PERFORMANCE RESULTS OF A NEW GENERATION OF 300 mm LITHOGRAPHY SYSTEMS

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ABSTRACT

ASML's recently announced TWINSCAN™ lithography platform is specifically designed to meet the specific needs of handling and processing 300 mm substrates. This new platform, already supporting a family of Step & Scan lithography systems for I-line and 248 nm DUV, is designed to further support optical lithography at its limits with systems for 193 nm and 157 nm. The conflicting requirements associated with higher productivity on one side, and more extensive metrology on the other, have led to the development of a platform with two independent wafer stages operating in parallel. The hardware associated with exposure, and the hardware and sub-systems required for metrology, are located in two separate positions. While a wafer is exposed on one stage, wafer unload/load and measurements of the horizontal and vertical wafer maps are done in parallel on the second stage. After the two processes are completed, where the exposure sequence typically is the longest, the two stages are swapped. The process is continued on the second stage, while the first stage unloads the exposed wafer and starts the process again.

This system has an innovative design. It consists of a Metrology Frame that holds the projection lens and all measurement systems, and which is fully de-coupled from the force frame holding the stage actuators. To further suppress vibrations resulting from stage movements, a 'balance mass' principle is adopted. This principle uses an opposite movement of the balance mass to cancel out the acceleration forces caused by the high 300mm stage mass, and the speed and acceleration associated with high productivity. Long-term stability and alignment accuracy support the required stringent overlay performance.

Dual wafer stage design requires careful characterization of the influence of stage-to-stage performance differences and calibration methods. Performance results of this new system indicate that dynamic performance of the stages is as expected and tracking errors for stage movement are negligible, demonstrating the benefits of balance masses. Crosstalk between the two independent wafer stages does not influence imaging and overlay performance.

With two wafer stages, a wafer map can be generated prior to exposure. The wafer coordinates in the wafer plane are determined by means of the ATHENA™ alignment system with two colors and seven diffraction orders. To control focus, the position of the wafer surface is measured with a new level sensor system that maps the entire wafer surface. The wafer coordinate system is aligned to the aerial image at the exposure position by a proprietary alignment method, based on the actinic exposure light under actual illumination and NA settings.

The first system based on dual wafer stage technology on the TWINSCAN platform is the AT:750 Step & Scan system, which is equipped with a Zeiss Starlith™750 248 nm DUV lens with a variable NA up to 0.7. When combined with the off-axis and multi-pole illumination capabilities of the AERIAL II illuminator, the system is capable of supporting leading edge imaging at the 130 nm node. Results presented in this paper demonstrate the system's capability to provide high throughput production processing of 300 mm wafers at the 130 nm node using a dual wafer stage system.

Keywords: 300mm wafers, photolithography, advanced imaging, overlay, productivity, focusing, alignment, stage design

1. THE NEED FOR 300 MM SPECIFIC LITHOGRAPHY TOOLS

Innovations in imaging, overlay and productivity for optical lithography have continued at an unprecedented rate in the last decade. Progress in imaging and overlay is generally seen as the most important driver for the semiconductor industry roadmaps, and are a necessary condition for the progression in resolution nodes. Progress in productivity is not as visible, although successive generations of photolithography systems have almost doubled productivity over the last five years (Figure 1). The transition to 300 mm substrates is primarily driven by the economic benefits[1] of the larger wafer size, and 300 mm process tools must continue to support the imaging, overlay and productivity progress that the semiconductor industry demands.

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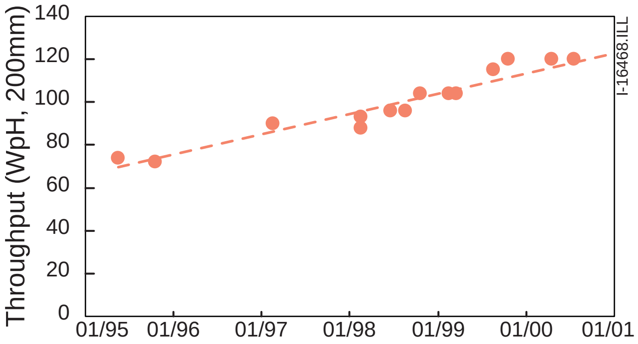

Figure 1 – Throughput for ASML lithography tools as a function of the date of introduction

Productivity, i.e. raw wafer throughput, of many semiconductor manufacturing processes (e.g. deposition, etch and cleaning processes) is, to a first order, independent of the wafer size. The photolithography process is a notable exception to this rule, since the primary process consists of exposing a field and then stepping to a subsequent field, the time of which scales linearly with the wafer area. Continuation of the historical trend in raw wafer throughput from 200 mm to 300mm, or even an equivalent throughput as expressed in wafers per hour for the larger wafers, requires innovations beyond the historical, gradual progression and indicates the need for new concepts for 300 mm lithography systems.

Any new family of 300 mm photolithography systems must also provide a basis for extension of the resolution roadmaps. Step and scan is a logical choice for the technology for such a family, since step and scan systems currently provide the optimum price-performance ratio[2]. Current predictions indicate that the resolution of optical lithography can be extended to cover at least the 70 nm node by shortening the wavelength (lambda) to 193 nm, and subsequently to 157 nm, while simultaneously increasing the numerical aperture (NA) of the lenses to 0.8 and beyond[3, 4]. At the same time the process factor k_1 in the Rayleigh resolution equation:

$$\text{Resolution} = k_1 * \text{lambda} / \text{NA} \qquad (1)$$

needs to decrease further to levels close to the theoretical limits of 0.25 for dense lines. Supporting production processes at these extremely low k_1 factors requires the highest possible stability, both in the process and in the equipment that supports it. Overlay performance, the requirements of which scale linearly with resolution, will also benefit from improved system stability. At the same time, the progression towards shorter wavelengths and higher numerical apertures will lead to a requirement for additional performance in focus accuracy, since the depth of focus (DoF) decreases linearly with the actinic wavelength, and to the inverse square with the numerical aperture:

$$\text{DoF} = k_2 * \text{lambda} / \text{NA}^2 \qquad (2)$$

where k_2 is a process dependent factor. The combination of these factors indicate that a new generation of 300 mm photolithography systems must provide innovations in productivity, superior system stability and a clear improvement in focus behavior. ASML’s recently introduced TWINSCAN platform, a new photolithography platform for 200 mm and 300 mm wafers, provides innovations in body stability and a new dual wafer stage system to meet these requirements.

