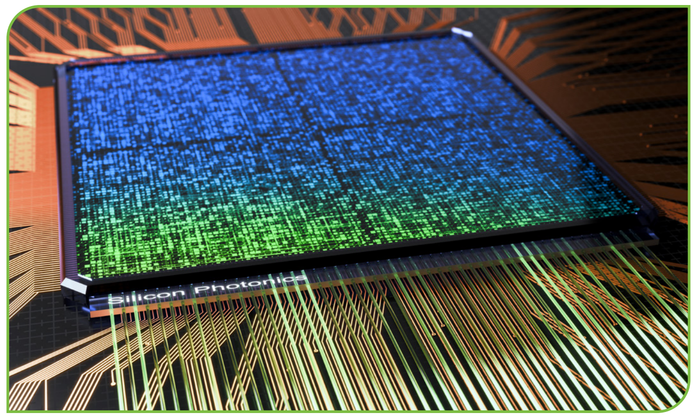
PRECISION ALIGNMENT IN PHOTONIC DEVICE ASSEMBLY AND TESTING

As photonic products become more sophisticated and highly miniaturized, the need for precision optical alignment during assembly and testing becomes increasingly critical. This is similar to how metrology becomes progressively more demanding in IC fabrication as circuit dimensions shrink and alignment tolerances tighten to support more compact advanced packaging methods



In the case of photonic devices, misalignments in optical coupling during assembly and testing can negatively impact system performance and reliability. It's not uncommon for these alignment tolerances to be in the micron or sub-micron range due to the small dimensions of the fibers involved.

This whitepaper explores the motion technologies that enable manufacturers to meet these demanding alignment requirements using two of the most important classes of current photonic products as examples. These are Photonic Integrated Circuits (PICs) and display systems for Augmented and Virtual Reality (AR/VR) headsets. It will review the requirements of these applications and the kinds of motion systems and associated software algorithms that can address their needs. It will also highlight some of the specific motion and positioning solutions from Newport that are most applicable for these uses.

PICs

Photonic Integrated Circuits (PICs) are at the core of many advanced optical systems, including telecommunications, data centers, and sensors. In the same way that a traditional silicon semiconductor wafer combines numerous individual electronic components onto a single substrate, PICs integrate multiple photonic components onto a single substrate. The use of photonic, rather than electronic, components offer significant advantages in speed, energy efficiency, and data capacity over traditional microelectronic components.

Just as ICs are interconnected electrically with wires or conductive traces, PICs typically interface with other devices by way of optical fibers or waveguides. And, in the same way that the ideal electrical interconnection has minimal resistance, the optimal fiber-to-PIC connection should have the lowest possible optical loss (or highest transmission).

There are several points in the PIC production process where optical alignment is required. These include:

Wafer level testing:

This consists of testing photonic components directly on the optical wafer before dicing and packaging. Testing at this point allows manufacturing defects to be detected at an early stage and yields to be maximized.

Typical tests include measuring insertion and reflection losses, verifying device functionality (ensuring that devices such as modulators, switches, or multiplexers are operating properly), optical resonator characterization, and dispersion and bandwidth measurements.

Fiber alignment:

This involves positioning input/output optical fibers precisely relative to the photonic components during assembly to ensure optimal light transfer and therefore minimize signal loss in the final product. This can be performed passively, using structures on the PIC to align the optical fibers. But superior results are achieved with active alignment. Here the fiber position is adjusted while the optical signal is monitored in real time.

Alignment between a single fiber and another optical channel has been performed for many years, but for PICs the task becomes more complex and sophisticated. Frequently several are held in a jig precisely aligned to each other. The first fiber is aligned to its source and then the set is adjusted to maximize the signal on the last fiber while maintaining the alignment of the first fiber. Once the proper alignment is found, UV cure epoxy is applied and the fiber set permanently bonded to the PIC.

Grating coupling testing:

Gratings are sometimes used to couple light in and out of photonic devices. These tests measure the coupling performance between a grating and optical fiber.

Optical transceiver testing:

In addition to insertion loss and coupling efficiency, transceiver testing may involve optical spectrum analysis, attenuation, total output power measurement, dispersion. and characterization of various performance parameters such as bit error rate (BER), jitter, and signal fidelity.

Assembly and packaging:

Here PICs may be interconnected with each other and various components such as lasers and detectors.

AR/VR Headsets and AR/VR glasses

AR/VR headsets combine high-resolution (typically stereoscopic) visuals and high-fidelity audio to produce immersive experiences for the wearer. The typical AR/VR device integrates multiple individual photonic components including microdisplays, waveguides, couplers and combiners, and sensors (which may integrate their own illumination). Precise alignment of these various elements relative to each other is therefore necessary to achieve the highest possible image quality, maximize field-of-view, and optimize brightness. For the sensors, the goal is to attain the greatest accuracy and longest range, and to reduce any latency in motion tracking.

