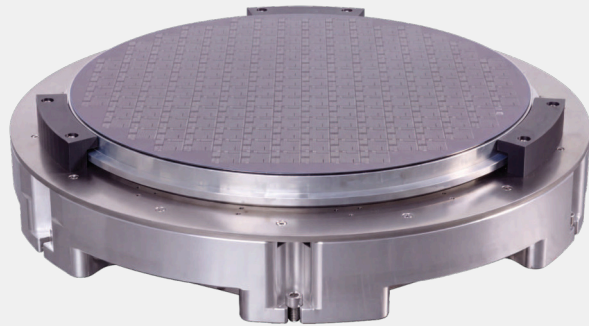


Advanced Motion Solutions for Semiconductor Bonding, Packaging, Inspection & Metrology

Magnetic Levitation, Air Bearing and Piezo Technology



Active Wafer Handling and Flatness Correction



Controlled Surface Shaping Using Piezo-Based Actuation

Warped and bowed substrates disrupt chucking, measurement, and yield throughout wafer processing. This piezo-based active chucks reshape the surface on demand, correcting bow and local deformation through the superposition of the first ten Zernike modes or freely selectable shapes, with long- and short-wavelength stroke and set-and-forget stability from full 300 mm wafers down to millimeter-scale substrates.



Technology Demonstrator

Key Advantages of the System Design

- ✓ **Active Shape Control** — Controlled correction of wafer bow, warpage, and local deformation
- ✓ **Scalable System Design** — Configurable for full wafers and smaller substrates
- ✓ **Flexible Shaping Modes** — Supports long- and short-wavelength deformation



Number of DoFs

First 10 Zernike modes or freely selectable



Stroke

Long-wave: $\pm 100 \mu\text{m}$
Short-wave: $\pm 3 \mu\text{m}$
More stroke upon request



System Sizes

From 300 mm wafers down to a few millimeters



Operation Modes

Highly dynamic and extremely stable set-and-forget operation

Active Wafer Handling and Warpage Correction



CHALLENGE

Warpage

Bent or warped substrates, such as wafers, create challenges during chucking as well as throughout measurement and production processes.

Varying Stroke and Resolution

Different applications demand different specifications for shape control.

Specimen Integrity Risk

Curvature concentrated at kink edges can risk specimen damage, while chucking at individual points can lead to unintended tent-like deformation.



SOLUTION

Active Shape Control

Use of an actively deformable chuck ensures reliable chucking while enabling dynamic adaptation of the substrate shape throughout the process.

Appropriate Amplitude and Pitch

Depending on the application requirements, the solution can provide long- or short-wavelength deformation, or a combination of both.

Smooth Shape Gradients

A stiff support structure ensures smooth shape gradients, with high-resolution, highly repeatable piezo actuators delivering the required deformation forces.



RESULT

Flexible Shapes

Superposition of Zernike modes maps complex and rotatable surface shapes.

Flexible System Sizes

Solutions ranging from entire wafers to arrays just a few millimeters in size, with larger strokes available upon request.

Set and Forget

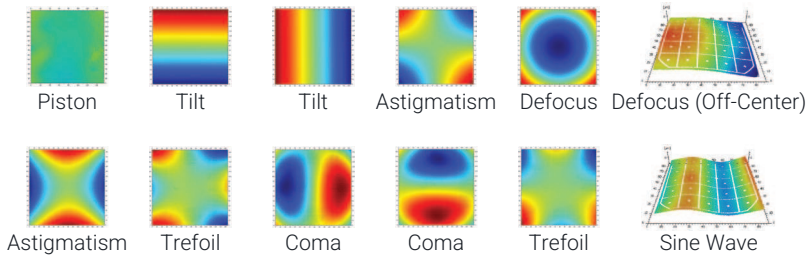
Semi-active (PIRest) operations enable optimized stability and power consumption.