2. DUAL WAFER STAGE SYSTEM

In a photolithography system, the most important value adding process is the exposure of the wafers. Besides exposure, a lithography process also includes wafer measurements to determine the position at which the exposure should take place and other overheads such as wafer load and unload. By using two independent wafer stages, it will be possible to increase the efficiency of lens use by performing the wafer measurements and other overhead activities in parallel with exposure. In this split of activities, the wafer exposure (for 300 mm wafers) is typically the longest, and therefore a dual wafer stage system provides the opportunity to improve the performance of the wafer measurements due to the extra time available. In a traditional system, each additional alignment mark has a detrimental effect on throughput, this is no longer the case in a dual wafer stage system. Up to 25 alignment marks can be measured without affecting the throughput of the system, thereby providing significantly better local alignment information. In addition, when measurement and exposure are done independently and simultaneously instead of in sequence on a single position the need for compromise is eliminated.

The basic implementation of the dual wafer stage functionality is best explained by looking at the 'life of a wafer' (Figure 2). The activities at the two positions, measurement and expose, take place independently and simultaneously with two wafer stages, and each wafer proceeds through the entire sequence on its own wafer stage. Synchronization of the measurement and the expose activities takes place at stage swap, during which the two wafer stages trade places (and tasks).

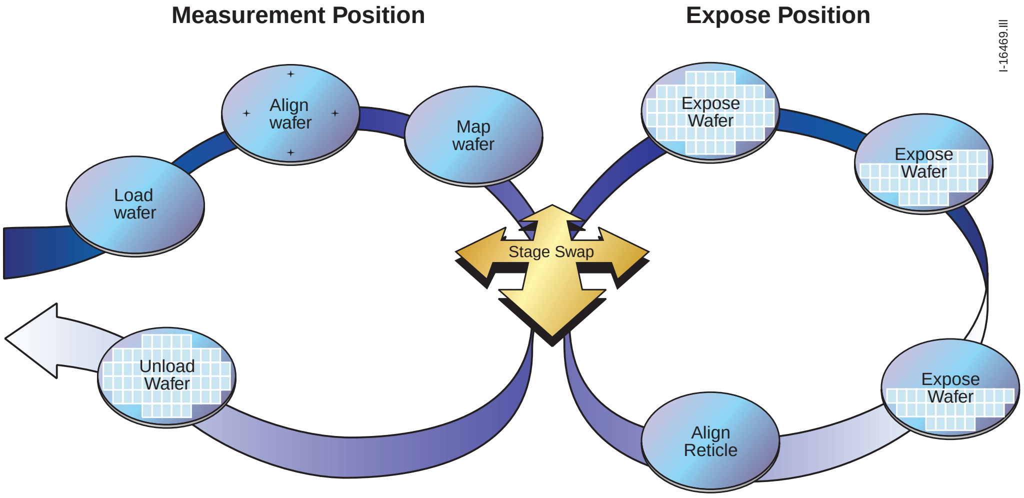

Figure 2 – Life of a wafer. Each wafer is first aligned and mapped at the measurement position, then brought to the expose position for reticle align and exposure, and finally returned to the measurement position for unloading.

In addition to the implementation of parallel operation using two positions and two wafer stages, a novel approach to wafer measurement is implemented. In current step and scan systems the wafer coordinates in the wafer plane are determined prior to exposure, using fiducial markers on the wafer stage as a reference[5]. These fiducial markers are then aligned to the reticle and during the actual exposure the positional information is used to 'blindly' step to the required position without further measurements on the wafer. Leveling information, required for focusing the image, is determined in real time while scanning the image.

In TWINSCAN, not only positional information but also wafer surface or height information is gathered at the measurement station prior to exposure, resulting in a full 3-dimensional wafer map, again referenced to fiducial markers on the wafer stage. Just before exposure, the fiducial markers are aligned to the aerial image, but this time not only in position but also in height (at two separate locations). As a result, every position on the wafer (in X, Y position and height Z) is now determined relative to the aerial image. Exposure and leveling can now proceed without any further measurements of the wafer. The implementation details of this approach are described in more detail in section 4 (Overlay) and section 5 (Focus System).

2.1. Productivity

Productivity of a lithography system is determined by many factors, including tool design, sub-system performance specifications, wafer layout, exposure dose and others. The parallel operation that a dual wafer stage implementation provides leads to a significant increase in productivity. The raw wafer throughput of a dual wafer stage system is more than 35% higher than a single stage system with similar sub-system performance under otherwise identical conditions.

For most practical cases, the exposure sequence takes longer than the wafer alignment and mapping at the metrology position. The time required for alignment increases with the number of alignment markers. For conventional lithography systems, additional alignment markers beyond standard 2 point alignment have a direct impact on the cycle time for each wafer, and hence a negative effect on throughput. On the TWINSCAN dual wafer stage implementation 25 or more alignment markers can be measured before the activities at the metrology station become the critical path for the system's productivity.

3. BODY DYNAMICS

It is well known that even minute vibrations can have a detrimental effect on the ultimate imaging performance of a lithography system[6]. The choice for a highly productive step and scan system dictates that the requirements for body stability must be met at all times during the dynamic step and scan sequence. The positioning accuracy and hence the ultimate performance of any step and scan system is determined by basic machine dynamics - Figure 3 shows a sketch of the basic machine dynamics of the TWINSCAN platform. Two separate frames, i.e. a Metrology Frame and a Base Frame (or force frame), form the basis of this design. One can clearly distinguish the lens, the two positions for measurement and exposure, the two independent wafer stages and the reticle stage.

