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# Thermo-mechanical system modelling of a lithography high precision optics

Julian Zips[1], Christoph Traxinger[1], Thomas Monz[1]

[1]*Carl Zeiss SMT GmbH*

*julian.zips@zeiss.com*

## Abstract

For the manufacturing process of microchips, lithography is one of the most important process steps. In this process step, silicon wafers coated with light-sensitive photoresist are exposed to images of nanostructures of integrated circuits. The images are produced by an illuminated photomask and subsequently demagnified by projection optics before wafer exposure. One of the most important key performance indicators of lithography scanners is the size of the smallest feature the wafer can be exposed with. Following Moore's law, the transistor density on a wafer doubles every two years. According to the Rayleigh criterion equation, there are two main parameters to realize this growth in performance: the numerical aperture and the wavelength of the applied light source. Currently, scanners are operated with light at a certain wavelength and a numerical aperture of up to 0.33. The resulting maximum possible optical resolution is reduced by the fact that lithography scanners suffer amongst others from tolerances (e.g. mechanical tolerances, material properties) and their sensitivity to physical disturbances. For profitability reasons the source power is continuously increased to maximize wafer output. However, with the increase in power the error contribution of parasitic effects (e.g. thermal drifts) reduces the optical performance of the scanner. This conflict of precision and power imposes severe challenges to the mechatronic design of lithography systems. The thermal architecture focuses on the minimization of the performance impact due to heat and mass transfer processes in the projection scanner.

One central component of lithography systems is a high precision optics module. This module consists of a set of lenses or mirrors integrated in a frame structure and a high precision positioning control system. The development of future high precision optics modules strongly relies on numerical modelling and simulation. For the design of thermal architectures, the numerical models need to fulfil the following requirements: All relevant heat and mass transfer processes must be captured with sufficient accuracy to describe the resulting thermal effects. Moreover, the corresponding transient mechanical deformations need to be reflected as they finally determine the machine performance. The industrial design process additionally imposes constraints in terms of limited computational resources.

This paper describes a numerical framework for thermal systems engineering of lithography systems in an industrial context. Two different state of the art modelling methods are applied: Finite-Element Method (FEM) models and state space models generated from the FEM model using model order reduction (MOR) techniques. In this work, Ansys Workbench in combination with MOR in Ansys (MORiA) is employed. This contribution demonstrates the capability of this MOR approach to enable efficient and highly accurate thermal systems engineering for industrial use:

- First, a model order reduction benchmark test is performed on a complex thermo-mechanical system. A critical assessment in terms of accuracy and performance will be given.
- Second, a consistent optimization of temperature sensor locations with respect to thermal observability and controllability is discussed. The Observability Gramian in combination with different cost functions is applied.
- Third, a thermal compensation scheme is developed based on the results of the state space model. The compensation approach is applied to minimize the projection error due to transient thermal drifts of the system.
- Finally, an exemplary thermal control system of the high precision optics module incorporating the reduced model is demonstrated. This control system is applied to thermally stabilize the system from deviations of the operating point due to thermal disturbances.

Keywords: lithography, thermal systems engineering, FEM, model order reduction