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Semi-analytic approximation of moving heat load response applied to wafer scanners

D.W.M. Veldman¹, R.H.B. Fey¹, H.J. Zwart¹,², M.M.J. van de Wal³, J.D.B.J. van den Boom³, H. Nijmeijer¹

¹ Department of Mechanical Engineering, Eindhoven University of Technology
² Department of Applied Mathematics, University of Twente
³ ASML

Introduction

A crucial step in the production of Integrated Circuits (ICs) is the projection of the pattern of electronic connections on a silicon substrate, called the wafer. The light used to project the pattern causes the wafer to heat up and deform, which leads to a degraded image quality. With tolerances approaching the subnanometer range, prediction and control of these deformations are necessary.

Figure 1 shows how the expose light travels over the top of the wafer. Since the thickness of the wafer is small, the temperature field can be determined by solving a heat equation in two spatial dimensions with constant coefficients and a moving source. When the velocity of the moving load is high, the discretization of such problems requires a fine mesh size that leads to models with many Degrees of Freedom (DOFs) for which simulations become time consuming.

Proposed method

We assume the applied heat load can be written as

\[ Q(x, y, t) = X(x) Y(y - vt) \bar{Q}(t). \] (1)

The heat load thus moves with a constant velocity \( v \) in the \( y \)-direction, \( X(x) \) and \( Y(y) \) describe the shape of the heat load in \( x \)- and \( y \)-direction, respectively, and \( \bar{Q}(t) \) describes how the heat load evolves over time. When the applied heat load is of the form (1), we are able to construct a semi-analytic approximation in which the problem in two spatial dimensions is decoupled into three problems in one spatial dimension. Especially on fine grids, this significantly reduces the number of DOFs. This is demonstrated in Figure 2.

Results

The method is applied to a wafer heating example similar to the one in Figure 1. We use the semi-analytic approximation to compute the temperature for the scanning of one field (a black rectangle in Fig. 1). Figure 3 shows a snapshot of the relative error in the semi-analytic approximation when it is compared to the result from a 2D FE analysis. In addition, the accuracy of the deformations resulting from the semi-analytic approximation of the temperature field is assessed. The results are shown in Table 1.

Table 1: Semi-analytic approximation results

<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in computational time*</td>
<td>90%</td>
</tr>
<tr>
<td>Max. error in temperature field</td>
<td>4%</td>
</tr>
<tr>
<td>Max. error in resulting deformations</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

*compared to 2D FE analysis with the same grid spacing

Conclusion

A method has been developed to efficiently compute the temperature field resulting from moving heat loads that can be used to accurately predict the thermoelastic deformations in a wafer heating example.