Deformation measurement of a plate with damping contact

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Abstract

A direct measurement of the distance between wafer and lens in a wafer scanner is difficult to achieve. An alternative could be to place position sensors at the borders of the chuck and use knowledge of the modes of vibration of the plate to reconstruct the deflection at the point of interest. The fluid film between lens and wafer used in immersion optics acts however as a local damper, changing the dynamics of the plate. This influences the sensor measurements and the reconstructed deflection. Using a finite element analysis of a thin plate it is shown that the mean difference between the measured and the reconstructed deflection can be much higher than when no damper would be present.

1 Introduction

In order to continue on the path towards smaller details in electronic chips, the static and dynamic error sources in the optical pathway of lithography machines have to be reduced. One of these error sources is the distance between the lens and wafer that is being illuminated. This distance should be controlled in order to stay well-focussed.

As it is difficult to measure deflection directly at the place where the wafer is illuminated, the measurements have to be done using an indirect method. In current lithography machines, the wafer is carried by a plate – the chuck –, which is very stiff and can basically be considered as a rigid body. Lighter chucks are however advantageous as the required actuation forces are lower, causing less heat production and deformation. Laro et al. [1]

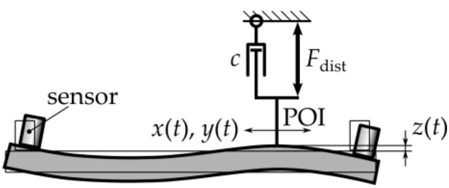

Figure 1: Using knowledge of the dynamics of the plate, the deflection at the point of interest (POI) can be estimated. The local damping at the point of interest changes the dynamics.

presented a thin chuck that has a low mechanical stiffness but whose deformations are controlled by using over-actuation in a feedback control loop.

As a consequence a rigid body approach will clearly not be good enough for such light plates. To overcome this problem, additional sensors could be placed at the sides of the plate so that the deflection of the plate at the point of interest can be estimated, using knowledge of the dynamics of the plate.

For immersion lithography a fluid is inserted between the lens and the wafer to increase the numerical aperture of the imaging system. This fluid however acts as a damper and will thus influence the dynamics of the plate. It is important to know how such a local damping force influences the reconstructed deflection.

2 Analysis method

2.1 Mode shapes

The deflection at the point of interest can be estimated using measurements of sensors at other locations on the plate. This can be done based on knowledge of the mechanical mode shapes of the plate. Each mode shape represents a certain resonance pattern. Any deformation of the plate can be expressed as a linear combination of the different mode shapes of the plate, and in general the mode shapes with the lowest corresponding eigenfrequencies contribute the most to the total deformed shape. Figure 2 shows the first eight mode shapes that are taken into account in the analysis.

The mode shapes are found with a finite element model. The dimensions of the plate are chosen to be 0.55×0.55×0.014 m, so the plate is relatively thin. This allowed the use of plate elements, which are less computational intensive than volume elements.

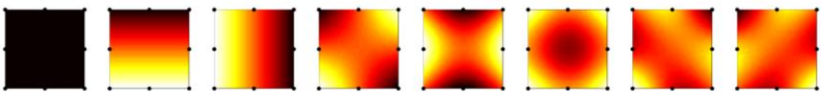

Figure 2: The first eight mode shapes of the free floating plate. The first three are the rigid-body modes that describe the out-of-plane motion.

2.2 Sensor positions

The type of sensors, sensor locations and number of sensors have to be chosen. Each mode shape has an unique profile of – for example – displacement, strain, curvature and acceleration. In this analysis the out-of-plane deflection is chosen as measurand.

The number of sensors has to be at least equal to the number of mode shapes that should be distinguished. Therefore eight sensors are used in this analysis.

The sensor locations were chosen using the method presented by Kammer [2]. For the plate, 21×21 candidate sensor locations were considered, evenly distributed over the plate. The algorithm eliminates one by one the sensor locations that contribute the least to the linear independence of the chosen modes at the sensor locations. The eight remaining locations are superimposed on the mode shapes of Figure 2. Four sensors are positioned at the corners of the plate, the other four at the centres of the sides. The found locations at the border are advantageous, as integrating the sensors at the sides might in practice be easier than at locations on the plate.

2.3 Local lens contact

The film of immersion liquid acts as a mechanical coupling between lens and plate. In this analysis two effects of this coupling are taken into account, namely a damping action and a source of disturbance force.

The lens and plate can be seen as two flat planes with a fluid in between. As the distance between the planes is very small, squeeze-film damping theory can be used to estimate the damping constant to be in the order of $c = 5000$ Ns/m.

The lens contact can also be seen as a source of disturbance force. In this analysis it is assumed that the plate is excited by a disturbance force caused by the lens, which is at 100 Hz. This frequency is sufficiently lower than the first non-rigid-body eigenfrequency of the plate and can therefore be considered as quasi-static.

The plate is modelled as free-floating, four actuators close to the corners of the plate apply forces proportional to disturbance force in such a way that any net force or moment due to the disturbance is cancelled out.

3. Results

For a grid of lens locations above the wafer the damped eigenfrequencies and mode shapes were calculated. In general, the eigenfrequencies tend to decrease compared to the case no damping is present. The transfers from disturbance force to deflection at the lens position and sensor locations were calculated. The sensor signals were used to reconstruct the deflection at the lens position based on the unmodified mode shapes, so without making use of knowledge of the changed dynamics. These reconstructions show average errors (see Figure 3) with a magnitude of 67 nm/N, which is 39% of the average deflection amplitude, and phase change.

In the case no damping would be present, the average deflection is higher than when there is damping, but the average error of the reconstruction is lower, namely 24 nm/N, which is 12% of the average deflection amplitude.

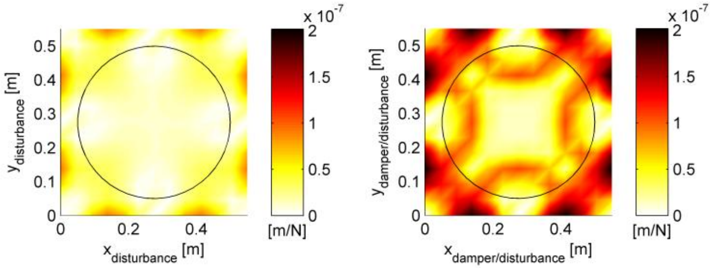

Figure 3: The difference (error) between reconstructed and actual deflection, on the left without damping, on the right with the damper. The *x*- and *y*-axes denote the position of damper and disturbance force.

4. Conclusion and discussion

Using a limited number of eight displacement sensors at the sides of a plate it is possible to reconstruct the deflection at the point of interest, caused by a typical disturbance, with an average error of 12%. The added damping at the point of interest tends to decrease the deflection, but also changes the mode shapes of the plate, reducing the accuracy of the estimation significantly. As the place of the added damper is known and, to a certain extent, the damping constant it is possible to calculate the damped mode shapes. Reconstruction of the deflection based on these mode shapes might lead to a better estimation. This will be part of further investigation.

References:

[1] Laro, D.; Boshuizen, R.; Oom, D.; Sanders, L. & van Eijk, J. Lightweight 450 mm Wafer Stages Enabled by Over-actuation. Proceedings of the euspen International Conference, 2010.

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