How Motion Control Enables Modern Datacom Technologies

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Macro Trends Driving Datacenter Growth

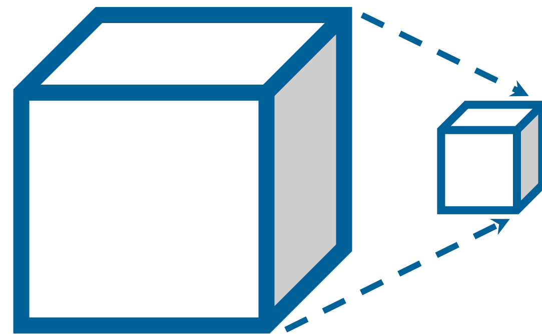
- Modern applications like artificial intelligence (AI) & high-performance computing (HPC) are driving compute demands that outpace Moore's Law
- Bandwidth needs are following a similar trajectory
- Scaling of established technologies is beginning to see diminishing returns
- Paradigm-shifting technologies such as silicon photonics (SiPh) & advanced packaging are key to addressing these requirements

Silicon Photonics Offers Key Advantages

Increasing level of photonics integration provides improvements in key areas:

Bandwidth & Latency

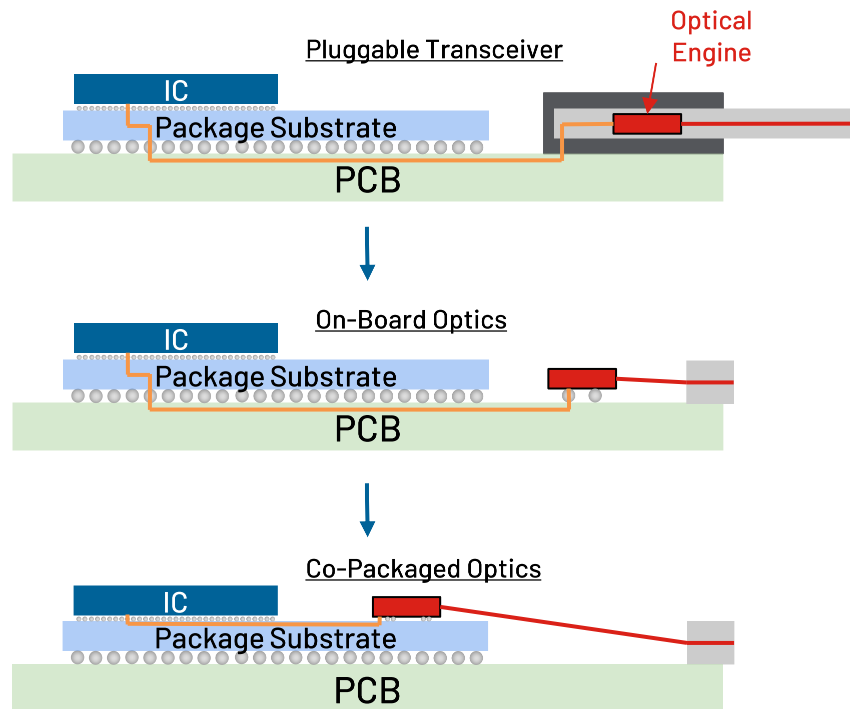
Energy Efficiency



Device Footprint

Optical Integration Scaling

- The industry continues to pursue higher levels of integration
- Advanced packaging techniques enable co-packaging optical engine with electronic integrated circuits (EICs)
- Tighter integration will continue to drive performance improvements



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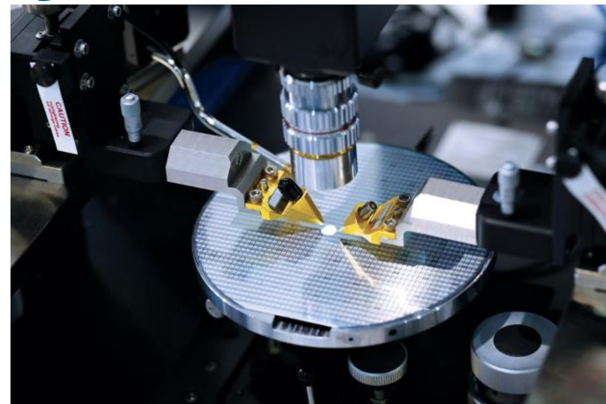
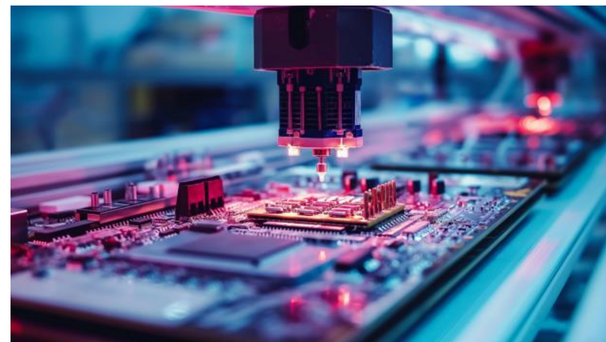
Increased Complexity = New Challenges

