Closed-Loop XY-Stage Control with Yaw Rotation Tracking

Precise Motion Control with attocube's IDS3010

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Introduction

The semiconductor industry strives for ever smaller node technologies and efficiency improvements. With today's EUV (extreme ultra-violet) and electron-beam technologies, it becomes more and more important to enable nanometer accurate and reliable positioning of, for example, wafers, reticles, beam alignment stages, optics, mirrors, etc. Especially fast and long range movements can only achieve nanometer precision, if corresponding sensors are utilized for closed-loop motion control. Such sensors have to fulfill the high standards and requirements of the production and quality assurance processes. Challenges derive from the required ultra-high vacuum (UHV) and cleanroom compatibility, exposure to high temperatures and, with the tendency towards bigger wafers, the necessity for the highest accuracy over large travel ranges.

attocube, an expert for nano-precise applications, developed and patented the Interferometer Displacement Sensor model IDS3010 according to the Fabry-Pérot interferometer principle [1]. The IDS3010 allows movement control and displacement detection with picometer resolution, nanometer accuracy, and up to 25 MHz real-time data outputs. The fiber-based device provides three channels for measuring multi-axis stage displacements as well as determining the angular changes. UHV compatible and miniature sensor heads provide high flexibility for different use cases and tool integration. A typical application in the semiconductor industry is multiple degree of freedom (DOF) position control of the wafer stage.

Figure 1a) visualizes the main stage control applications of a "traditional" xy-stage control application, where the moving stage is equipped with two mirrors and the optical components of the interferometer are fixed to the machine frame. Figure 1b) shows a xy-stage control, where the sensor heads are fixed to the moving stage and the mirrors are fixed to the frame. This configuration is possible, because our sensor heads are fiber-based and small in dimension and weight (outer diameter of only 14 mm and weight of only 7 grams).

Figure 1 highlights two possible xy-stage control applications for the IDS3010, but our interferometer's ability to operate in various environments and working distances (up to 5 meters) provides nearly unlimited possibilities for other motion control applications. This application note demonstrates the IDS3010's capabilities and results, with our laboratory test replicating the typical semiconductor industry 3-DOF setup.

Setup

The measurement setup, similar to the example shown in Figure 1a), consists of an electromagnetic xy-stage that has a one meter travel range along the x-axis. Two high-quality planar mirrors were placed on the moving stage, which function as the measuring surfaces. To control the stage position, we utilized an IDS3010 with three stationary collimated sensor heads (model M12/C1.6/wf).

The IDS3010 allows instantaneous position feedback through available real-time data outputs (SinCos, AquadB, HSSL, Linear Analog Output, and BissC). These interfaces provide the real-time inputs for closed-loop positioning control systems. For our laboratory tests, we used the SinCos data output with 5 MHz bandwidth and nanometer resolution.

As the displayed tests are executed at ambient conditions, we use the Environmental Compensation Unit (ECU) to ensure accurate [2] measurements. The environmental compensation is not needed in vacuum conditions, which is the standard for sophisticated semiconductor applications, leading to even higher levels of precision.

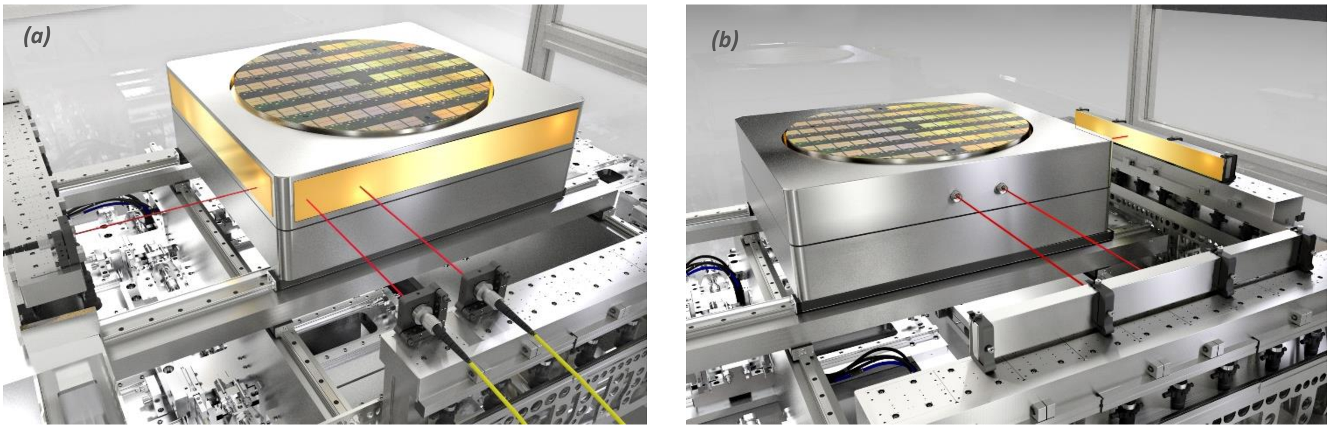

Figure 1: Two xy-stage control application examples are shown. (a) Wafer mounted on a moving stage, where mirrors are attached. Three sensor heads are fixed to the frame. The xy-movement of the stage is controlled by the IDS3010. (b) Another possible application is shown in which miniature sensor heads are mounted on the moving wafer stage, while the mirrors are fixed to the frame.

