Precision Equipment and Tools that Enable Practical Probe-based Nanomanufacturing

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Abstract

We discuss the use of process modelling in equipment design of probe-based nanomanufacturing (PBM) stations and cover equipment modules that enable low-cost transition of PBM from lab to practice. We also discuss the design of a pilot PBM station which includes three new technologies:

(1) A meso-scale 6-axis nanopositioner that moves the tool relative to work piece

(2) A meso-scale kinematic coupling that aligns work pieces to the nanopositioner

(3) A modular transfer line design that enables sealed enclosure and work handling

The technologies are integrated within the PBM station shown in Fig. 1.

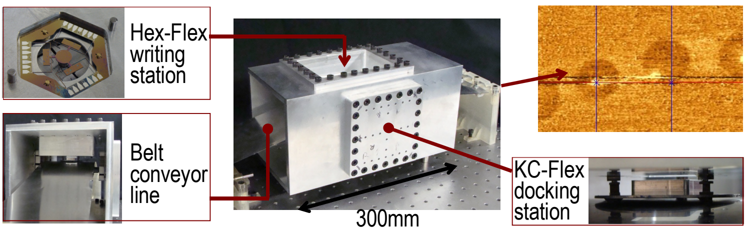


Figure 1: Assembled PBM station

1 Introduction

In PBM, micro-scale tips are used to make, manipulate, or measure nm-scale features on a substrate. Examples of PBM include Dip Pen Nanolithography and NanoEDM. These processes enable nanofabrication of unique nano-scale features/devices in laboratory settings, i.e. in low- to moderate volumes. Unfortunately, there is a lack of manufacturing technology for PBM processes. The cause of this lies in the history of PBM research. Typically, the feasibility of a new PBM process is demonstrated by equipping an AFM with a tip and then characterizing the process. In transitioning a PBM process to practice, the original AFM is often retained. Ad hoc solutions are then implemented to create workable equipment out of research AFMs. In the following, we discuss our first steps to create non-AFM equipment and demonstrate our first experimental results.

2 Process modeling

We elect to model a Dip pen nanolithography (DPN) process. DPN is a popular and flexible probe based manufacturing process that is capable of generating nanoscale features using an AFM tip [1]. AFM based systems have been used in DPN research, however these systems restrict throughput due to manual handling and tool set-up times (10s of minutes) relative to cycle time (seconds). To make the transition to practical manufacturing, it is important to have predictive knowledge about the process so that the throughput and quality requirements may be achieved. Analytical models provide the link between these process characteristics/outputs for given input parameters. These models may be used to set input paramters, e.g. equipment design parameters. A schematic of DPN writing is shown in Fig. 2 (a) and ink diffusion from tip to substrate is shown in Fig. 2(b).

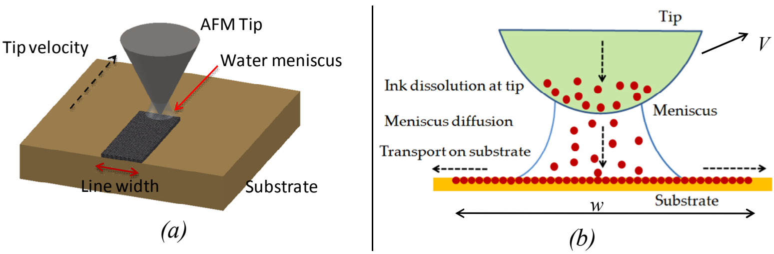


Figure 2: (a) Schematic of DPN writing and (b) diffusion of ink to work piece

A diffusion-based analytical model was created to map process parameters to process outputs [2]. The link between velocity control and temperature control for (i) tolerance on the line width and (ii) tool life were found. The values for 1 nm line width tolerance are shown in Table 1.

