Calibration strategies for precision stages in state-of-the-art registration metrology

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1. INTRODUCTION

Future lithography trends pose new challenges to the metrology equipment used in the semiconductor industry. For example, photomasks have to fulfill even tighter specifications as pattern placement errors can have direct effects on the final device yield. In order to keep pace with this development, state-of-the-art registration tools must be able to measure the position of photomask patterns with an unprecedented precision – not only in terms of reproducibility, but also accuracy. As the production of mask sets can be distributed across several sites, different registration tools have to match each other in an absolute sense. Furthermore even with the latest manufacturing capabilities, assembled stage mirrors will not be perfectly flat to the required sub-nm level. In order to both correct for the individual stage inaccuracies, as well as for the tool deviations from a given standard, a calibration strategy has to be employed.

2. CALIBRATION CONCEPTS

There are two basic approaches available for the calibration of metrology stages. It could be as simple as using a “golden mask.” In this case, all or part of the required information can be drawn from a standard specimen of precisely known geometry, which in turn must be qualified by an external measurement. Alternatively, the results of autonomous self-consistency checks can be used to determine certain contributions. Such self-calibration strategies [1, 2] can result in complete knowledge about the stage errors, except for absolute scaling errors, which still require a reference. In addition, a viable calibration measurement sequence should fulfill criteria of stability and the capability to address tool specific errors. Hence the individual implementation depends sensitively on both the stage description and the corresponding error patterns. This second approach generally provides an independent and self-sufficient method for each tool, which does not require traceability and can be used anytime.

3. ERROR PROPAGATION, SYMMETRY, AND STABILITY

In the absence of systematic error sources, a given calibration sequence can be evaluated by its capability to filter random white noise. Figs. 1 and 2 visualize a potential 2D-calibration sequence on a quadratic 20-by-20 grid and its corresponding white noise error propagation function. This is a quantitative merit function reflecting the efficiency of noise suppression with respect to the measurement effort. In a linear approximation, the noise suppression is inversely proportional to the number of degrees of freedom in the parameter space to be fitted. A more precise description of the stage properties with as little free parameters as needed would thus benefit the overall stability. Another criterion is the spatial uniformity of the error propagation. Fig. 3 shows a decomposition of the noise propagation in the basis of vector field functions, obtained from group theoretical considerations. This method of analysis allows selective improvements of a calibration sequence via simulations, as well as a better identification of errors in real measurements.

4. CONCLUSIONS

This paper will show that the self-calibration approach is the better option to satisfy the demanding accuracy specifications for the latest registration metrology tools. Compared to the ‘golden mask’ solution, it is advantageous that no extremely well-known standard is needed, hence it can be employed anywhere and anytime and automatically fully utilizes the intrinsic measurement precision of each tool.

References:

1. M. Raugh, “Self-calibration of Interferometer Stages,” ARITH-TR-02-01, Interconnect Technologies Corp. 2002

2. M. Raugh, “Auto calibration method suitable for use in electron beam lithography,” patent US 4583298 A1, 1984

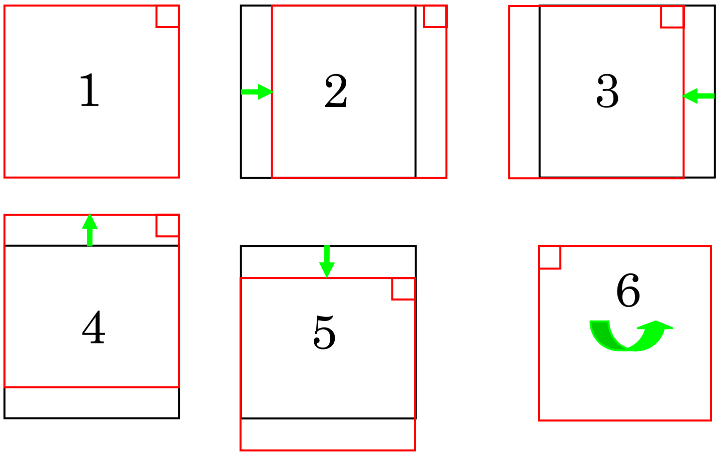

Fig. 1:
A sample calibration sequence with 6 reticle positions (red) relative to the stage (black).

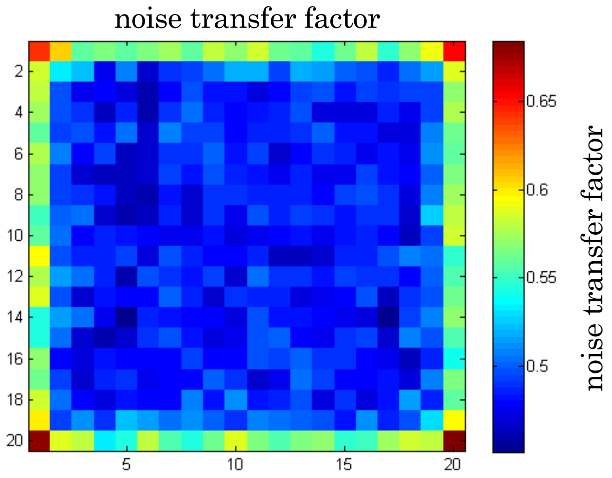

Fig. 2:
Error propagation function for white noise on a 20-by-20 grid

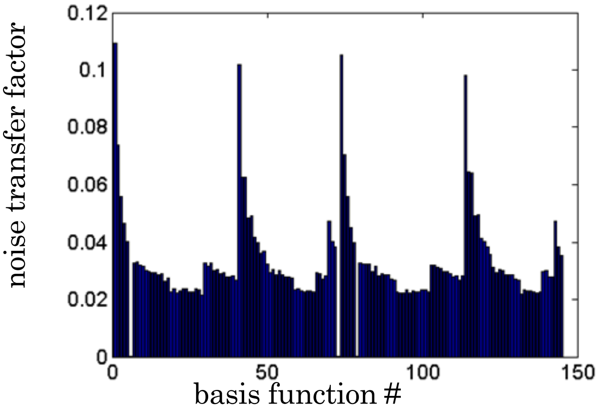

Fig. 3:
Decomposition of the propagation function in terms of an orthonormal vector basis