Mechatronic System Design of an Optical Element Curvature Actuation System

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Abstract

In the market of Integrated Circuit (IC) manufacturing, photolithography is seen as the crucial and enabling step in achieving smaller feature size. To realize these features, photolithography equipment with tighter focus budgets are required [1]. Main contributor to the budget is wafer unflatness [2]. This study proposes a way to reduce focus budget dependency on wafer unflatness by a curvature correction mechanism which is achieved by actively controlling optical element curvature with a piezoelectric actuation system.

1 Curvature correction principle

In [3], the idea of achieving aerial image curvature adaptation by actively controlling tranmissive optical element curvature was introduced. The double telecentric nature of the projection lens in ASML TWINSCAN^{TM} systems makes it possible to achieve the desired curvature effect at wafer level by manipulation of an optical element containing a chrome pattern. Mathematical relations in [3] showed that curvature is realized by bending moment application (see figure 1.a), but at the penalty of optical element strain and stress-birefringence. The strain causes the chrome pattern to deform, which - if not corrected - results in overlay errors. Furthermore, stress-birefringence is undesired for hyper-NA lithography [4].

To identify feasibility, wafer curvature values were obtained from wafer topology data using the curvature augmented levelling algorithm. Optical element curvature values were derived from these values. Using the relations from [3], required bending moments and strains were calculated. Application of pre-stress to compensate chrome pattern deformation was omitted because the lithography lens can counteract it. Stress-birefringence levels were finally calculated which were found to be within specified limits [4].

2 Actuation concept

Realization of the required bending moment in the optical element is achieved by the schematic concept of figure 1.b. An intermediate body is attached to the bottom of the element using two interface rods which have high stiffness in z-direction and are compliant in x- and y-direction. Contact between the rods and element is enforced by vacuum preload. A bending moment on the intermediate body and subsequently the optical element is realized by placing a serially combined piezoelectric actuator with compliance at an offset of a horizontal leaf spring, which in turn is attached to the carrying frame. The combined compliances of the horizontal leaf spring and interface rods ensure a statically determined configuration for the optical element whilst the piezoelectric actuator and tuned compliance ensure a high bandwidth torque actuator.

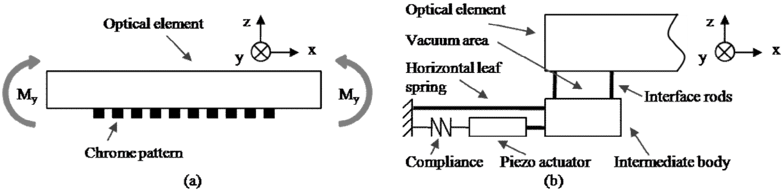


Figure 1: Schematic representation of (a) the optical element, its pattern location and applied bending moments (M_y) and (b) the curvature actuation system.

3 Control strategy

For optical element curvature control, the control strategy of figure 2 is proposed. It contains a static stiffness feedforward path to enhance speed of actuation. A closed loop controller is implemented to counteract curvature tracking errors caused by disturbances and neglected plant dynamics in the feedforward controller such as piezo hysteresis and creep of the piezoelectric actuator. In specific, a local strain feedback loop is created between each piezo actuator and its attached strain gauge.

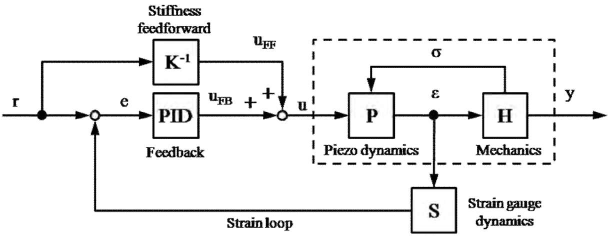
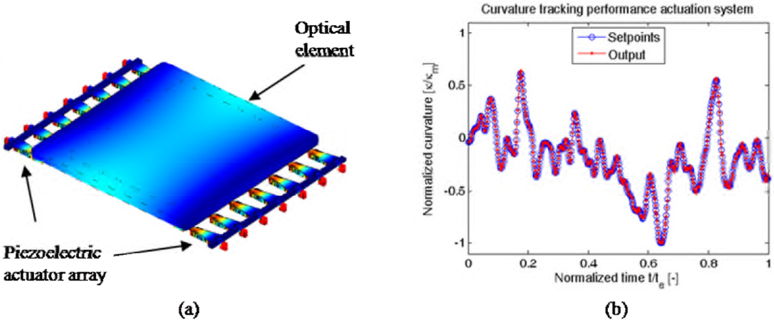


Figure 2: Feedforward and feedback control architecture for the actuation system.

4 System performance prediction

The curvature tracking performance of the design was analyzed using a reduced order Finite Element (FE) model of the assembly which was obtained by combining optical element and actuator Craig-Bampton models (see figure 3.a). The actuator was included by rewriting the piezoelectric constitutive equations into a simplified mechanical equivalent. Applied voltage command signals to the actuators were derived from curvature setpoints in combination with a stiffness feedforward. Curvature values were then extracted from the out-of-plane optical element deflection over the pattern area. Results in figure 3.b highlight satisfactory dynamic curvature tracking performance. The analysis did not include disturbance influences however.



(a) (b)

Figure 3: System modelling, with (a) the FE model (b) tracking performance.

5 Test setups

To experimentally verify performance potential of the curvature actuation system, two experimental setups are designed. The first setup is a single axis demonstrator which focuses on the performance identification and model validation of a single actuator unit (see figure 4.a). The actuator applies a bending moment to one end of a beam which represents part of the optical element. Vacuum preloaded air bearings enforce a frictionless support in z-direction at the other end. The beam z-deflection and Ry-angle are measured using capacitive sensors.

The second setup is a multi-axis demonstrator which focuses on the ability of the full actuation system to achieve a uniform curvature across the optical element (see figure 4.b). It contains two arrays of piezoelectric bending actuator units. Optical element zdeflections are measured by means of a separate measurement system whilst applying voltages to the actuators.

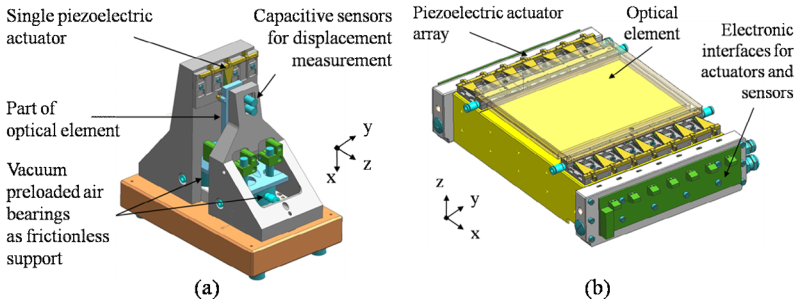


Figure 4: Experimental setups to identify performance potential of the curvature actuator with (a) single-axis demonstrator and (b) multi-axis demonstrator.

6 Conclusions and future work

This paper discussed the design of a piezoelectric actuation system to actively control optical element curvature. Although the paper focused on the application of the concept for an optical element containing a chrome pattern, the principle is generic for any optical element. Mechanical modeling has proven the performance potential of the concept. Realization of a single- and multi-axis experimental setup is nearly complete. Future work focuses on control strategy development and experimental analysis in the two test setups.

Acknowledgements

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