Parameter	Active Wafer Chuck	Piezo Arrays
Number DoFs	10 (Zernike modes up to 3 rd order)	Selectable
Stroke (active operation)	Rigid body motion: up to $\pm 150\text{ }\mu\text{m}$ ** Deformation modes: up to $\pm 100\text{ }\mu\text{m}$ **	Actuator array: $\pm 3\text{ }\mu\text{m}$ Multilayer array: $\pm 1.5\text{ }\mu\text{m}$
Minimal increment motion (closed loop)*	< 15 nm	–
1 st resonant frequency	> 350 Hz	–

* Preliminary specifications

** More strokes available upon request

Surface Measurement Result



LET'S TALK ABOUT YOUR APPLICATION

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Wafer Positioning and Bonding for Advanced Packaging



6DoF Positioning and Force Control for High-Throughput Packaging

Advanced packaging demands positioning resolution, dynamic performance, and controlled process forces in a single motion system. Built on magnetic levitation, this demonstrator combines long-travel multi-axis positioning, nanometer-class stability, and integrated force control in one contact-free stage, ready to scale toward high-throughput bonding.



Key MagLev Advantages

- ✓ **6DoF Control** — Precise control in multiple axes
- ✓ **Force Control** — Precise control of process forces
- ✓ **Low Moving Mass** — High dynamics and short settling
- ✓ **Contact-Free Operation** — No lubricants, wear, or particle generation

					
Dynamics	Alignment Capability	In-Position Stability	Force Controlled Bonding Capability	Repeatability	Z-Stroke Crosstalk
Acceleration: 2* ... 6 g Velocity: 400* ... 2000 mm/s	X: 400 mm* Y: ±200 µm* θZ: ±1 mrad* θXY: ±0.5 mrad*	Z: <2 nm* θXYZ: <20 nrad*	Z: ±200* ... 1000 µm >100 N* process force mN* resolution**	Double-digit nanometer*	XZ/YZ: single-digit nanometer crosstalk over full Z stroke

* Asterisked values represent the performance of the demonstrator shown; additional values indicate achievable performance with different system configurations.

** With integrated force sensor

Wafer Positioning and Bonding for Advanced Packaging

CHALLENGE

Precision Control in 6DoF

- Bonding requires high positioning resolution and accuracy in multiple axes.
- Fast detection of contacts and transition to force controlled operation impacts process throughput.
- Process forces impact process outcome and critically the yield.

Dynamic Performance

Move-and-settle time and acceleration limit tool output; added mass and compliance stretch settling times.

Clean Operation

Guides, bearings, and lubricants generate particles requiring airflow to manage them



SOLUTION

Contact-Free Levitation Over Long Travel

Accuracy does not rely on a mechanical guide. Minimal disturbances in force signal enables detection of any spike in force.

High Force Density, Low Moving Mass

Direct actuation and low moving mass for high acceleration and short settling times.

No Contact, No Lubricants, No Wear

With contact-free bearing and actuation, no particles or airflow are generated, eliminating mechanical disturbances.



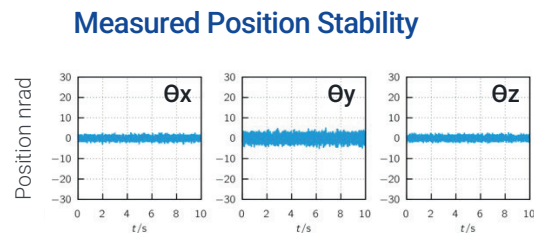
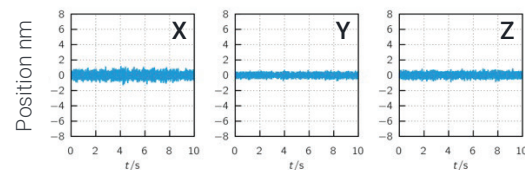
RESULT

One Stage

- Long-range travel, nanometer positioning, and force control in one contact-free body.
- Fewer interfaces, less commissioning effort.
- With all process-critical motion contained in one stage, the overall machine is simplified.

New Machine and Process Concepts

- Full control over position, force, and torque in 6DoF.
- Switchable control modes in each DoF for e.g. position control in XY and RZ, virtual stiffness in RX and RY, and constant velocity approach in Z with contact detection and force application.
- Constant monitoring of forces and torques to ensure process consistency.