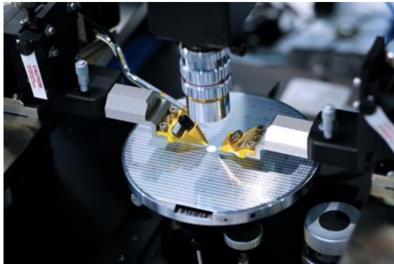
- Tighter integration requirements present new manufacturing, test & packaging challenges, particularly at scale
- Quality control in all stages of manufacturing is critical
- **Precision at micrometer & even nanometer levels is often required**



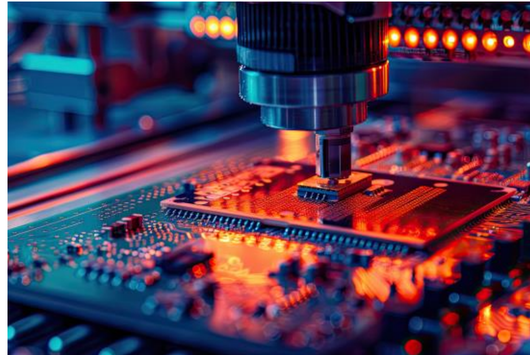


Photonic Device Precision Processes

Component Manufacturing & Test | Advanced Packaging | Device Assembly & Test



Wafer- & Die-level Test



Precision Alignment for Heterogeneous Integration & Chip Stacking

Optical Alignment & Assembly

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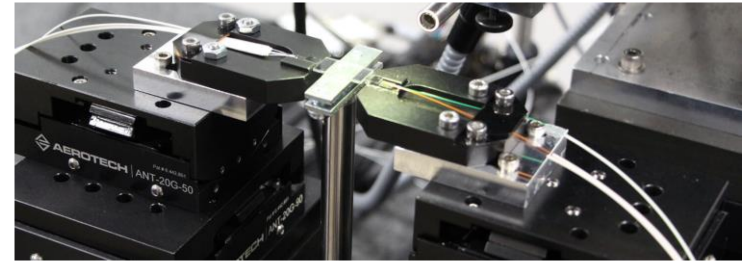
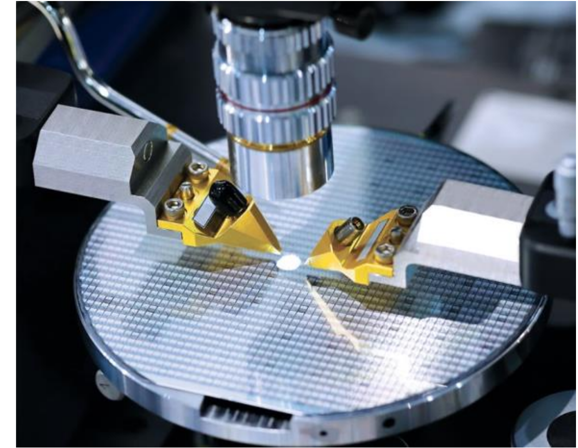
Wafer- & Die-level Test

- While SiPh-based PICs are manufactured using many of the same techniques as traditional EICs, test methodologies are significantly more complex
- In addition to electrical connections, optical paths need to be tested, introducing much different requirements



Dual-sided optical testing of photonic device



Wafer-level testing

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Silicon Photonic Wafer Probing

- Successful wafer-level edge coupling of fiber arrays in a trench depends on optical positioning sensitivity & device-under-test (DUT) geometry