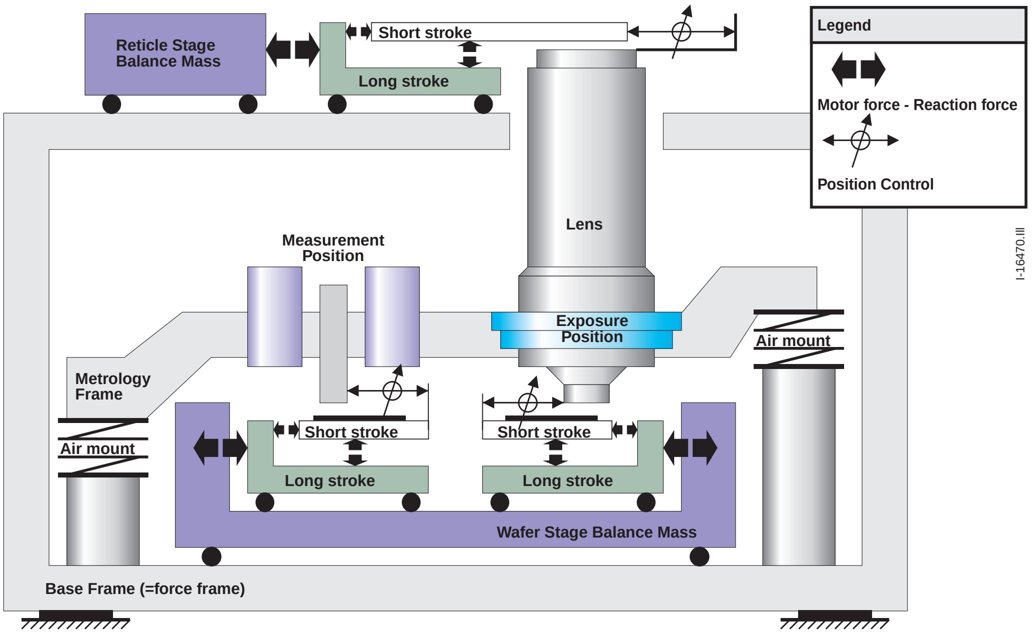

Figure 3 - Sketch of basic TWINSCAN machine dynamics

To ensure a stable image and stable measurements, the lens and the measurement equipment at the measurement position are mounted on a Metrology Frame that is fully isolated from any outside disturbances. This Metrology Frame is designed for maximum stability. It is supported by three actively controlled air mounts with a very low suspension frequency. These air mounts provide excellent vibration isolation of the Metrology Frame from forces and motions of the Base Frame and the fab floor. Hardware that could disturb the stability and integrity of this Metrology Frame, such as moving parts, heat sources, etc., is removed from the Metrology Frame and supported by the Base Frame instead. Stage positions for both wafer stages and for the reticle stage are measured directly on this Metrology Frame which now serves as a stable reference for the positional servo control loops. To minimize mechanical and thermal drift, the reference points for these measurements are taken close to the optical axis of the lens.

3.1. Balance masses eliminating internal and external force disturbances

In order to provide a high wafer throughput, the wafer stages and the reticle stage must accelerate quickly to the desired scan speed, which results in large acceleration forces. In TWINSCAN, these forces are exerted on a Balance Mass, rather than being dissipated into the Base Frame. If these forces would be exerted on the Base Frame the ultimate scan accuracy would be limited, despite the vibration isolating Air Mounts.

The stage, the long stroke stage motor and the balance mass form a sub-system that is horizontally isolated from the Base Frame by means of air bearings. The long stroke motor that drives the stage operates between the stage and the balance mass. Upon actuation, the motor force moves the stage in the desired direction whilst the reaction force moves the balance mass in the opposite direction. The external forces from this sub-system on the Base Frame are negligible. To prevent the Balance Mass from drifting away, a low bandwidth drift control loop (not shown in Figure 3) can make small corrections.

This Balance Mass principle is used for the reticle stage as well as the wafer stage. On the reticle stage, the balance mass is restricted to the scan direction, whereas for the two wafer stages a single balance mass moves freely in both X and Y directions. This in-situ cancellation of reaction forces from scanning and stepping motions not only improves the dynamic behavior of the system itself, but also limits the vibrations injected into the fab floor that could lead to disturbance of other step and scan systems or sensitive equipment in the wafer fab.

3.2. Contact-less short stroke actuator systems

The ultimate positioning accuracy of the TWINSCAN stages is provided by short stroke actuators - long stroke actuators which can travel distances of up to 1 meter do not provide sufficient accuracy to control the stages at nm levels. Stages are positioned relative to the optical axis by taking differential interferometer measurements from the lens-bottom (for the wafer stage) and the lens top (for the reticle stage). The stage positions are measured in 6 degrees of freedom, and the stages are positioned with contact-less actuators (Lorentz, or voice coil motors), also with 6 degrees of freedom. The short stroke Lorentz motors isolate the stages and exert a force that is to a first order independent of the relative position of the stationary magnet and the magnetic coil. There is no physical contact between the stages and any other part of the system. In theory, Lorentz motors provide a perfect isolation of vibrations.

3.3. Experimentally proven dual wafer stage high speed scan performance

During actual exposure, the scanning movement of the wafer stage must be well controlled. The positional error during a scanning exposure can be measured and expressed in terms of a moving average (MA) error[6]**.** The averaging of positional errors is done over the exposure slit, since during a scanning exposure an image is built up by scanning a slit across the image. Figure 4 shows the raw and moving average (MA) servo errors in Y (the scan direction) and Z (height) during an exposure scan, along with the acceleration setpoint of the wafer stage. Once the wafer stage has reached the desired scan speed (acceleration setpoint is now zero) and the servo system has become stable, the servo performance is well within the specified MA boundaries (shown by dashed lines that represent the MA specification).

From the basic machine dynamics, shown in Figure 3, one can see that a single wafer stage balance mass absorbs the reaction forces of both independently operating long stroke wafer stage actuators. For horizontal scan movements, the wafer stage balance mass is physically isolated from the Base Frame. Air mounts isolate the Metrology Frame and prevent the transmission of the remaining vibrations. Theoretically, there should not be any cross-disturbance of one chuck to another (and vice-versa).

Cross disturbances are indeed negligible, as verified experimentally. To determine these cross disturbances most clearly, the wafer stage was actively controlled at the exposure position at standstill, while the other wafer stage at the measurement position was making scan movements. The results, presented in Figure 5, show the servo errors for the wafer stage at the exposure position along with the acceleration profile of the other wafer stage. The acceleration profile is represented by straight line with spikes in Figure 5, where the spikes represent the actual acceleration and the straight line depicts periods of constant velocity with no acceleration. It can be concluded that the wafer stage on the exposure position is hardly influenced by the acceleration forces on the wafer stage at the measurement position. The peak MA (moving average[6]) error of the exposure stage is less than 0.85 nm, which would lead to a negligible overlay penalty as a result of the cross disturbances of two independently moving stages.