Preliminary measurements performed in lab environment

	RMS	p-p
x/nm	0.33	2.50
y/nm	0.20	1.48
z/nm	0.24	1.81
θ_x /nrad	0.77	6.18
θ_y /nrad	1.43	10.53
θ_z /nrad	0.80	5.53

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Wafer Positioning for Inspection and Metrology

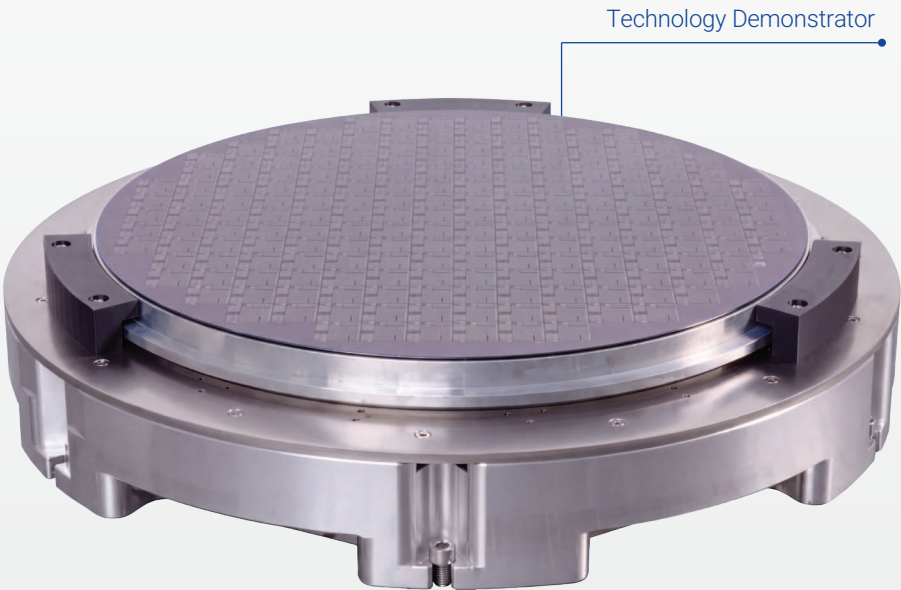


Ultraprecise Theta Positioning for Error-Critical Applications

In ultraprecise theta positioning, axial, radial, and angular error motion can directly affect measurement accuracy. Maintaining the rotor position and plane during continuous rotation is therefore critical for precise and repeatable inspection and metrology. Magnetic levitation enables active control of these degrees of freedom throughout unlimited theta travel, while allowing the rotor dynamics to be adapted to the measurement task

Key MagLev Advantages

- ✓ **Active Rotor Plane Control** — Stabilization of axial position and tip/tilt during rotation
- ✓ **Dynamic Error Compensation** — Active correction of radial, axial, and angular errors
- ✓ **Programmable Stiffness and Damping** — Adaptable rotor dynamics for positioning and measurement



Range of Motion	Dynamic Focus Tracking	In-Position Stability	Payload	Active Plane Stability	Velocity
ΘZ : unlimited* X/Y : $\pm 200 \mu m^*$ ΘXY : $\pm 0.25 mrad^*$	Z : $\pm 600 \mu m^*$	Z : $3 nm^*$	$2^* \dots 25 kg$	Axial error: $< 5 nm$ Non repeat: $< 3 nm RMS$ Tilt error: $< 50 nrad^* p-p$	$> 600 rpm^*$

* Asterisked values represent the performance of the demonstrator shown; additional values indicate achievable performance with different system configurations.

Wafer Positioning for Inspection and Metrology

CHALLENGE

Theta Positioning

Advanced wafer inspection and metrology require extremely low axial, radial and angular error motion during continuous rotation.

Rotor Plane and Axis Stability

Axial runout, radial motion, and tilt directly translate into measurement error, particularly as rotational speed and wafer POI radius increase.

Non-Repeatable Error and Disturbance Sensitivity

Asynchronous error motion, structural vibration, and external disturbances can limit achievable measurement.

Throughput and Settling

Increasing rotational speed alone is insufficient. Acceleration, disturbance recovery, and move-and-settle behaviour determine usable process throughput.

Cleanliness and Services Infrastructure

Mechanical bearings introduce wear and lubricants. Air bearings require air infrastructure and introduce pressure-dependent, airflow, and acoustic behaviour.



