Prototype Development of an Optical Element Curvature Manipulator with Controlled Piezoelectric Actuator

C.L. Valentin[1,2], B. Festen[1], J.P.M. Vermeulen[2], B.C.T. van Bree[3], D.J. Rixen[1], R.H. Munnig Schmidt[1].
[1]*Delft University of Technology, Faculty 3mE, Department of PME, Delft, NL.*
[2]*ASML BV, Research Mechatronics, Veldhoven, NL.*
[3]*Janssen Precision Engineering BV, Maastricht, NL.*

c.l.valentin@tudelft.nl

Abstract

Photolithography is the limiting step in realizing smaller feature size of Integrated Circuits (IC). For the 3x node, ArF immersion lithography systems with tighter focus budgets are required [1]. Wafer flatness is a main budget contributor [2], which can be reduced by ASML's TWINSCAN™ focus strategy with included curvature correction. A piezoelectric actuation system has been developed for this purpose that controls the curvature of an optical element in the lithography system [4]. This paper presents the prototype developments.

1 Focus Improvement Strategy

In [4], a piezoelectric optical element curvature manipulator was presented that is able to reduce focus budget dependency on wafer flatness. The manipulator adapts the curvature of a transmissive optical element containing a chrome pattern in the lithography tool, resulting in a curved focal plane (Figure 1). By fitting this curved focal plane to the wafer topology, non-correctable focus errors [3], i.e. errors between the wafer and focal plane, are reduced.

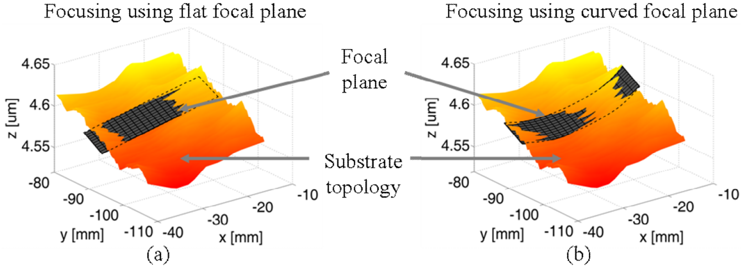

Figure 1: Focus strategy in lithography systems with (a) the conventional strategy fitting a flat focal plane through wafer topology data and (b) the strategy using a curved focal plane.

2 Curvature Setpoints

Required curvature information for the manipulator design was derived from customer wafer topology data (Figure 2). The curvature value distribution was analyzed, providing a maximum curvature specification of 0.8×10^{-3} [1/m]. Frequency content of the curvature values was obtained from spatial data using knowledge of the lithographic process, scan speed and lens magnification [5] giving an estimate of the required control bandwidth of the manipulation system (< 100 [Hz]).

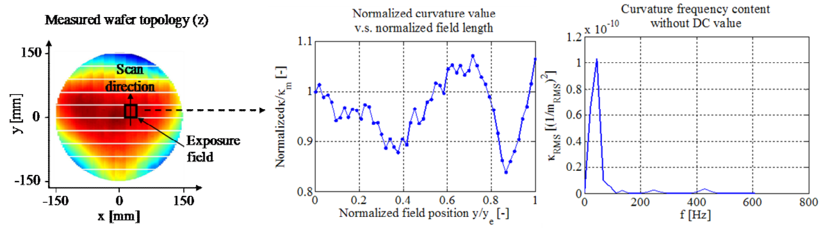

Figure 2: Graphic representation of the curvature setpoint derivation process.

3 Actuation Concept

In [4], the relation between the optical element curvature and the applied bending moment was derived. This bending moment is realized by the actuation principle shown in Figure 3. To realize a theoretically pure bending moment, each actuator unit consists of an intermediate body that is attached to the optical element with interface rods and vacuum preload. The piezoelectric actuator with serial compliance and horizontal leaf spring located between the intermediate body and surroundings creates a local force loop. Each piezoelectric actuator is equipped with a strain gauge for feedback control to counteract disturbance induced curvature tracking errors as well as piezoelectric hysteresis and creep. The piezoelectric actuators and strain gauges were calibrated in the setup of Figure 4 before mounting them into the assembly. Residual error after calibration of one actuator sensor pair is provided in Figure 5 after fitting a linear trend through the data, which are within specifications.