4. OVERLAY

In the TWINSCAN dual wafer stage system, the alignment of the wafer to the aerial image proceeds in two steps. At the measurement position, the position of the alignment markers on the wafer is measured relative to reference markers on the wafer stage. Subsequently, after transferring the wafer on its stage to the exposure position, the aerial image of a reticle

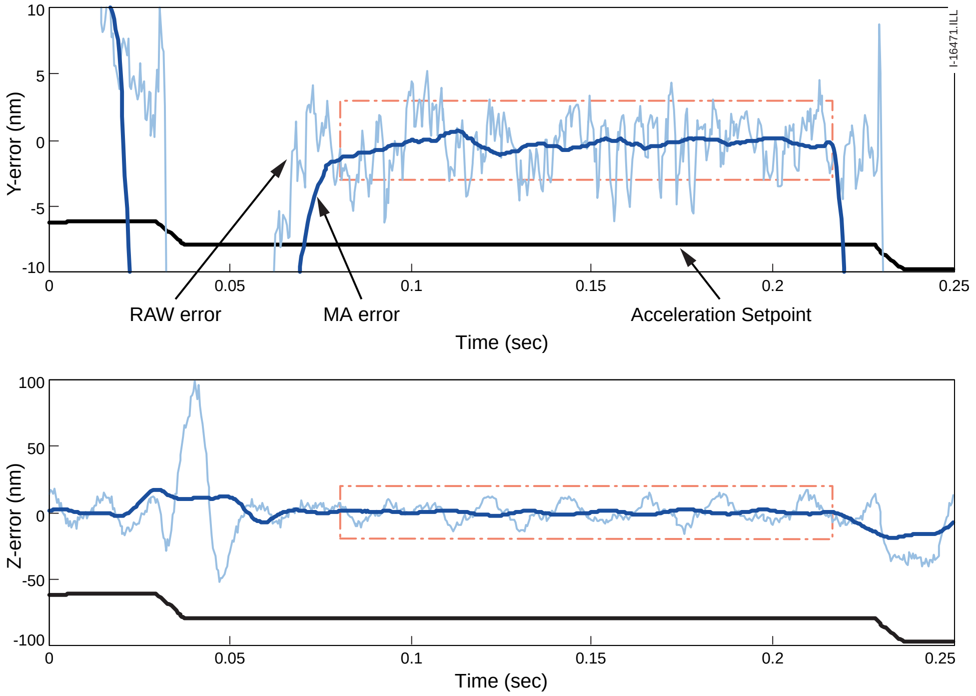

Figure 4 - Raw and MA servo error of the exposure wafer stage during exposure while scanning in the Y direction. Setpoints for scan speed and acceleration were 250 [mm/s] and 8 [m/s^2], respectively. The trapezoidal signal is the setpoint acceleration; the horizontal lines represent the MA specification.

alignment mark under actual illumination and NA settings is projected onto and aligned to reference markers on the wafer stage. By combining these two measurements, the position of the wafer relative to the actual aerial image is known and the image can now be projected on the desired location on the wafer with minimal overlay errors. In the TWINSCAN dual wafer stage system all measurements for wafer alignment are taken at the measurement position, whereas the exposures are made at the exposure position, where the stage is controlled by a different interferometer system. Therefore, the alignment scheme must be designed to be insensitive to possible interferometer scaling differences. The alignment sequence will be described in more detail below.

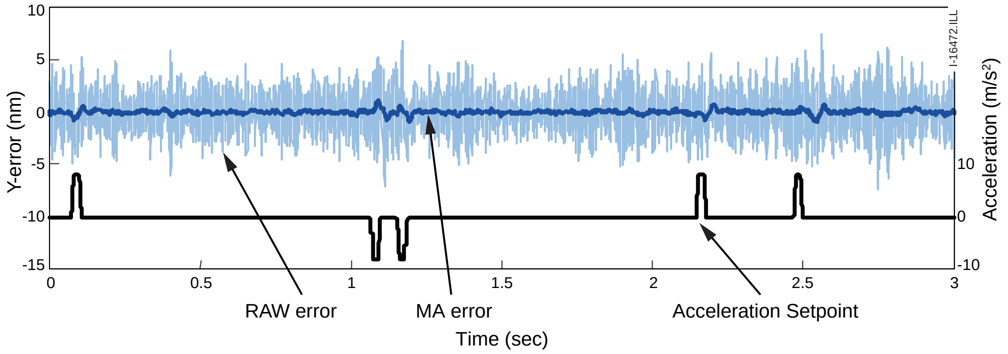

Figure 5 - Raw and MA Servo Error of Exposure Chuck at standstill, while the Measurement Chuck makes a scan in Y direction at 0.25 m/s with an acceleration of 8 m/s^2. The trapezoidal signal is the setpoint acceleration of the Measurement Chuck. It is shown that cross-disturbances between Measurement and Expose are less than 1.7 nm p-p, well within the specified boundaries.

4.1. Wafer alignment

At the measurement position, the position of the wafer relative to two reference markers on the wafer stage is determined by means of the ATHENA™ alignment system with two colors and seven diffraction orders[5]. The reference markers on the wafer stage are located on two TIS plates (TIS plate 1 and TIS plate 2, see Figure 6) that are located on diagonal positions on the wafer stage. At the start of the alignment sequence, the positions of the markers on the TIS plates are measured with the ATHENA sensor which determines the position of the wafer stage and the interferometer scaling in X and Y.
Subsequently, the ATHENA sensor measures the position of the alignment markers of the wafer, which now determines the position and rotation of the wafer with respect to the wafer stage in the coordinates of the measurement interferometric system.

In the TWINSCAN dual wafer stage, these alignment measurements are taken while the second wafer stage is being exposed. As the exposure process is typically longer than the measurement process, up to 25 alignment markers can be measured without affecting the system throughput. The availability of alignment information distributed over the wafer surface provides more accurate information of (local) wafer distortions that could affect overlay.

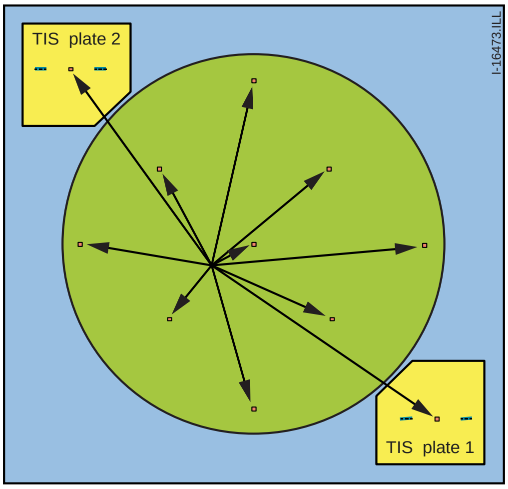

Figure 6 – Schematic representation of the wafer stage with a wafer and two Transmission Image Sensor (TIS) reference markers. From the distances between the two TIS markers the interferometer scaling in X and Y can be determined.