SOLUTION

Active Rotor Plane Stabilization

The levitated passive rotor can actively control axial position and tip/tilt during rotation, maintaining the process plane rather than relying solely on passive bearing accuracy.

Multi-DOF Error Correction

Independent actuation provides control over radial, axial, and angular parasitic motion while maintaining continuous theta rotation. Repeatable error components can additionally be characterised and compensated electronically.

Active Disturbance Rejection

Corrective forces and moments can be applied in all directions to suppress vibration, rotor imbalance effects, structural excitation, and process-induced forces.

Programmable Rotor Dynamics

Electronic control enables stiffness and damping to be adapted to the operating condition — for example high dynamics during positioning and high stability during measurement.

Contact-Free, Air-Free Rotation

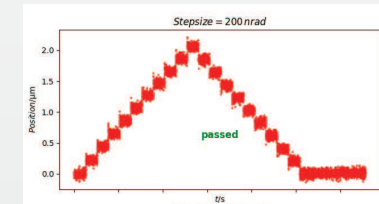
Magnetic levitation eliminates mechanical bearing contact and avoids the compressed air infrastructure. No bearing friction, no lubricant, no bearing wear, and no air-pressure-dependent flying height.



RESULT

The Ultimate Theta Stage

- Precision theta rotation with active control of rotor centre and plane in one contact-free system.
- Reduced dependency on mechanically perfected bearing surfaces and passive spindle accuracy.
- Active correction of axial, radial, and tilt errors can reduce the need for additional compensation mechanisms.
- Programmable stiffness and damping allow the same stage to support both high-dynamic positioning and ultra stable measurement.
- Air-free operation simplifies machine infrastructure and removes pressure-related positioning effects.



Theta Minimum Incremental Motion

Enabling

- **Active control at the process point:** Control focus, height, angular alignment, and fine X/Y positioning during measurement.
- **More measurements per wafer:** Higher inspection coverage without sacrificing throughput while improving precision.
- **Adaptive machine platforms:** Change inspection strategies through software, not stacked mechanics.

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Wafer Positioning for Inspection and Metrology



High-Precision, Highly Dynamic Positioning for High-Throughput Tasks

High-throughput inspection and metrology demand nanometer accuracy and the dynamics to measure on the fly. A magnetically levitated, long-travel wafer stage delivers both, holding focus and stability under high acceleration while active 6-axis control and contact-free operation keep every measurement clean and repeatable across the full wafer.

Key MagLev Advantages

- ✓ **Dynamic Focus Tracking** — Active height control during scanning
- ✓ **Active Error Compensation** — Correction of tip, tilt, and cross-axis errors
- ✓ **Contact-Free Operation** — No lubricants, wear, or particle generation



					
Dynamics	Auxiliary Axes	Primary Stroke	In-Position Stability	Repeatability	Dynamic Focus Tracking
Acceleration: 2* ... 6 g Velocity: 400* ... 2000 mm/s	Y: $\pm 200 \mu\text{m}^*$ Θ_{XY} : $\pm 0.5 \text{ mrad}^*$ Θ_Z : $\pm 1 \text{ mrad}^*$	Wafer positioning: 400 mm* (X)	Z: $< 2 \text{ nm}^*$ (p-p) Θ_{XYZ} : $< 20 \text{ nrad}^*$ (p-p)	Double-digit nanometer*	Z: $\pm 200^* \dots 1000+ \mu\text{m}$ Z: $> 200 \text{ Hz}^*$

* Asterisked values represent the performance of the demonstrator shown; additional values indicate achievable performance with different system configurations.

Wafer Positioning for Inspection and Metrology

CHALLENGE

Precision Control in 6 DoF

- Every path deviation causes errors in feature position and distorts images.
- Residual motion and drift during imaging can blur features and limit measurement repeatability.
- Cross-axis and out-of-plane errors tilt the sample, causing defocus and Abbe errors.

Dynamic Performance

Tool output is limited by move-and-settle time and acceleration – not just peak speed. Added mass and compliance further stretch settling times.