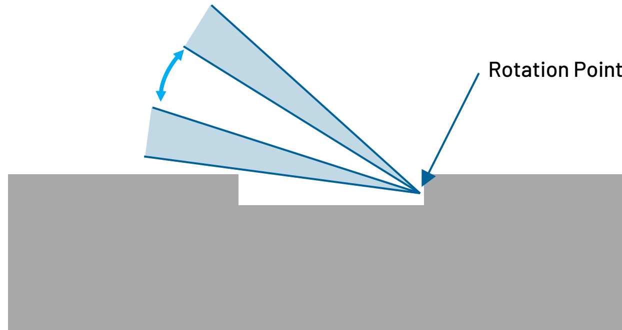
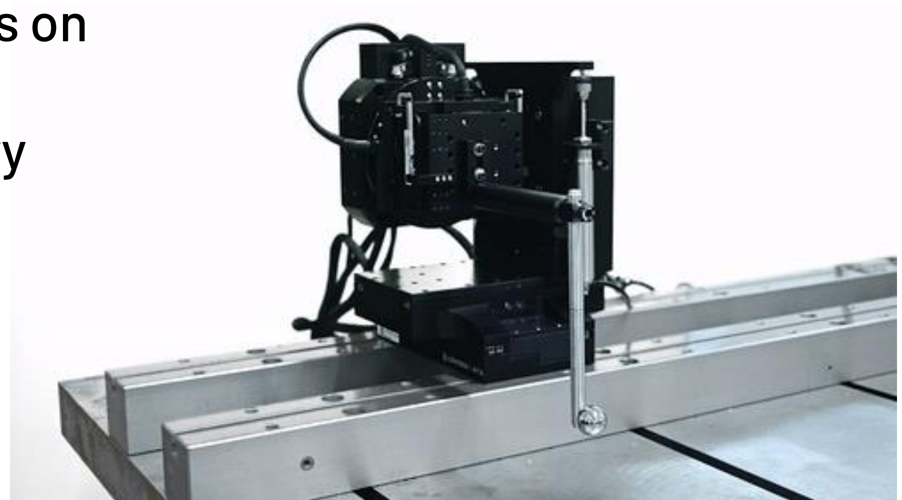


Diagram showing wafer-level edge coupling in trench



Positioning system pivoting about assigned work point

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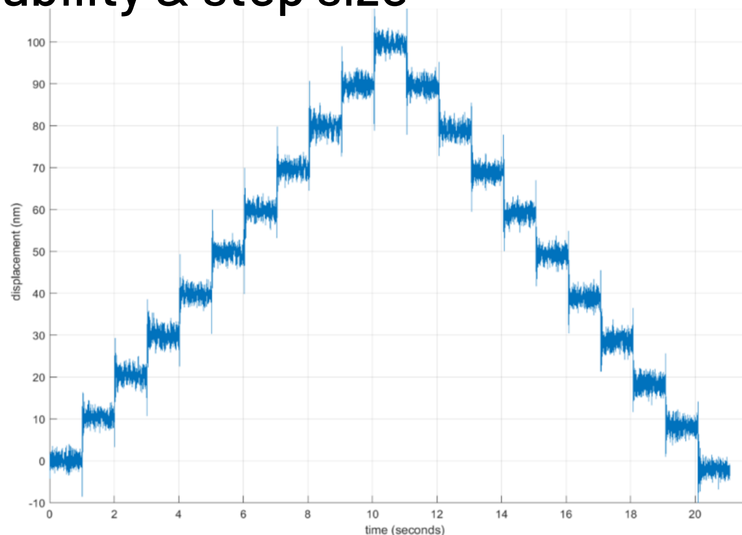
Silicon Photonic Wafer Probing

- Crossed-roller bearing stages combine industrial robustness with high stiffness, nm-level in-position stability & step size