During the dual wafer stage sequence, from measurement and then stage swap to exposure at the exposure position, the wafer is clamped onto the wafer stage to make sure that the position of the wafer does not change. After the stage swap, the position and rotation of the wafer stage is measured relative to the aerial image of four alignment markers on the reticle. These markers are located close to the four corners of the reticle image. The aerial image is aligned to the wafer stage by means of a Transmission Image Sensor (TIS), integrated in the TIS plates (Figure 6) and is capable of determining the position of the aerial image in X, Y (position) and Z (focus). To secure optimal stability, the TIS sensors are positioned very close to the ATHENA markers on the same TIS plate. The interferometer scaling at the exposure position is determined by performing a second measurement with an additional TIS sensor at a second TIS plate.

4.2. Overlay budgets compared to current performance

Overlay performance for current lithography systems is determined by the accuracy at which the alignment markers can be measured (called the global alignment accuracy), by the accuracy at which the stage position can be determined (called stage accuracy) and by the stability of the system. In addition, in a dual wafer stage system the stage to stage matching might contribute to the overall overlay performance.

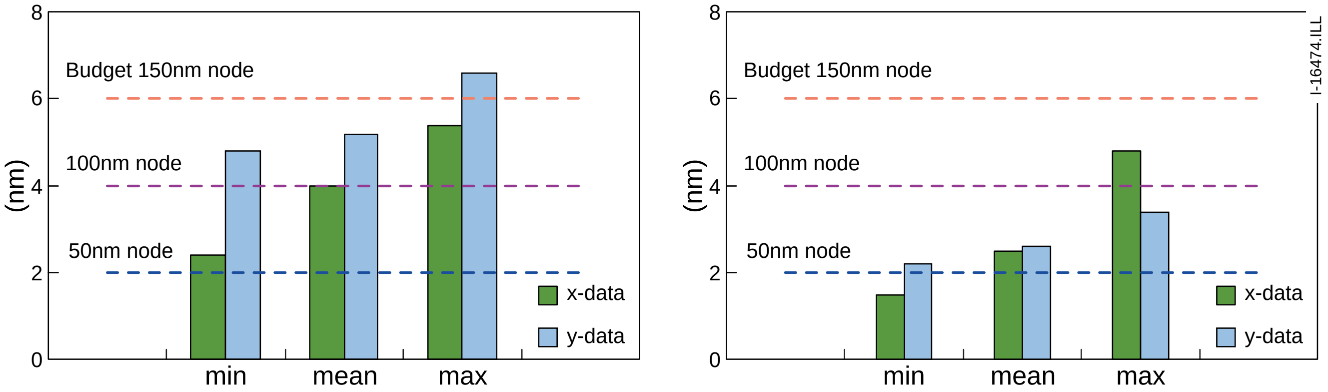

Figure 7 – Typical alignment reproducibility for the ATHENA™ wafer alignment sensor (left) and TIS reticle alignment sensors (right) compared to the required accuracy budgets for the 150nm node, the 100nm node and the 50nm node.

Global alignment accuracy is mainly determined by the accuracy of the ATHENA and TIS measurements. Figure 7 shows the current typical performance of these sensors against the required accuracy budgets for the 150nm node, for the 100 nm node and for the 50 nm node. The alignment reproducibility of the ATHENA wafer alignment meets the requirements for current applications at 130nm. The reproducibility of the Transmission Image Sensors (TIS) for reticle alignment, on average, already meets the needs for the 70 nm node (in between the 50 nm and 100 nm node, not shown in Figure 7).
Typical results of stage accuracy for TWINSCAN, of short-term single machine, single stage overlay and of long term overlay are shown in Figure 8. From the alignment accuracy, the stage accuracy and the short term and long term overlay performance one can conclude that TWINSCAN meets the overlay requirements for current and future leading edge lithographic needs.

To verify that production load, e.g. lens heating, does not adversely affect overlay performance an overlay test was done on a total batch of 24 wafers. The results shown in Figure 9 show that the single machine overlay remains stable and low over the entire batch without any signs of drift.

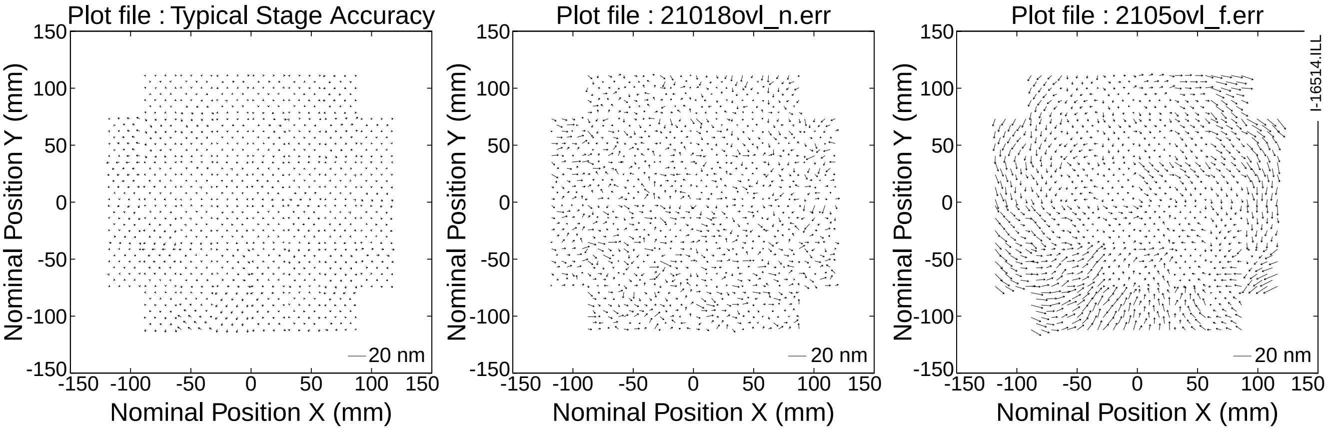

Figure 8 – Stage accuracy (left), short term single machine overlay (3 subsequent wafers, center) and long term single machine overlay (3 day overlay, right). Stage accuracy (99.7%) is 4 nm, short-term single machine overlay is 10 nm and long term single machine overlay is 13 nm. All data is for a single stage to itself.