Clean Operation

Guides, bearings, and lubricants generate particles requiring airflow to avoid sample contamination.



SOLUTION

Contact-Free Levitation Over Long Travel

- Accuracy does not rely on a mechanical guide.
- Position stability only depends on sensors and motor current ripple and is no longer limited by air bearing noise.
- Dynamic compensation enables high acceleration with minimal tipping and tilting.

High Force Density, Low Moving Mass

Direct actuation and low moving mass delivers high acceleration, short settling, and ripple-free scanning.

No Contact, No Lubricants, No Wear

With contact-free bearing and actuation, no particles or airflow are generated, eliminating disturbances.



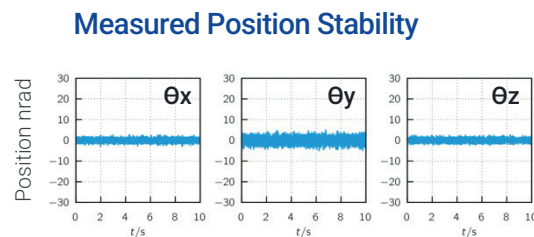
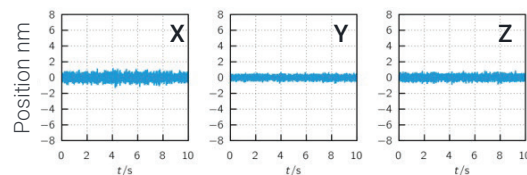
RESULT

One Stage

- Long-range travel and nanometer positioning in one contact-free body.
- Fewer interfaces, less commissioning effort.
- All process-critical motion contained in one stage simplifies the overall machine.

No Air, No Wear

- No compressed air supply, plumbing, or air film noise disturbing the measurement.
- No wear, no lubricants, no particles: stable accuracy over the whole lifetime.
- Stiffness and damping are configured in software and are thus adaptable in each process step.



Preliminary measurements performed in lab environment

	RMS	p-p
x/nm	0.33	2.50
y/nm	0.20	1.48
z/nm	0.24	1.81
θ_x /nrad	0.77	6.18
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High-Performance Scanning and Metrology



A-323 Planar Air Bearing Scanner for Highly Dynamic XY Motion and Flexible Axis Integration

The A-323 air bearing planar XY scanner is the next evolution of the A-322 platform. Providing 500 x 500 mm travel in its basic configuration, the new architecture is designed to improve precision and repeatability while enabling significantly higher acceleration, faster step-and-settle performance, and greater flexibility for integrating additional motion axes.

Key Improvements

✓ Split-Beam Cross-Axis Design

Reduces the load's center of gravity and Abbe errors while improving yaw control and repeatability.

✓ Reaction-Force Transfer Architecture

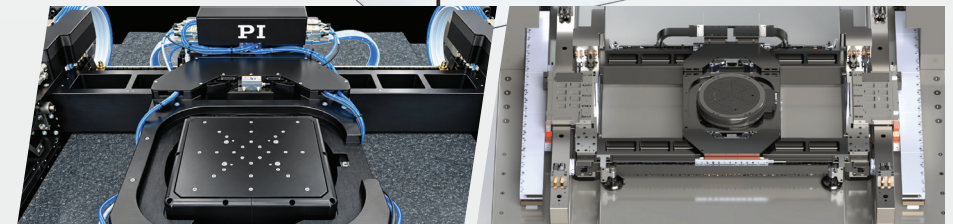
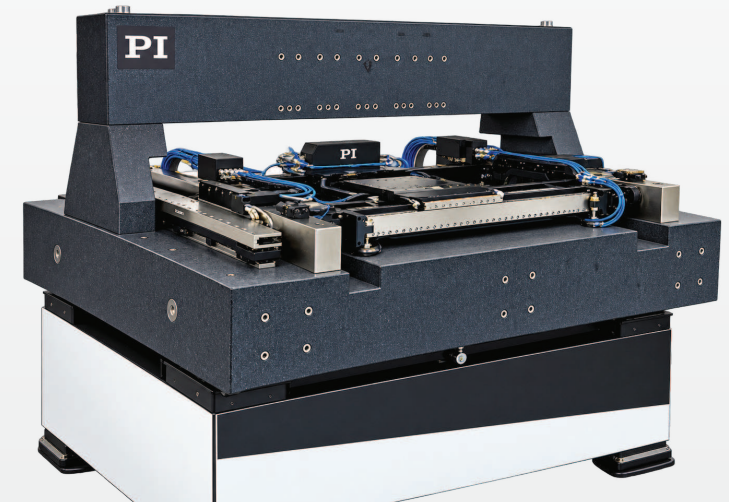
Reduces vibration and enables faster acceleration and settling.