Because AR/VR systems consist of so many separate components, there are quite a few alignment tasks performed in their assembly and testing. These include:

Optical Axis Alignment:

Some AR headsets rely on a beamsplitter to introduce an image projected from a microdisplay into the user's line of sight. This enables the display to be combined with the wearer's direct view of the real world. In this case, all the free-space optics in the system must be aligned to a common optical axis. Again, this may involve several individual components, including relay/projection optics and the beamsplitter.

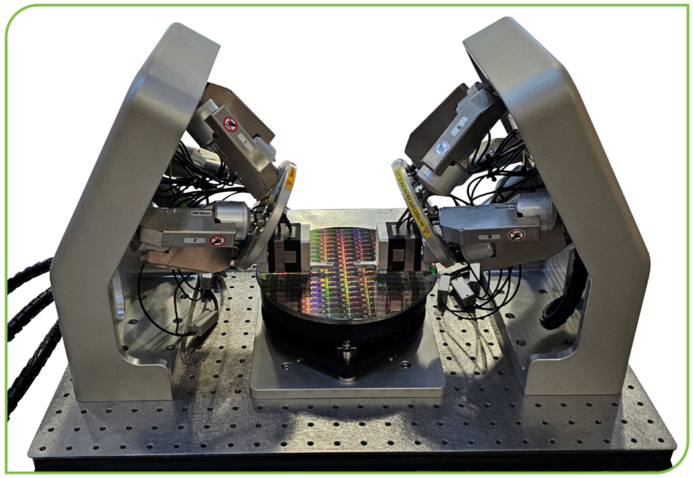
Display-to-Waveguide Alignment:
More advanced AR/VR systems use waveguides instead of beamsplitters to channel light from the display to the user's eyes. Aligning the display source to this highly compact waveguide is one critical task because it usually involves tight tolerances, and any errors can result in poor image quality. These might include blurring, color misregistration, or uneven brightness across the field of view.

Binocular alignment:
A key assembly task is positioning each display system so that it aligns with the expected position of the wearer's optical axis (defined as a line going through the center of the eye lens and fovea). This alignment must be consistent in terms of position and angular orientation. Additionally, it may be necessary to ensure a specific separation between the optical axes of the two displays (inter-pupillary distance).

The focus, field-of-view, and magnification of the two displays must also be closely matched. This is necessary to allow the user to comfortably fuse the individual left and right images into what appears to be a single image. Adjusting these parameters may require positioning different components or groups of components.

Eye-Tracking System Alignment:
Eye-tracking is more commonly employed in VR systems, as opposed to AR systems. In this case, the sensors responsible for tracking user eye movement must be aligned with the display and the lenses to ensure accurate detection.

External sensor alignment:
AR/VR headsets often include cameras or sensors to track user movement and the surroundings. This enables features like head tracking, gesture recognition, or real-world environment mapping. The alignment involves positioning the lenses relative to the cameras or sensors so that the sensor captures the image or data in the correct focal plane.



Production Testing Requirements

While the alignment tasks just outlined are diverse, there are still many common requirements among them in terms of both functionality and precision. For PIC assembly processes, alignment tolerances for linear position are usually in the micron or sub-micron range, and anywhere from ±0.1 µrad to ±10 µrad in terms of angular alignment. In AR/VR headsets, tolerances for display-to-waveguide alignment have similar values. Most of the other alignment tasks in AR/VR headsets are somewhat more forgiving than this; angular alignment tolerances for some of these might be in excess of 1 mrad.

An additional requirement in both applications is the nearly universal need for high throughput. Tasks such as fiber alignment must be quick and repeatable, as manufacturers strive to maximize throughput without sacrificing quality to obtain competitive costs. Achieving alignment with both the speed and accuracy just mentioned requires more than just precision motion hardware; it also relies on sophisticated software and algorithms designed to optimize the process. Whether testing PICs at the wafer level or aligning displays in AR/VR systems, the challenge is to quickly and accurately achieve "first light" (the point at which an optical signal is detected) and then fine-tune the alignment for optimal performance. This process requires an integrated approach combining advanced motion control systems with intelligent algorithms that can handle the complexity of positioning micro-scale components in three to six degrees of freedom.

In both PIC and AR/VR applications, the first step is locating the initial signal, a task often performed using algorithms such as raster scanning or spiral searching. These algorithms map out a search pattern that moves the components incrementally until a signal is detected. Once the first light is found, the alignment process shifts to optimization. Here, more refined techniques, such as centroid or hill-climbing algorithms, are used to adjust the positioning with sub-micron precision. This optimization minimizes signal loss and ensures the highest possible performance in data transmission for PICs or image clarity and tracking accuracy for AR/VR headsets.