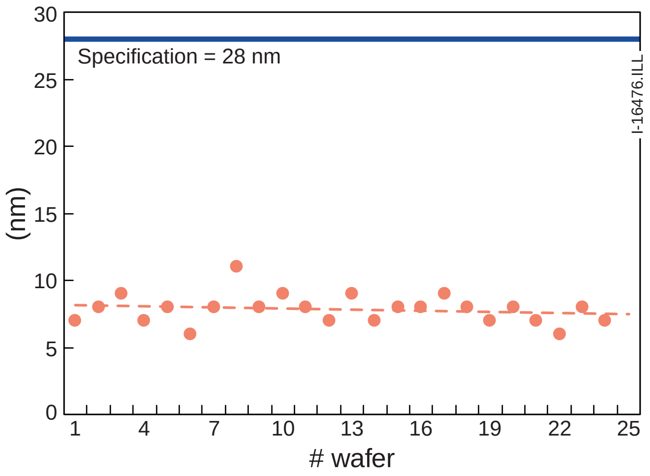

Figure 9 – Single machine overlay performance over a full batch of 24 wafers. Average value is 8 nm with no visible trend over the batch. All wafers were processed on the same stage.

4.3. Stage to stage matching

Overlay performance can be improved by processing subsequent layers of a device on the same system in order to eliminate machine to machine differences. In a dual wafer stage system such as TWINSCAN there is a likelihood that a wafer in a second pass ends up on the ‘other’ stage. Therefore, to ensure an optimal overlay performance, both stages are matched to each other. The matching process is essentially a part of the conventional machine to machine matching, i.e. matching of the two stage grids. Since the two stages operate in the same body, the grid stability will be significantly better than in case of matching two different machines and the difference between single stage overlay and dual stage overlay will be minimal.

5. THE FOCUS SYSTEM

The Rayleigh resolution equation (1) and the equation describing the depth of focus (2) can be combined into a single equation that describes the depth of focus (DoF) as a function of resolution and NA:

$$\text{DoF} = \text{constant} * \text{Resolution} / \text{NA} \qquad (3)$$

The equation demonstrates that DoF is continuously decreasing with the drive towards lower resolutions where lenses with an increasing numerical aperture (NA) will be applied. Eventually the DoF will become so small that wafer and reticle flatness will become limiting factors. The constant in equation 3 is process dependent and can be influenced with optical enhancement techniques. These techniques, such as phase shift masks and assisting features on masks, offer a complex and sometimes expensive solution for lithographic processes. A more attractive and cost-effective approach, and the one followed in TWINSCAN, is to design an imaging system with the highest usable depth of focus.

5.1. Wafer height measured prior to exposure

In order to position the wafer surface in the focal plane during exposure, the height of the wafer surface must be determined. In current step and scan systems, leveling information required for focusing the image is determined while scanning the image. In TWINSCAN, the wafer plane height is measured at the measurement station prior to exposure and the height information is used during exposure to position the wafer surface exactly in the focal plane. The required vertical positional accuracy is ensured by Z-interferometers.

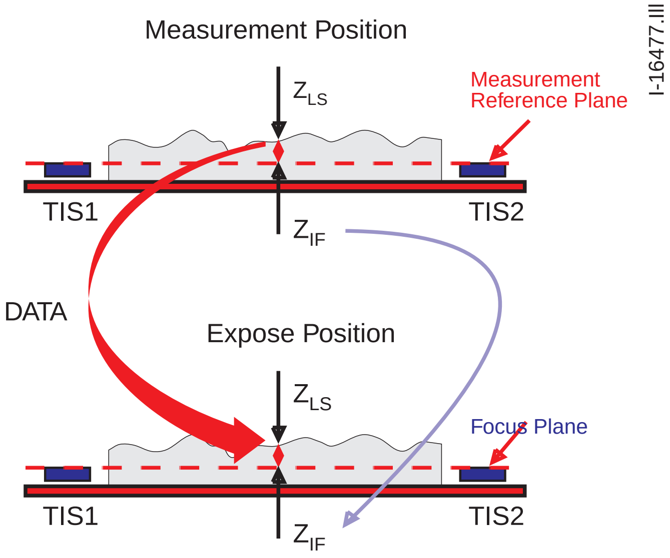

Figure 10 - Schematic drawing of the focus and leveling principle of the TWINSCAN system.

The focus (or leveling) function consists of three basic steps. During the first step, at the measurement position, the height of the wafer surface is measured with a new level sensor with high spatial resolution. The height of the wafer surface is determined with respect to a reference plane, formed by the two TIS plates on the wafer stage (see Figure 10). In the second step, optimal height setpoints for each exposure field that are a best match of the dynamic height response of the exposure slit to the measured wafer surface are calculated. Finally, in the third step, at the exposure position, the focal plane is measured with the TIS sensors, the measurement reference plane is translated to the focal plane and the wafer is exposed with height setpoints that position the wafer surface exactly in the focal plane. Focus drift problems are reduced to the drift occurring in the time to expose a single wafer, since the focal plane measurement is part of the (vertical) wafer alignment and is measured for every wafer.

The measurement of the wafer surface with respect to the reference plane is done with a new 9 spot focus (level) sensor synchronized with the Z-interferometer. The sensor is an optical system of which each spot of the array can measure the wafer surface height over an area of 2.8*2.5 mm^2. The combination of improved sensors and Z-interferometry leads to a better absolute accuracy of the wafer height measurement. A complete wafer height map is determined by scanning the wafer underneath the sensor in a pattern corresponding to the exposure fields, and measuring the surface height (see for example Figure 11). The spatial resolution of these measurements is increased to 2.8*0.5 mm^2 by using overlapping measurements. At the edge of the wafer the surface measurements can be done up to a single spot distance from the wafer edge. Therefore, accurate height information is available right to the very edge of the wafer, and ‘edge’ dies can be leveled as accurately as ‘inner’ dies. During exposure, there is no difference in height positional accuracy between scans from the inside of the wafer towards the edge and scans inwardly from the wafer edge. This results in a more optimal exposure routing and thus an increase in throughput.

The algorithm used for calculating optimal height setpoints for the wafer stage during exposure is optimized for best imaging results. In this algorithm an optimum is determined for the focus error (MA) and the focus vibration (MSD), taking into account the response characteristics of the wafer stage for the desired movements in Z and the two tilt axes. These algorithms do not have to be performed in real time and since all information concerning the wafer surface is known in advance, they do not have to be causal. Consequently, the calculated profiles can be better optimized on imaging performance compared to systems where the focus control is done in real time. It is also possible to implement these algorithms flexibly, and to provide user selectable alternative algorithms for various applications.
Since the measurement of the wafer surface is done at the measurement position, and exposure takes place at the exposure position with a different set of interferometers, the focal plane has to be determined with respect to the measurement reference plane. The TIS provides the reference with respect to which the wafer surface is related. The wafer map is

measured relative to the surface of the TIS at the measurement position. At the expose position, the position of the aerial image (in X, Y and Z) is measured with the TIS on the same TIS plate and the best focus position is derived.