✓ Improved Cable Routing

Simplifies installation and integration of customer-provided equipment.

✓ Flexible Central Pocket

Accommodates additional motion modules for Z, tip/tilt, and rotation.



Travel / Speed / Accuracy

Travel Range: 500x500mm
Max Velocity: 2m/s
Accuracy: 0.1 μ m
Pitch/Yaw: 10/2 μ rad



Acceleration

Approximately 2 g



Potential Applications

Semiconductor metrology and inspection
Photonics
Precision measurement

High-Performance Scanning and Metrology



Engineering for More Dynamic Performance

The A-323 introduces a new system architecture designed to improve precision and repeatability while enabling higher acceleration, faster step-and-settle performance, and flexible integration of additional motion axes.

Split-Beam Cross-Axis Design

The split-beam design allows the payload to sit lower and closer to the motor force plane, reducing pitching and rocking during acceleration. It also reduces the Abbe offset between the payload and encoder measurement plane. The gantry configuration provides better yaw control across the working area.

Flexible Central Pocket

The flexible central pocket allows different motion modules to be integrated depending on the application. Options include the A-523 Z-tip/tilt stage, a compact 5 mm Z stage, rotary axis, or rotary/Z/tilt modules. Keeping these additional axes low helps preserve the dynamic advantages of the architecture.

Reaction-Force Transfer Architecture

Motor reaction forces are redirected into the machine frame rather than exciting the precision positioning structure. This reduces disturbances during high-acceleration moves and can significantly improve settling following a step, supporting the more dynamic performance of the A-323.

System Integration

Newly developed air-bearing pucks improve stiffness and stability. Integrated cable tracks, pneumatic routing, and provisions for the cooling system ensure cleaner implementation and help make the platform easier to integrate into larger automation and metrology systems.

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Inspection and Metrology for Semiconductor Manufacturing

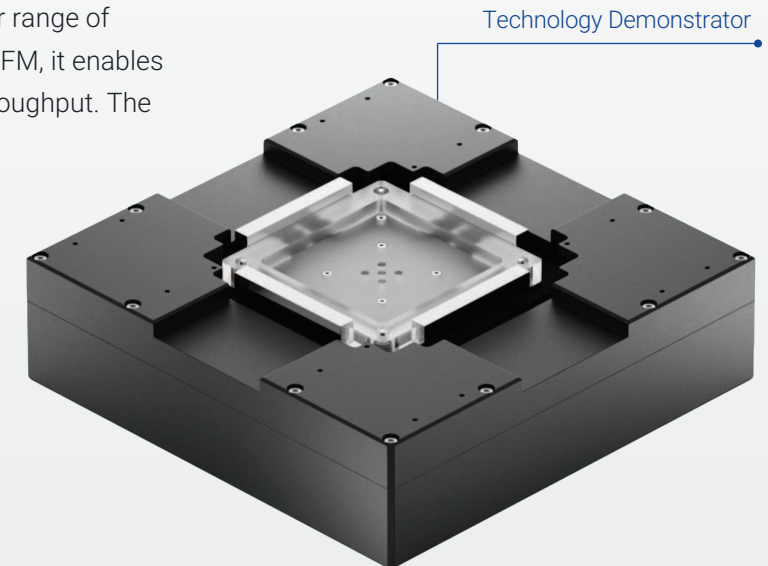


Subnanometer Precision Across Millimeter Scan Ranges for High-Throughput Inspection and Metrology

Shrinking nodes, features, and pitches demand higher resolution and accuracy, while high throughput and inline process control favor scanning larger fields of view at high speed. This MagLev demonstrator combines a millimeter range of motion, picometer-class resolution, high dynamics, and active 6DoF control in one contact-free stage. For AFM, it enables high-resolution scanning and long-range profiling at die level without stitching, increasing measurement throughput. The range of motion can be scaled up or down to fit the application, up to wafer-level scanning and profiling.