6-DOF serial kinematic precision positioning system



10 nm steps of 6-axis positioner measured at workpoint offset

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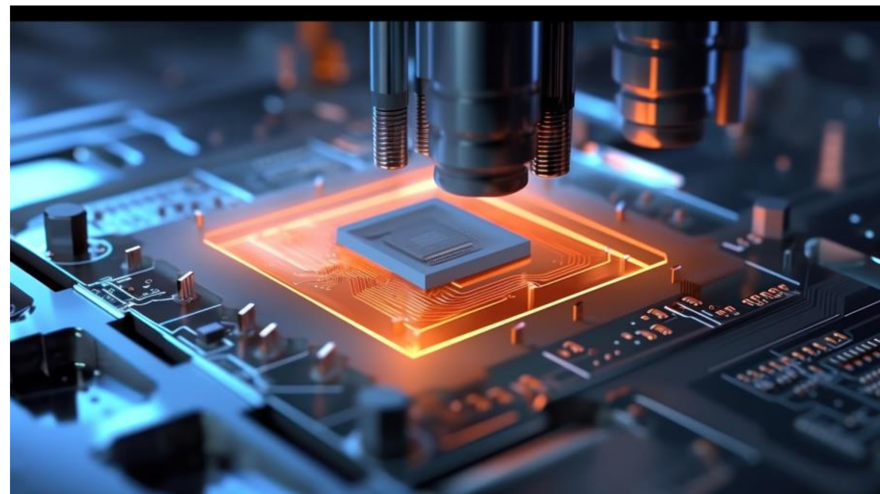
Advanced Packaging

- Advanced packaging techniques are inherently required to integrate PICs with traditional EICs
- Emerging technologies like co-packaged optics (CPO) continue to drive requirements for improved precision without sacrificing throughput
- These processes often require µm- or nm-level sensitivities



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2.5D & 3D Stacking

- Advanced packaging techniques like 2.5D and 3D stacking are used for heterogeneous integration
- Vertically stacking chips, wafers, interposers and other devices requires high precision to align critical features
- Processes must combine high yield and high throughput, both of which are enabled by precise and high-dynamic motion control

Precision pick-and-place for device packaging

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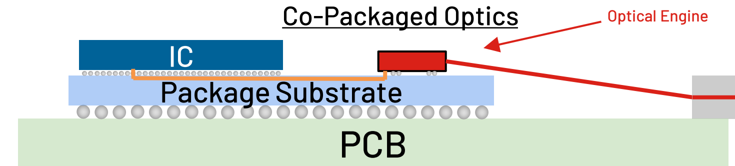
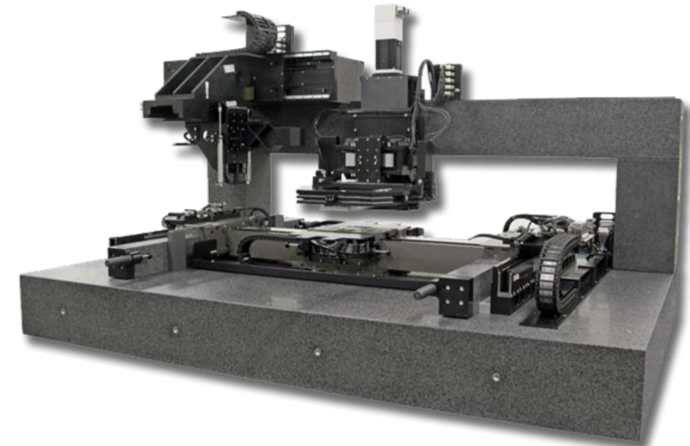
Heterogeneous Integration

Co-packaging EICs & PICs

- Methods like fan-out wafer-level packaging (FOWLP) have already been deployed for co-packaging
- Scalability remains a key challenge for heterogeneous integration processes
- Emerging methods like micro-transfer printing are being explored to increase throughput via parallel processing





10-DOF motion platform on granite for planarity-sensitive alignment

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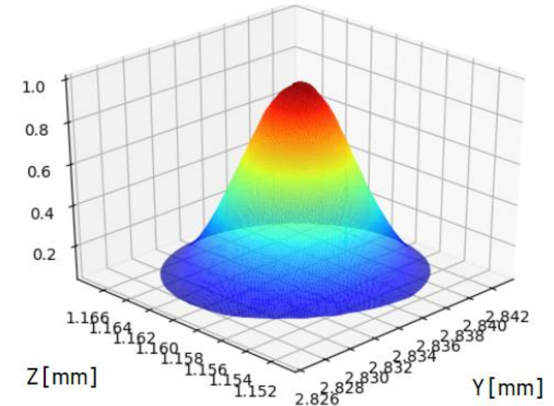
Alignment for Device Assembly

- Alignment processes for device-level assembly also require high precision, often in many degrees of freedom
- µm-level optical misalignments can create unacceptable levels of insertion loss
- Maintaining precise positioning during bonding processes can require closed-loop position & force control