Table 1: DPN process metrics

Metric	Condition	Value
Throughput	Typical	~ 1 μm^2/min
	Theoretical maximum	10x typical
Tool life	For accurate feature size	~ 1-5 minutes
Velocity control for 1nm tolerance	For 45nm line	~10 nm/s
	For 145nm line	~0.5 nm/s
Temperature control for 1nm tolerance	For 45nm line	~2 ^{0}C
	For 145nm line	~0.2 ^{0}C

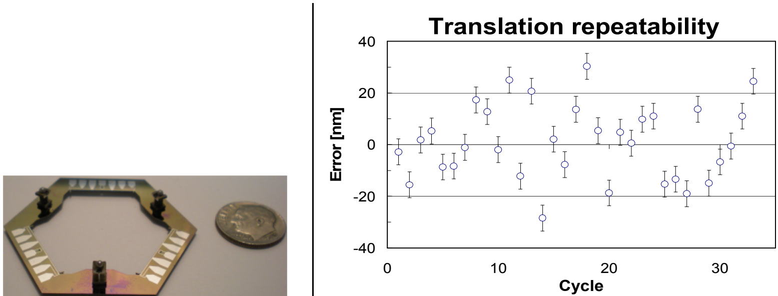
These numbers were used to (i) set the design of the (i) positioner that moved the tool relative to work piece and (ii) show the need for a temperature-controlled enclosure (see section 5).

3 Small-scale nanopositioner stage

We used a microfabricated HexFlex 6-axis nanopositioner with integrated piezoresistive strain sensing [3]. The device, shown in the upper left of Fig. 1, meets the requirements in Table 1, and is capable of a 50x50x50 μm^3 work volume, 3nm out-of-plane resolution, and 22 nm in-plane resolution. The nanopositioner and supporting electronics (without DAQ) costs less than $500 US. The HexFlex measures ~4 cm in diameter. The positioner is capable of writing with a 55,000 DPN tip array (2D tip array that requires 6 axis positioning for tool-substrate alignment).

4 Fixturing

DPN processes can make features from a few 10s of nanometers to microns in size. It is important to have low-cost fixturing technology with comparable accuracy/repeatability. It is difficult and/or expensive to create kinematic couplings that achieve better than 100nm repeatability due to the influcence of friciton between the balls and grooves. We have created a meso-scale coupling that uses strategically placed flexures to prevent stick-slip betwen ball and groove (in two directions simultaneously) thereby enabling 35nm repeatability. The fixture is shown in the lower right of Fig. 1 and in Fig. 3(a). Repeatability test results are shown in Fig. 3(b).



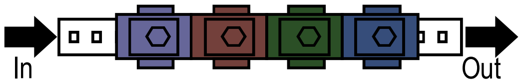
(a) *(b)*

Figure 3: (a) Meso-scale kinematic coupling and (b) results of repeatability tests

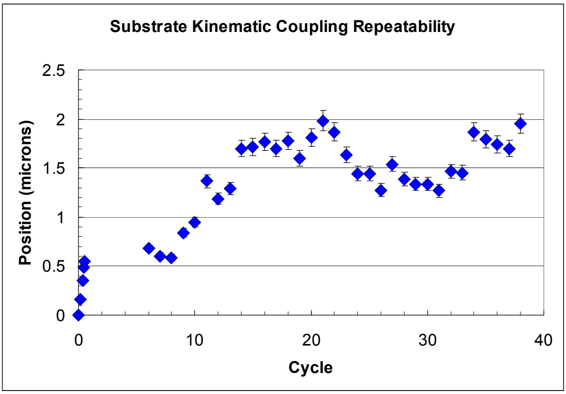
Ideally, it is desired to have 10nm or better repeatability, however the 35nm performance is a significant step forward, considering the fixture costs less than $50 to make in small volumes. More than 90% of the costs comes from EDM of the mm-scale flexures and grooves. We are working to approach the 10nm performance.

5 Modular transfer line architecutre for enclosures

The station shown in Fig. 1 will be connected with other stations to create a nanomanufacturing line as shown in Fig. 4(a). The station is constructed of structual tubing with pockets in the tube sides that accept and hold devices that conduct the processing in the station. This is illustrated in Fig. 1. The modules are designed to be connected together via quasi-kinematic coupling. This connection enables a semi-kinematic alignment with ~ 1 micron repeatability (see Fig. 4(b)) while making it possible to have a sealed connection between the modules. The later is important to (i) make possible the temperature control specifications from Table 1 and (ii) prevents release or entrainment of undesired materials within the manufacturing line. We have used this station to write features as shown at the top right of Fig. 1.



(a)



(b)

Figure 4: Assembled PBM station

References

[1] Piner, R.D., et al., "Dip-Pen" Nanolithography. Science, 1999. 283(5402): p. 661-663.

[2] Saha, S.K. and Culpepper, M.L., Process modeling and characterization of Dip Pen Nanolithography for nanomanufacturing. Submitted manuscript.

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