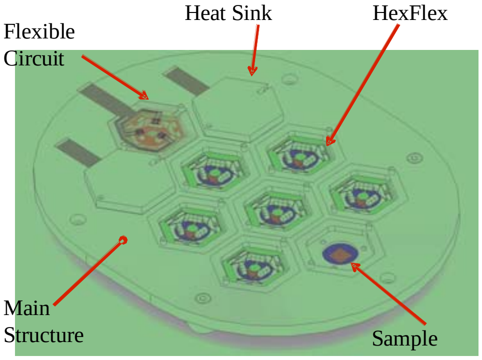

Figure 4. DPN station, station footprint is 28cm x 80cm.

Sensing system

The nanopositioner is equipped with 12 sensors–six for displacement sensing and six for force sensing–that are located at the base of the stage's supporting flexure beams, as shown in Figure 5. The sensors are piezoresistive, therefore they have been placed near the root of the flexure, where the strain is maximum. This layout, combined with temperature compensators, should enable sensing in the year two prototypes with 1.5 nm resolution.

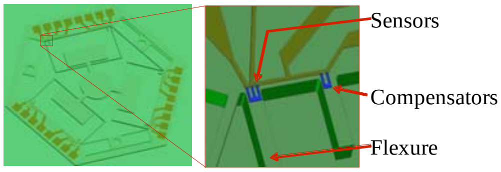

Figure 5. Arrayed nanopositioners within DPN station

Predicted performance

Table 1. Performance metrics

x	± 8.6	µm
y	± 9.5	µm
z	± 17.3	µm
θ_x	± 2.1	mrad
θ_y	± 1.9	mrad
θ_z	± 3.5	mrad
ω_n	1800	Hz
Estimated $/positioner	100	dollars
In-plane resolution	10	nm
Out-of-plane resolution	10	nm

Quasi-static test results

In Year 1, several tests were run to determine the open-loop, calibrated and quasi-static performance characteristics of the nanopositioner. Figure 6 shows the result of the in-plane $(x, y, \theta z)$ motions. The open-loop performance shows that the device is accurate to within several 10s of nanometers. The addition of the sensing systems during Year 2 will reduce the errors to the nanometer level.

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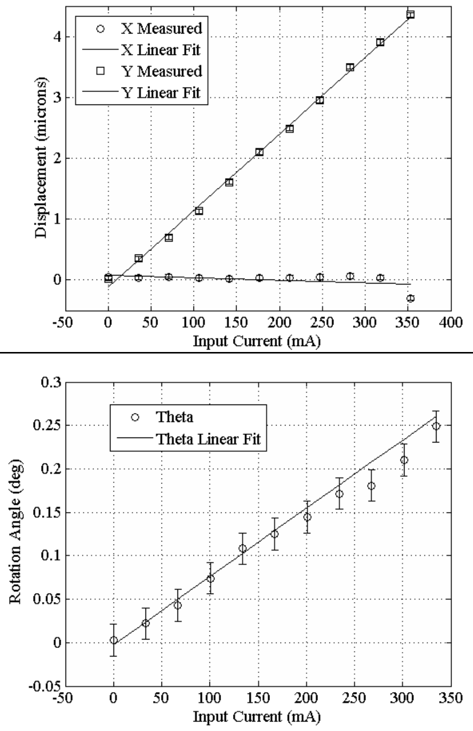


Figure 6. Calibrated, open loop X, Y and θz motion

Dynamic characteristics

Figure 7 shows that the devices possess a natural frequency in excess of 1800 Hz.

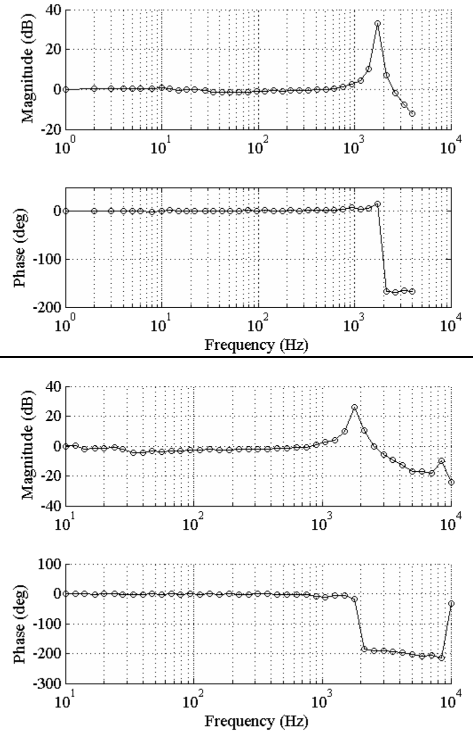


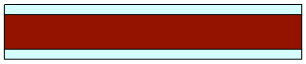
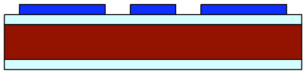
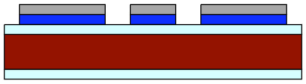
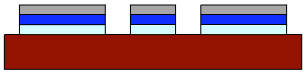
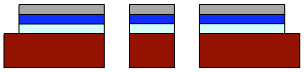
Figure 7. Bode plots for the X (top) and Y (bottom) axes

Therefore, they may be run at 10 Hz with nanometer-level accuracy. An upper limit on the number of features that may be written per second with an array of 10 nanopositioners is 40,000 tips/array x 10 arrays x 10 features/second = 4 million features per second.

Microfabrication

The microfabrication process is shown in Table 2. A 500 nm layer of oxide insulates the piezoresistors and electrical contacts from the wafer. The piezoresistors are created from polysilicon, and aluminum is used to form electrical connections. Deep reactive ion etching is used to define the planar structure of the HexFlex positioner through the 400 µm wafer. A 150 mm wafer is capable of producing seven positioners.

Table 2. Microfabrication process

	Process step	Cross section
1	Deposit 500 nm oxide	
2	Deposit and pattern 1 µm of Poly-Si for piezoresistors	
3	Deposit and pattern 1µm Aluminum to serve as contacts	
4	Pattern oxide	
5	Perform DRIE to create HexFlex structure	

Collaboration between the OSU NSEC and MIT

This work is to support work on Molecular Manipulation of DNA for Biomedical Applications that is being conducted by Prof. Lee and colleagues at the OSU NSEC. The combination of the MIT and OSU teams brings together the principles of chemical-biological-nanofabrication (OSU) and electromechanical systems-precision engineering-manufacturing (MIT). The combination of these skills is critical to the long-term success of this technology.

Publications

1. DiBiasio, C.M. and Culpepper, M.L., “Design of a Meso-scale Six-axis Nanopositioner with Integrated Position Sensing,” Proceedings of the 5th International Symposium on Nanomanufacturing, Singapore, Singapore, January 23-25, 2008.