Fast Alignment Systems
Speed Up Silicon Photonics Device Testing

New multi-channel optical alignment attacks throughput bottlenecks in silicon photonics wafer testing and packaging

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The 20th century has often been called the age of electronics, since the biggest changes in our lives were enabled by the rapid rise of semiconductor technology and the digital revolution that ensued. At the turn of the millennium, many proclaimed the dawning of the age of photonics, but when the bottom fell out of the telecom market, CEOs lost faith, investors got cold feet, and innovation was often put on the back burner. With the advent of the smart phone and the rise of streaming services and social media, things began to turnaround. Demand for data kept increasing exponentially and photonics was back in the spotlight. The National Photonics Initiative got members of Congress involved, and in July 2015 a new $600 million public-private partnership was announced by the Obama administration to help strengthen high-tech U.S.-based manufacturing. The stage was set for the next generation of devices, integrating electronics and photonics on a single chip.

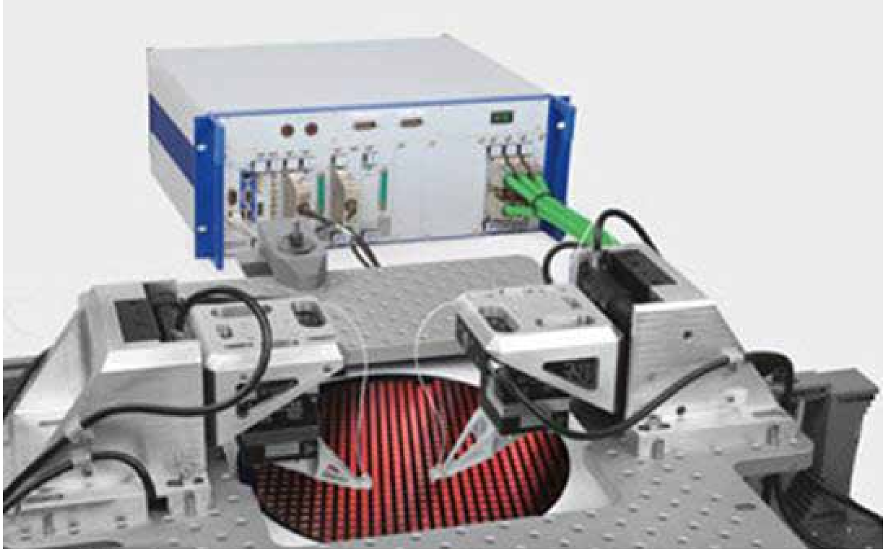


Figure 1: The double-sided FMPA (Fast MultiChannel Photonics Alignment) system with two XYZ hybrid positioners consisting of servomotor stages and a piezo scanner.

The challenge: convergence of photonics and electronics

The convergence of photonics and semiconductor design and fabrication is propelling both fields in exciting new directions.

Viewed grandly, this convergence into Silicon Photonics (SiP) is just another step in the over-arching trend of two decades in which the physical scale of photonic interconnects has steadily diminished:

a) Transoceanic fibers replaced satellite communications links, providing more capacity with lower latency;
b) Transcontinental fibers supplanted copper trunks, lowering costs and enabling digital data communications;
c) Regional photonic networks brought bandwidth and enabled interconnectivity to every corner of developed countries;
d) Metro photonic networks enabled dense connectivity for cities and industry;
e) Fiber to the home brought true broadband to neighborhoods.

And now, the escalating energy and bandwidth requirements of the cloud propel the trend further, with photonic interconnects emerging as the essential next step for data centers: photonic connectivity between racks, boxes in each rack, cards in each box, chips on the cards, and, soon, between cores in the chips.

PI's solution to fast SiP alignment automation leverages fab-proven controls and mechanisms as shown in configuration for planar test.

The new design and fabrication technologies that blend photonic and electronic devices on a chip are a boon for bandwidth, efficiency and functionality, but they pose fresh challenges for device testing. For example, the high costs of packaging even ordinary electronic chips routinely dictates 100 percent testing of many classes of chips, especially higher-value ones that are more challenging to package, such as microprocessors. This degree of testing prevents the costly packaging of bad product. Add photonic elements, and those packaging challenges magnify, increasing the importance of testing as early as possible in each device's manufacture.