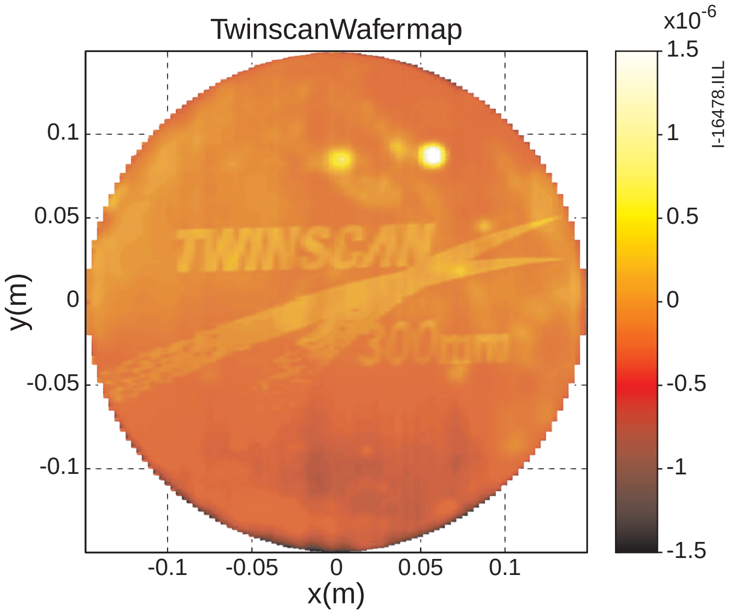

Figure 11 – Wafer map of a 300 mm wafer with a TWINSCAN logo in resist. The colors indicate the height variation over the wafer (with respect to a global reference plane) as indicated in the color bar with height in meters. Reproducibility of the focus measurement is better than 25 nm.

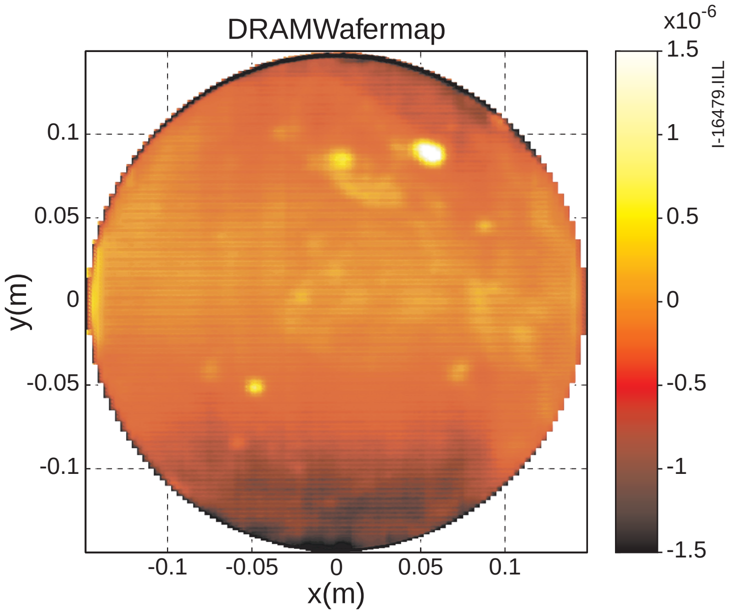

Figure 12 – Wafer map of a 300 mm processed wafer containing DRAM, clearly showing the cellular nature of the DRAM device structures. The colors indicate the height variation over the wafer (with respect to a global reference plane) as indicated in the color bar with height in meters. Reproducibility of the focus measurement is better than 25 nm

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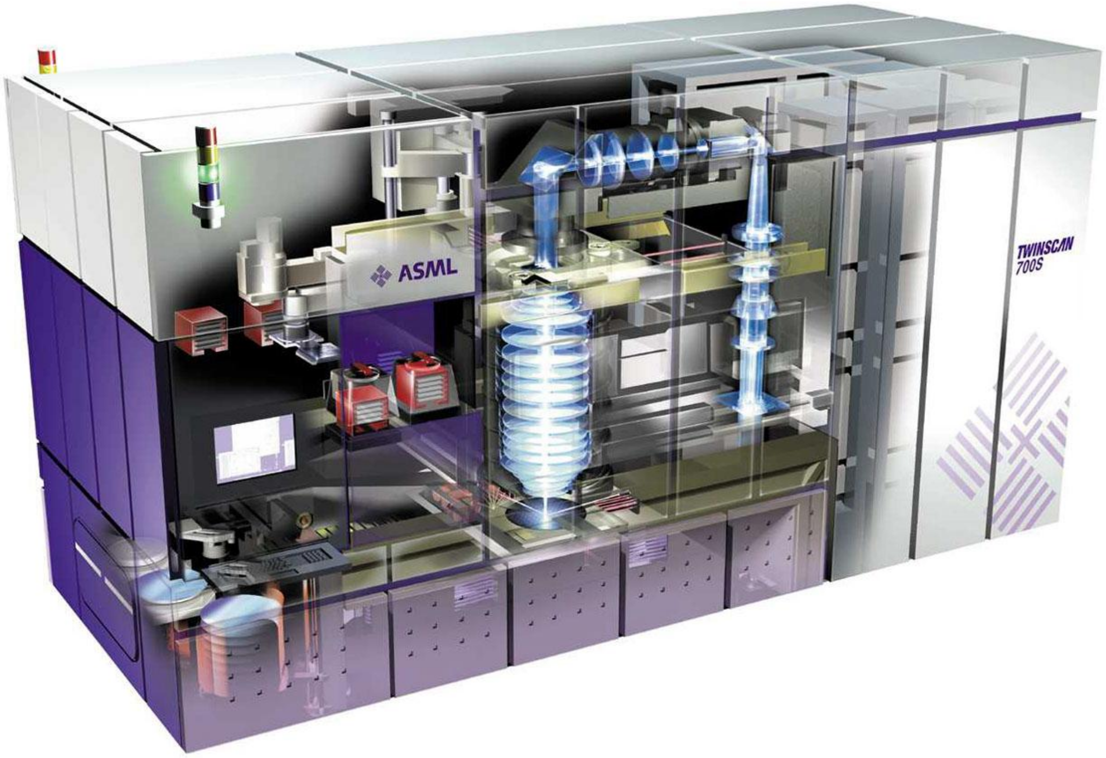

Figure 13 – Representation of the TWINSCAN AT:750 dual wafer stage system, equipped with a Starlith™ 750 lens for 130 nm imaging.