Motion control systems play a critical role in enabling these alignment processes. For PIC testing, positioning systems often need to support multiple degrees of freedom, including both linear and rotational axes. The ability to control movement with sub-micron precision while maintaining stability is key, as even slight deviations can lead to significant optical losses. Systems must also be capable of operating at high speeds to meet production demands, especially in wafer-level testing environments where throughput is crucial.

In AR/VR applications, the alignment of optical components, such as microdisplays and waveguides, generally involves fewer degrees of freedom but still requires high precision, as any misalignment can distort the user experience. Here, linear motion systems are often sufficient, but they must still offer precise control to ensure optimal image quality.

Speed and precision are always in balance during the alignment process. Faster movement can reduce overall testing or assembly times, but without careful control, it risks losing the fine accuracy needed for successful coupling or image alignment. Motion systems must provide both – rapid movement for coarse adjustments and ultra-precise control for fine-tuning. The integration of feedback systems, which monitor the optical signal in real time, allows for continuous adjustment, ensuring that the alignment process is both fast and reliable.

Overview of Newport Motion and Positioning Solutions

Newport offers a wide range of motion control and positioning solutions that can deliver the combination of speed, accuracy, and stability required for cost-effective production testing and assembly tasks. By combining cutting-edge hardware with advanced software, Newport delivers versatile solutions that can adapt to the unique requirements of each application.

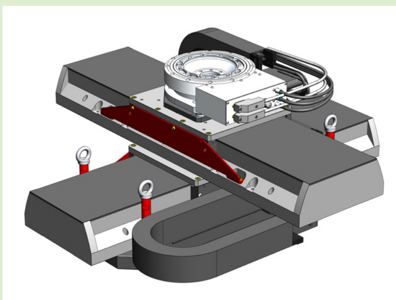
Because these diverse components can be combined in a virtually limitless number of ways, the system designer’s product selection task can seem overwhelming. The following examples show some typical combinations for the most common applications. They should provide some guidance on where to start when specifying a motion control system.

Photonic Integrated Circuits:

Wafer/die positioning

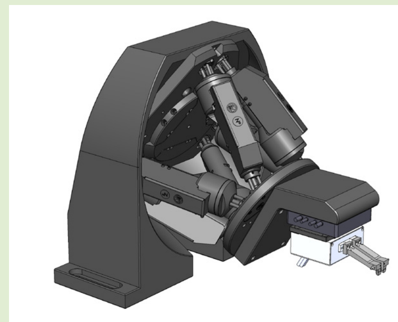
Combining two crossed IDL linear motion stages with a ZVR integrated vertical and rotation stage enables xy positioning over a large area, plus high-resolution z motion and rotation.

Components included here:
X: IDL225-400LM
Y: IDL225-400LM
Z-Theta: ZVR-PC



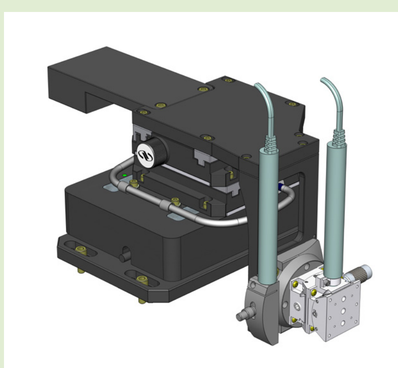
Silicon photonics testing

Hexapod: HXP50-MECA
Nanopositioner: NPXY100SG-D



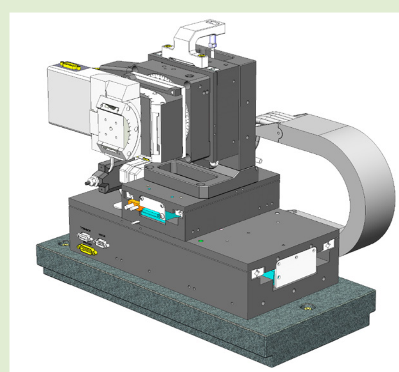
Optical/electrical probing

Components included here:
X: M-VP-25XL
Y: M-VP-25XL
Z: M-VP-5ZA
ThetaX: M-RS65 with TRA12CC
ThetaY: M-GON40-U with TRA12CC
ThetaZ: M-GON40-L with SM-13



Communication module optical alignment/ assembly

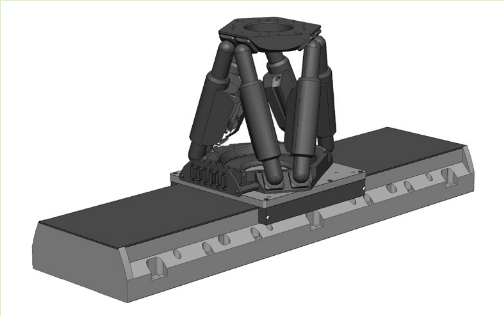
X: XML210-S
Y: XMS100-S
Z: XMS50V with pneumatic counterbalance
ThetaX: BGS50CC
ThetaY: URS100BCC
ThetaZ: BGS80CC