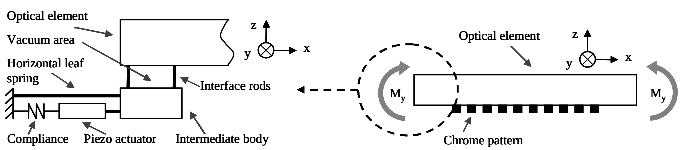

Figure 3: Schematic representation of (right) the optical element, its pattern location and applied bending moments (M_y) which are realized by a multiple actuator units; (left) one actuator unit.

4 Experimental Results

Performance of the curvature actuation system was investigated using two experimental setups. The first setup focuses on the performance identification of a single actuator unit (Figure 6). In the setup, a single actuator unit applies a bending moment to a dummy beam which is supported by vacuum preloaded air bearings. Information from four capacitive sensors positioned along the beam length is used to extract realized beam curvature (Figure 7). The result shows a good correlation between the desired and identified curvature of the beam.

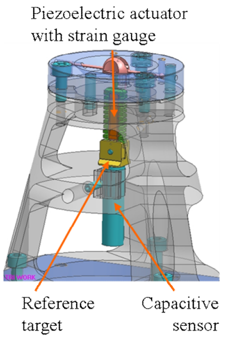

Figure 4: Piezo-strain gauge calibration setup.

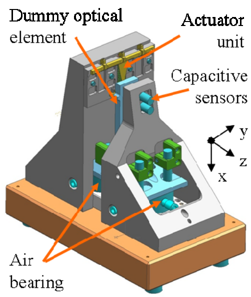

Figure 6: Single-axis demonstrator setup.

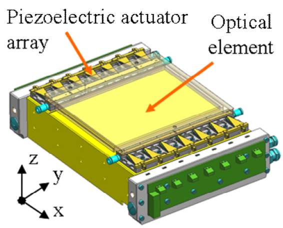

Figure 8: Multi-axis prototype.

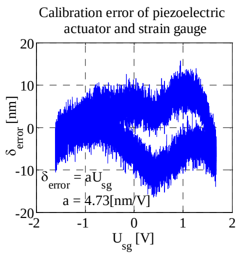

Figure 5: Identified actuator calibration curve.

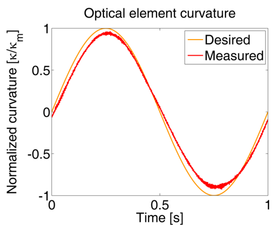

Figure 7: Single-axis curvature results.

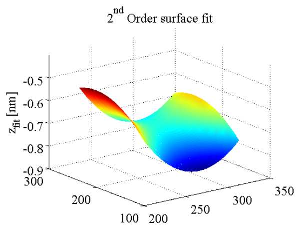

Figure 9: 2nd order fit through the raw deformation data.

The second setup is a full scale multi-axis demonstrator (Figure 8) of the actuation system [4] in combination with a measurement tool. The latter consists of a scanning stage with two capacitive sensors which measure the distances between the optical element and reference plane during the surface scan. Curvature information of the optical element deformation is obtained by comparing measurement data of the loaded versus unloaded configurations. Figure 9 shows the second order polynomial surface fit through the data without feedback controller. The fit shows that the desired and expected anticlastic curvatures are present in the results. It is also visible that there is a translation of the optical element in z-direction. This is probably caused by the presence of a non-pure bending moment throughout the optical element that is induced by piezoelectric actuator hysteresis. The parasitic bending moment generates reaction forces on the optical element supports. These forces in combination with the finite stiffness of the supports induce support deformations and subsequently optical element displacement. It is expected that this effect reduces after implementing the piezoelectric feedback control.

5 Conclusions and future work

This paper presented the prototype development of a piezoelectric optical element curvature manipulation system. Experimental analysis has shown that the systems are able to realize curvature deformations of an optical element. Future work will focus on implementation of multi-axis feedback control.

Acknowledgements

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