5.2. Measurement Results

Figures 11 and 12 show two measured wafer surfaces with the new leveling technique. Figure 11 shows a 300-mm bare silicon wafer covered with a resist layer of approximately 340 nm. The wafer is exposed with the TWINSCAN™ logo after which the resist is developed. The wafer map is measured in 10 measurement scans, each using all 9 spots (array) of the level sensor covering a width of 30mm for each scan. Surface measurements shown in Figure 11 cover the entire wafer, and the details of the logo, resolved by the individual 2.8x0.5 mm^2 measurements, are visible all the way up to the edge of the wafer.

To test the reproducibility of the wafer map, the wafer map is measured 25 times. For each position on the wafer, a 3-sigma value is calculated. These 3 sigma values are then averaged and a 3-sigma value over the whole wafer surface is calculated. This is called the wafer map reproducibility and shows reproducibility values of the order of 25 nm.

Figure 12 shows the result of a surface measurement of a processed wafer containing DRAM structures. In this wafer map one can see DRAM structure details, which gives an indication of the high spatial resolution of the measurements.

In both wafer maps (Figures 11 and 12) a few positions are visible (top right) where the wafer surface is much higher than the surrounding surface. These so-called ‘focus spots’ (causing areas of defocus) are the result of contamination of the wafer stage. From a comparison between Figures 11 and 12 one can see that the ‘focus spots’ are at the same position and thus related to the chuck.

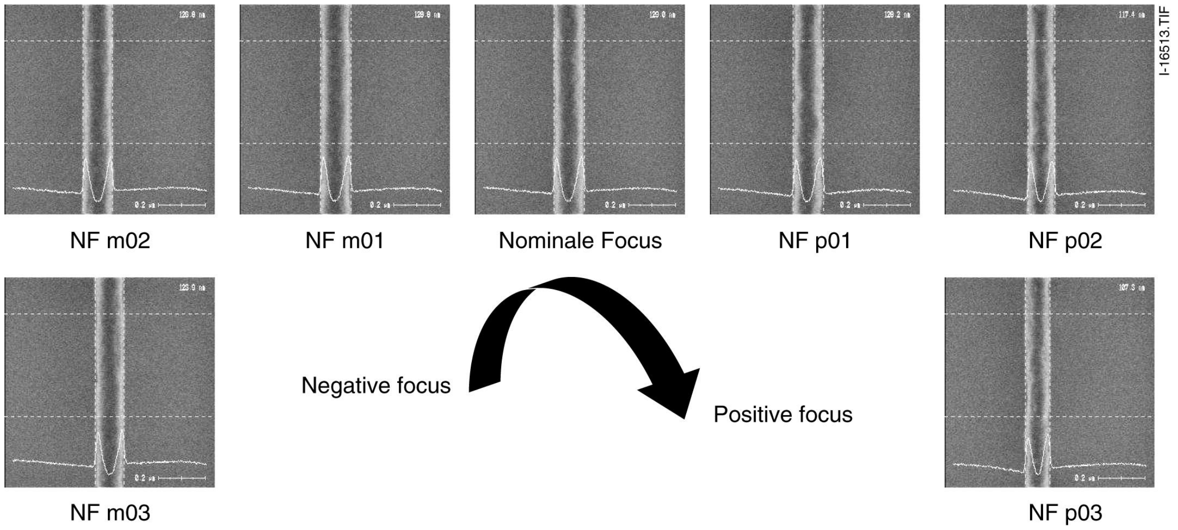

Figure 14 – SEM pictures of 130 nm isolated lines at best energy through focus, demonstrating an IDoF of 0.6 µm

6. IMAGING

6.1. Optical layout of the AT:750 Step & Scan system for DUV Lithography

The first system based on the TWINSCAN dual wafer stage architecture is the AT:750, a deep-UV step and scan system using a 0.7 NA Starlith™ 750 lens operating at 248 nm, and capable of imaging at 130 nm resolution[7]. The basic layout, shown in Figure 13, reveals the optical path consisting of the AERIAL™ illuminator and the lens, the measurement position with the ATHENA™ alignment sensor and the level sensor and the two wafer stages.

Imaging data for 130nm isolated lines, depicted in figure 14, shows the IDoF for the TWINSCAN AT:750 system at best energy to be around 0.6 µm. The practical exposure – dose (ED) window for isolated lines, shown in figure 15, demonstrates a useable Depth of Focus of 0.34 µm at 10% Exposure Latitude

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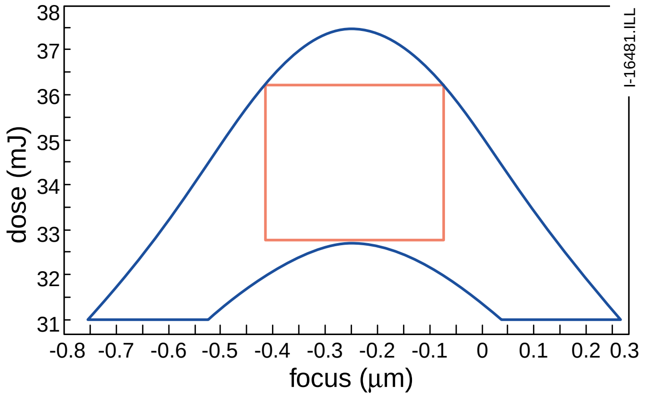

Figure 15 – IDoF for 130 nm isolated lines at 10% exposure latitude is 0.34 µm.

7. CONCLUSIONS

The specific requirements for 300 mm photolithography, including the need to continue the progression in productivity whilst providing a platform to continue the development of future generations of photolithography equipment have led to the development of the TWINSCAN platform. The implementation of dual wafer stages results in an increase in productivity, and at the same time provides additional measurement capabilities. Basic system dynamics, including cancellation of stage acceleration forces by means of balance masses, are designed to meet the requirements of the 70 nm node. A novel approach to wafer leveling provides a solution to the increasing requirements in focus accuracy. Imaging results of TWINSCAN systems based on the Starlith™ 750 lens demonstrate the capability to image at the 130 nm node.

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