AR/VR/MR Tools:

Waveguide image quality testing

HXP200 mounted on top of IDL280-600LM



Head mounted display performance testing

Yaw: RGV160BL-S

Pitch: RGV100HL-S

Roll: RGV100HL-S

Software

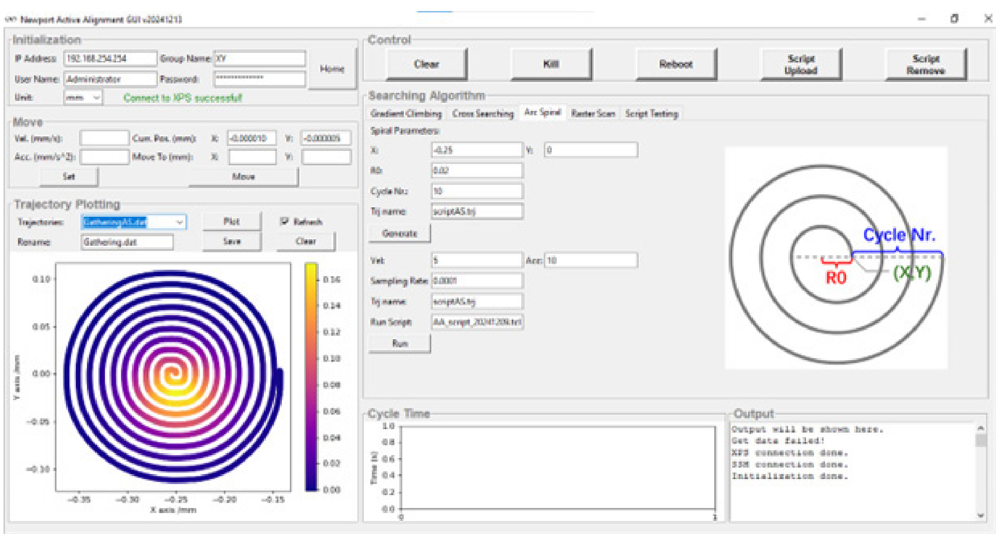
The hardware just described is only part of the solution that Newport provides. Our XPS motion controllers are equipped with sophisticated processors that incorporate preprogrammed optical alignment algorithms. These Photonic Device Search Algorithms (PDSAs) enable the optimization of different alignment tasks under a variety of conditions and can be used singly or in combination.

For example, some search algorithms work best for finding the first light (the periphery of a light beam) after which there are other algorithms available that are faster and more precise at reaching the peak power location. The choice of the second algorithm might depend on whether the beam has a Gaussian distribution or top hat profile with multiple peaks. Some algorithms can be used to profile both types of beams and can also be used in parallel. The chart summarizes these built-in PDSAs and indicates the tasks for which they are useful.

PSDA	Beam Profile: Gaussian or Single Peak	Beam Profile: Plateau or Multiple Peaks	Find First Light	Find Peak Power	Find Peak Power along Beam Axis (Z)	Stop when Threshold Reached	Max Number of Axes
Axis by Axis	•			•			6
Dichotomy	•			•			6
Escalade (Continuous)				•	•		3
Escalade (Square)				•	•	•	3
Raster		•	•	•		•	2
Spiral (Continuous)		•	•	•			2
Spiral (Square)			•	•		•	2

The XPS utilizes an Ethernet communications link and a web site as a Graphical User Interface (GUI) to access all its built-in software tools. This makes the XPS controller independent of the user's operating system. In fact, any networked device, based on any operating system, can access the controller through the internet. This allows remote control of the system, code development, file transfer, or diagnostics to be performed from any location. The various alignment algorithms just listed are available in the form of Application Programming Interface (API) functions that are executed through simple text commands.

This software integration is a key differentiator in Newport motion control systems. Our software not only controls the hardware but also provides real-time visualizations and data collection tools. These enable users to track and optimize the alignment process. With features like graphical interfaces and customizable algorithms, the software makes it easier to set up, monitor, and adjust the alignment in real-time. All this makes it easier to bring a process on line, to keep it functioning in volume production, and to acquire all the data needed to meet traceability and compliance requirements.



Conclusion

Precision alignment is the cornerstone of success in both PIC and AR/VR headset testing and assembly. And as these technologies advance, the demand for accuracy and speed in the alignment process becomes even more critical. Throughout this evolution, Newport will remain at the forefront, delivering innovative solutions that enable the next generation of high-performance photonic products.

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