Optimization of actuator shapes for a wafer heating application

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Motivation

Wafer heating (see Fig. 1) significantly affects the imaging quality of ASML's wafer scanners. Thermal actuators can be used to improve the imaging quality, but it is not trivial which placement of actuators is most effective to counteract the effect of the expose light. Therefore, tools are needed to design an effective thermal actuator layout.

Thermomechanical wafer heating model

The model is formulated in the \((x, \zeta)\)-coordinate system which is fixed to the expose light. Based on the expose heat load \(Q_{\text{exp}}(x, \zeta, t)\) and the actuation heat load \(Q_{\text{act}}(x, \zeta, t)\), the temperature field \(T(x, \zeta, t)\) and the displacement fields in \(x\)- and \(\zeta\)-direction \(d_x(x, \zeta, t)\) and \(d_\zeta(x, \zeta, t)\), respectively, are computed. The scanning of one field (one black rectangle in Fig. 1) during the time interval \(t \in (0, t_e)\) on the infinite domain \((x, \zeta) \in \mathbb{R}^2\) is considered.

Optimal actuator shape design

The actuation heat load is of the form

\[ Q_{\text{act}}(x, \zeta, t) = B(x, \zeta)u(t) \]

where the shape of the actuation heat load \(B(x, \zeta)\) is fixed over time and only the intensity \(u(t)\) is time-dependent. Note that when the sign of \(u(t)\) does not change, the sign of \(B(x, \zeta)\) will indicate where heaters and where coolers should be placed.

The actuator shape \(B(x, \zeta)\) and intensity \(u(t)\) are designed as the minimizers of the following optimization problem.

\[
\min_{B(x, \zeta), u(t)} J = \int_0^{t_e} \int_{\mathbb{R}^2} Q_{\text{act}}^2(x, \zeta, t) \, dx \, d\zeta \, dt \\
\text{subject to} \\
1) \text{The displacement in the slit is sufficiently small, i.e. inside the exposed area} \\
\quad d_x^2(x, \zeta, t) + d_\zeta^2(x, \zeta, t) < \delta_{\text{exp}}. \\
2) \text{There is no slip between wafer and supporting structure, i.e. on the whole wafer} \\
\quad d_x^2(x, \zeta, t) + d_\zeta^2(x, \zeta, t) < \delta_{\text{slip}}. \\
3) \text{There is no actuation applied in the slit.} \\
4) \text{The sign of } u(t) \text{ does not change.}
\]

Results

When the actuator shape \(B(x, \zeta)\) and intensity \(u(t)\) are optimized to keep the maximum displacement in the slit below \(\delta_{\text{slit}} = 2\) nm while keeping the displacement on the whole wafer below \(\delta_{\text{slip}} = 3.67\) nm, the results in Fig. 2 are obtained. Without thermal actuation the maximal displacement in the slit is 4.1 nm, which means that slip between wafer and supporting structure will occur without thermal actuation.

Conclusions

A method to design optimal actuator shapes for the wafer heating problem has been developed.