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Two sensor heads (SH1 and SH2) measure the displacement on the yz-mirror surface. The SinCos signal of SH1 is used for closed-loop control of the x-axis. SH1 and SH2 are horizontally separated by 40 mm; therefore, the yaw rotation can be calculated and utilized as the real-time compensation for a 4-DOF setup. In our 3-DOF setup, we could not compensate the yaw rotation along the x-axis. The third sensor head (SH3) controls the y-axis. The sensor heads are connected to the three axes of the IDS3010 via flexible optical fibers. No additional optics are required.

When measuring on a plane mirror, the M12/C1.6/wf sensor head's angular tolerance is specified to be ± 30 m° at a distance of 1 meter. This tolerance is still user-friendly, in order to align the setup of a precise xy-stage, but it also guarantees low cosine errors. This is an additional benefit in comparison to other interferometer manufacturers. On top of that, our measurement principle allows us to have a large sensor head portfolio, including an option where we can measure over a range of 5 meters on a plane glass surface instead of measuring on a mirror.

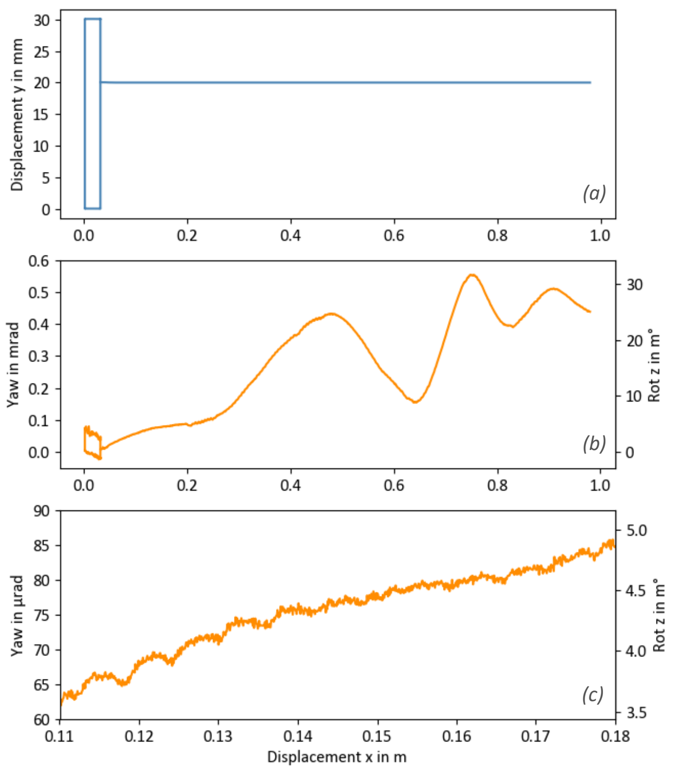

Figure 2: (a) The displacement data of a xy-stage movement is shown. The x-axis was moved with a stroke of 1.0 meter, while the y-axis was moved only 30 mm and included an offset distance. (b) The yaw (rotation of the z-axis) of the xy-stage movement shown in (a) is depicted. The total yaw rotation is in the range of 30 m°. (c) The zoom-in of the yaw rotation highlights detailed angular movements in the range of tens of µ°.

Measurement Results

Figure 2a) presents the xy-displacement values of an exemplary drive. First, a square of 30 x 30 mm was realized. Afterwards the x-axis was moved to a total stroke of 1.0 meters. At this point, it is important to comment that SH3 needs to have a certain offset distance of around 300 mm for SH1 and SH2 to measure up to 1 meter. This master-slave axes relation is well specified. The corresponding yaw (rotation of the z-axis) of the xy-stage movement is shown in Figure 2b). The graph shows that the yaw rotation increases up to around 30 m° by moving the x-axis up to 1 meter. Figure 2c) shows repeating angular deviations in the range of µ°, which are primarily caused by the distances between the magnetic poles distributed along the motion axis. The yaw rotation could be compensated if the electromagnetic stage would have additional precise rotation equipment.

Conclusion

The IDS3010 proves to be a suitable tool for closed-loop xy-stage applications. Both displacements and angles can be detected with bandwidths up to 25 MHz. The miniaturized sensor heads allow flexible integration and ensure the right combination of usability and accuracy for demanding positioning tasks. Moreover, the lightness of the sensor heads (7 grams) offers new setup possibilities, which could reduce the moving mass significantly. Ethernet connection and several standard programming languages (*e.g.* C+, C#, DLLs, Python and LabVIEW) allow for easy network integration into a variety of different systems.

References

[1] Patent: Interferometric displacement sensor for integration into machine tools and semiconductor lithography systems; US10260863B2.

[2] National Metrology Institute of Germany (PTB) calibration certificate; Calibration mark: 54012 PTB 15; 2016.