Optical power signal measured across ~20 µm x ~20 µm range

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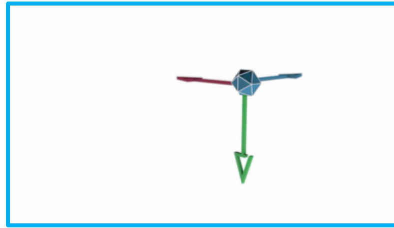
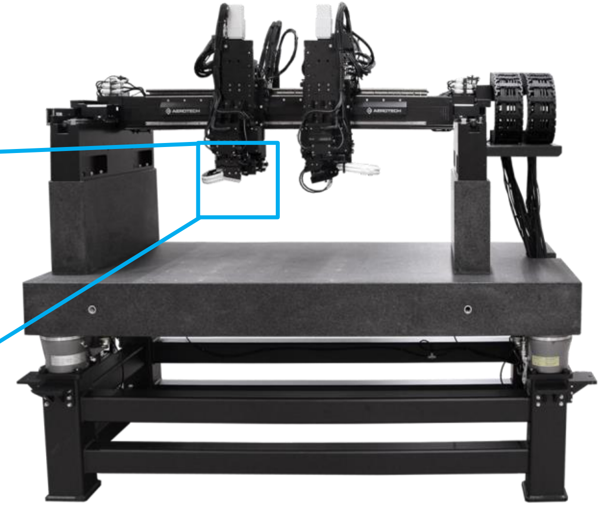
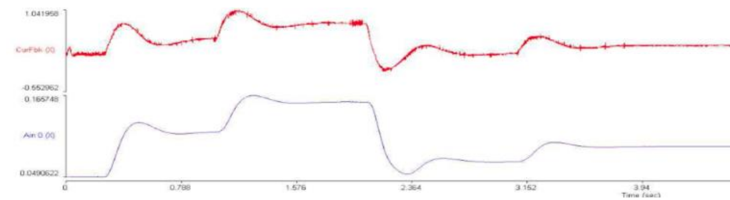
Alignment for Device Assembly





- Aligning components simultaneously requires multi-axis coordination
- Linear motor technology enables high dynamics with μm- and nm-level precision
- High-bandwidth force control loops ensure appropriate forces are applied during assembly

10+ DOF motion platform for optical device packaging

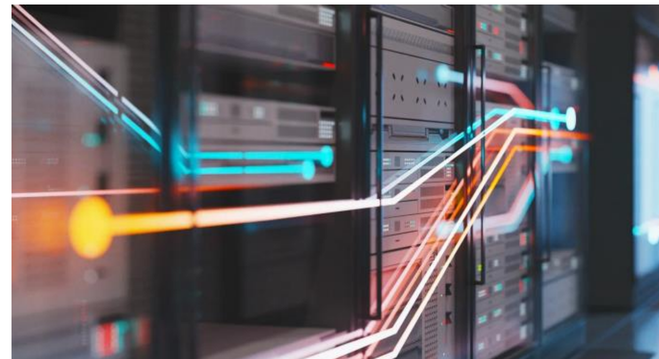


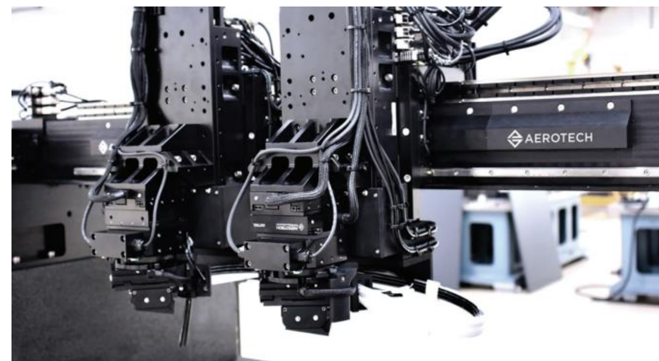
Closed-loop force control

Conclusion

Precision automation is critical to modern datacom infrastructure.

- Amplified by macro trends like AI & HPC, demand for data center bandwidth is increasing exponentially
- Paradigm-shifting technologies will be fundamental to addressing this demand
- Precision motion control is playing an increasingly important role in the manufacture & test of these technologies





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Questions?

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