Key MagLev Advantages

- ✓ **Accuracy** — Piezo-level performance in mm travel
- ✓ **Scan Fidelity** — Low tracking error
- ✓ **High Dynamics** — Fast turnarounds, short settling
- ✓ **Contact-Free Operation** — No lubricants, wear, or particle generation



Range of Motion	Dynamics	Resolution	In-Position Stability	Repeatability	Accuracy
X/Y: 12.1* ... 50 mm Z: 50 μ m* Θ XYZ: 2 mrad*	Acceleration: 0.15* ... 1g Velocity: 15* ... 100 mm/s	X/Y: $\leq$ 50 pm* Z: $\leq$ 100 pm* Θ XY: $\leq$ 1.5 nrad* Θ Z: $\leq$ 0.5 nrad*	X/Y: $<$ 70 pm* Z: $<$ 110 pm*	$<$ 3 nm*	$<$ 10* nm with calibration

* Asterisked values represent the performance of the demonstrator shown; additional values indicate achievable performance with different system configurations.

Inspection and Metrology for Semiconductor Manufacturing



CHALLENGE

Small Features Across Larger Scan Areas

Shrinking features and advanced packaging, such as hybrid bonding, require subnanometer height measurements.

Scan Fidelity and Stable Measurements

Tracking, pitch/roll errors, and stage jitter can distort surface profiles or mask shallow dishing.

Throughput and Cleanliness

Move-and-settle overhead limits sampling. Guide wear and lubricants pose risk to surface contamination.

SOLUTION

Accuracy: Fine Motion Over Millimeters

One contact-free stage combines fine scans and millimeter travel with fewer XY interfaces.

Scan Fidelity: Active Control in 6DoF

6DoF control and ILC (iterative learning control) feed-forward reduce motion errors.

Fast, Frictionless Motion

Direct actuation enables dynamic scanning and fast site changes without bearing wear or lubrication.

RESULT

Precision Over 5 mm

2.8 nm repeatability and <10 nm accuracy with calibration.

Low Noise During Scanning

130 pm RMS Z-jitter with ILC at 20 mm/s over 8 mm.

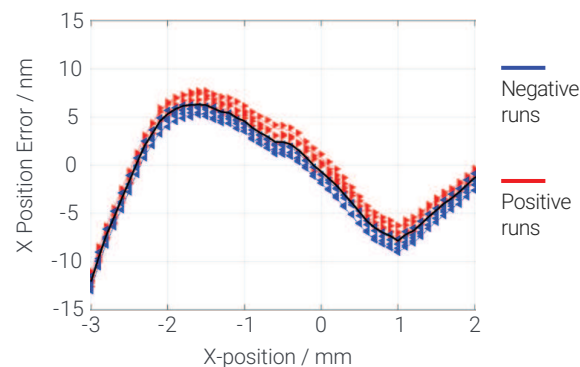
One Clean Motion Platform

Fine scans and millimeter travel with no bearing wear or lubricant sources.

Positioning Accuracy and Repeatability, X-Axis

2.8 nm repeatability

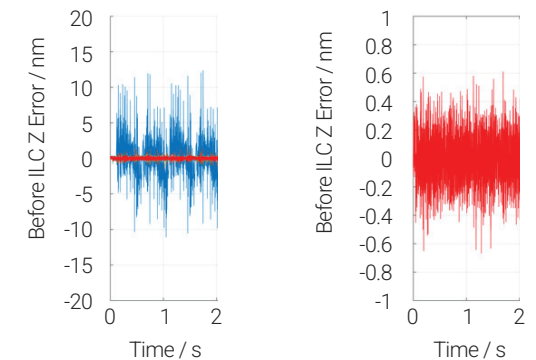
22.3 nm accuracy over 5 mm without calibration



Z-Error Before and After ILC Correction

130 pm RMS while scanning

Z-jitter with ILC 20 mm/s scan speed over 8 mm



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