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Precision positioning for thermal scanning probe lithography

Philip Paul[1,2], Simon Züst[2], Felix Holzner[1], Simon Bonanni[1], Colin Rawlings[3], Urs Dürig[3],Konrad Wegener[4], Armin Knoll[3]

1 SwissLitho AG, Technoparkstrasse 1, Zurich, 8005, Switzerland
2 Inspire AG, Technoparkstrasse 1, Zurich, 8005, Switzerland
3 IBM Research—Zurich, Säumerstrasse 4, Rüschlikon, 8803, Switzerland
4 Institute of Machine Tools and Manufacturing, Leonhardstrasse 21, 8092 Zurich, ETH Zurich, Switzerland

paul@swisslitho.com

Abstract
Thermal scanning probe lithography is a comparatively new method for creating arbitrary depth topographical features at the nano-scale. The same tip can be used for patterning as well as imaging, allowing highly accurate stitching and overlay functionality below 10 nm on a 10 um field. In this publication, we report the efforts to ensure the hold stability when scaling the mechanics to an 8" wafer positioning system

Thermal scanning probe lithography, wafer positioning

1. Introduction

Thermal scanning probe lithography (tSPL) has recently entered the lithography market as the first true alternative to electron beam lithography (EBL). In 2014, the first dedicated lithography systems based on this technology have been installed at universities in Europe and America.

The tSPL technology is attractive due to the fact that 3D structures on the nano meter scale can be created without a development step. In tSPL, a heated atomic force microscope tip is used to locally evaporate a special polymer material, polyphthalaldehyde (PPA). The doping of the silicon cantilever is lower in the region at the base of the tip, in order to locally heat up the tip (Figure 1). During writing, the temperature of the heater is set to 700-900 °C. The tip is scanned over the surface, and pulled into contact when required. Actuation for writing is applied by means of a potential difference between the cantilever and the surface resulting in a Coulomb force [1].

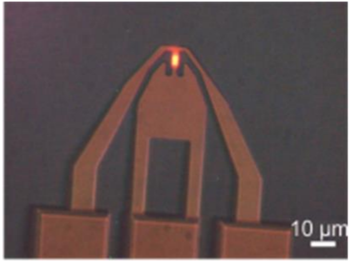

Figure 1. optical micrograph of a tSPL cantilever with tip heater glowing

The Electrostatic actuation allows the force to be modulated instantaneously, and it minimises the accelerated mass to a deflection of the cantilever. While conventional piezo actuation at the base of the cantilever is limited to the resonance frequency of the cantilever, this direct application of force allows actuation beyond the mechanical resonance frequency of the cantilever [2].

The same tip may also be used as an atomic force microscope for imaging with sub-nano meter vertical resolution. The imaging mode allows two unique features to be implemented. Firstly, interleaving the topography imaging with the lithography process enables the implementation of in-situ feedback control of the patterning process [3].

The second feature enabled by the topography imaging function is the ability to implement marker-less stitching and overlay functionality. The stitching algorithm exploits the unique fingerprint-like surface roughness of the resist layer. The first field is written and imaged with a stitching margin. After a step to the next field, the topography is recorded at the nominal position. A correlation between the imaged field and the stitching margin of the previous field is used to determine the position offset, which can then be corrected with the fine piezo positioner. As the same tip is used for patterning and imaging, referencing errors are eliminated. A residual error of ca. 10 nm was determined for a 10 um sized field [4].

Similarly, the residual topography in the resist layer can be used to overlay a pattern with an existing structure. Sub-5 nm pattern alignment was achieved [5].

The initial model of the thermal scanning probe lithography machine can only address a working area of 10 cm x 10 cm. This size of work piece is aimed at universities and research facilities. 8" wafer positioning mechanics are being developed to suit the requirements for larger scale research facilities.

The central requirement for the wafer positioner is the capability to remain stationary for the duration of a patterning operation of several minutes.

2. Methodology

The key metric of interest in tSPL is the relative motion between the tip, and the intended position on the work piece.

The parasitic motion of the tip was determined using the tip to image the surface of a pre-structured calibration sample. As an independent measurement, a 2D interferometer (Heidenhain) was mounted on the wafer positioner and the head attached to the bridge structure.

Thermal modelling was carried out in Matlab using a linearised thermal transport and expansion model.

3.1. Test Setup

An image of the test setup is shown in Figure 2. The wafer positioner is mounted on a pneumatic vibration isolated granite table. For mounting flexibility during evaluation, the fine piezo system and tip were mounted on a bridge structure assembled from aluminium optical rails.

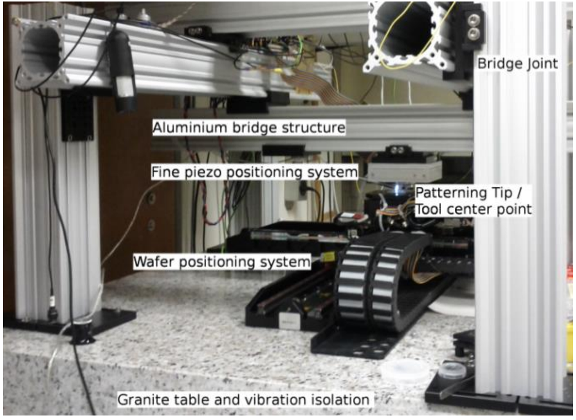

Figure 2. Test setup for evaluating wafer positioner

3. Results

Several sources of parasitic motion were identified:

3.1. Line-to-line jitter motion

The fastest time constant parasitic motion is line to line jitter, representing motion in the sub-second time scale. A number of sources were identified to be creep-induced loosening of the bridge joints, insufficient clamping of the cantilever in its holder, transmission of vibrations via electrical cabling, and timing errors in the control system.

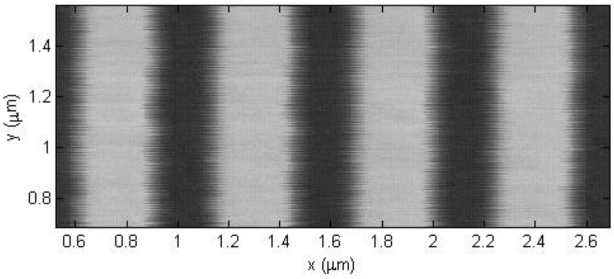

Figure 3. Line to line jitter reading a grid structure (frayed edge shows parasitic motion)

3.2. Motion on the minute time scale

Motion on the minute time scale is visible as a gradual shift over a full read (or write) field, or between subsequent read operations of the same field. The main contributors to this motion were identified as the temperature increase of the motor of the z-positioner during operation, and residual settling motions after a motion step on the big stroke positioner.

Eliminating the identified sources of error identified in Sections 3.1 and 3.2 yields a stable read process, as shown by the vertical lines in Figure 4. The lines are straight and vertical, and the fraying due to the line-to-line jitter has also vanished.

3.3. Thermal equilibration of the big stroke positioner

The thermal time constant of the big stroke positioner was determined to be of the order of 30 minutes. A thermal model was developed to describe the heat flow and corresponding thermal expansions through the big stroke positioner. This thermal model can be used to predict expansions via a state estimator mechanism.

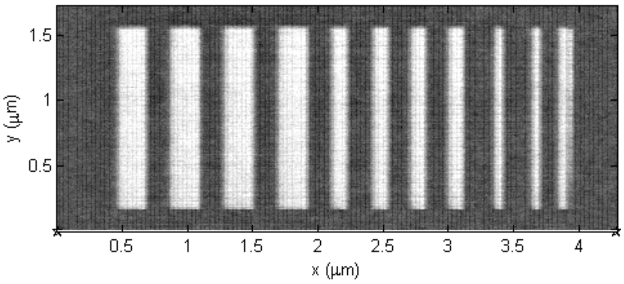

Figure 4. Read image after stabilisation measures

The coupling elements between the components of the positioning system play a dominant role for the accuracy of the thermal model. The heat transfer coefficient through the bearing system was determined experimentally for varying conditions in order to calibrate the model, and estimate its uncertainty. The second coupling coefficient is the convection constant between the structure and the environment. As the convection constant is highly dependent on environmental conditions, the experimentally determined value still only represents an estimate of the convection constant for the installed machine.

A measurement of relative tip position vs. temperature was carried out over a period of 24h without feedback on the positioning stage. It can be seen from Figure 5 that the simulation qualitatively follows the measurement. A residual integrator error accumulates over the long measurement period. The integrator error needs to be addressed to use the state estimator as part of the control system.

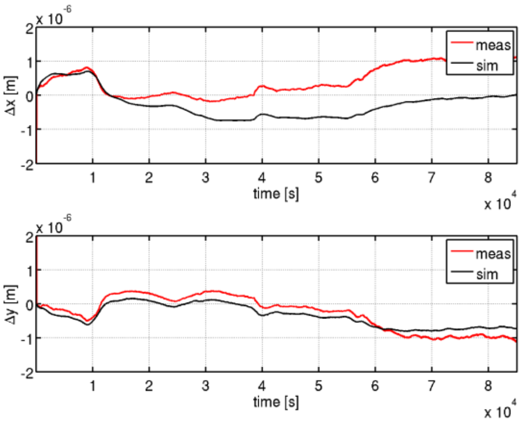

Figure 5. Simulation vs. measured thermal displacements of the big stroke positioner

4. Conclusions

Several independent mechanisms degrade the hold stability of a wafer scale positioning system. Careful identification and elimination of these results in a sufficiently stable system for thermal scanning probe lithography.

Further improvements are expected by tracking the wafer chuck using an interferometer.

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