Electrical testing of conventional microcircuits involves physically contacting un-diced chips on the fully-patterned wafer using electrode probe arrays. Aligning the probes to such chips to micron-scale accuracies is generally adequate, so vision technologies and conventional positioning control are sufficient for performing the probing and testing at sufficient speeds as to be economically viable.

By comparison, testing of photonic devices requires non-contact, nanoscale alignment between the device under test, and a probe fiber or other element. Meanwhile, final packaging alignments can involve multiple devices, each requiring nanoscale alignment to each other, often in multiple degrees of freedom. Today's devices, such as waveguide elements, often have multiple inputs and outputs, some or all of which must be aligned and held in a stable, repeatable configuration in order for work to proceed. Yet despite the exponential complexity and escalating resolution requirements of photonic probe-test and packaging, process throughputs must still be very high if production economic goals are to be met. And, of course, all such processes must be highly repeatable.

Photonic alignment processes: background information

Photonic alignment processes fall into two general categories: (1) rapid areal scans of one device versus another (such as a probe fiber) to build an overall profile of the coupling; and (2) the gradient search, which imposes a small patterned motion of one device versus the other, from which the path to the maximum optical power is deduced. Both aim to localize the mutual orientation at which coupled optical throughput is maximized, and both can be applied to transverse (XY), longitudinal (Z), and angular optimizations.

Gradient searches have the advantage of enabling tracking to prevent drift and to correct disturbances. They do require a clean coupling, or they might lock onto a local maximum. Fast scans are useful for determining the approximate location of the main mode of a coupling, enabling a hybrid approach where the gradient search is initiated within the vicinity of the global maximum, avoiding the local maxima entirely.

Since elimination of drift and continuous optimization are generally desired in photonics testing and packaging applications, the gradient search tends to play a central role in most implementations. Classical analog implementations of the gradient search were introduced in the mid-1980s and have remained essentially unchanged ever since. These have been popular in laboratory-class applications where their good speed, low cost, and flexibility is a good match. For production-class applications, however, a digital implementation is preferred since these are inherently limitable, with ev ery motion being the result of a calculation. Considering the multi-million-dollar value of fully patterned wafers, this is a key point.

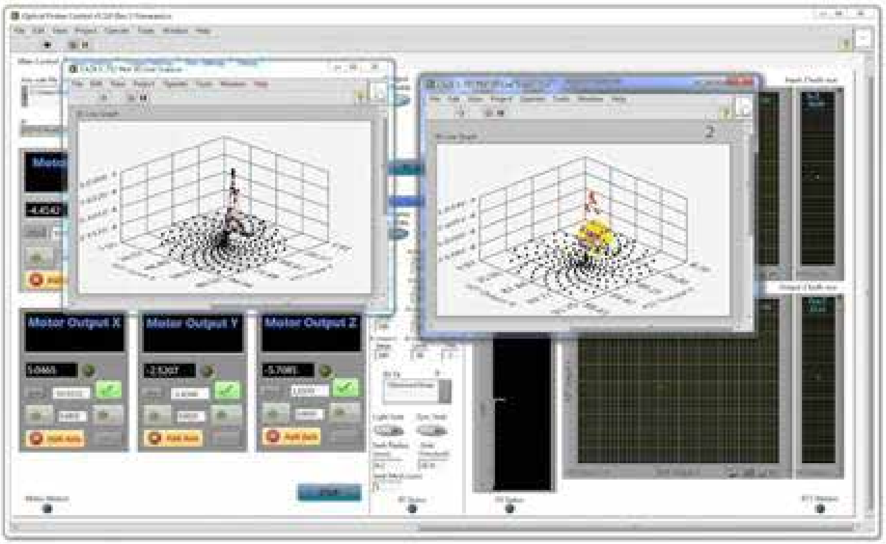


Figure 2: An example of real-time system-control GUI built on software libraries from Physik Instrumente, running a fast area scan on both sides over 100x100 micron capturing range. This takes typically between 0.25 and 0.7 seconds.

The first digital gradient search was patented in the early 1990s and has been a mainstay of photonics packaging automation ever since. However, it (like the areal scans) could only be applied sequentially to the couplings in an optical train. This sequential methodology multiplies the time required to align a device by some multiple of the number of inputs and outputs, with the multiplier depending on the degrees of freedom involved in each coupling optimization.

This loomed as an economic bottleneck for production of today's emerging, complex silicon photonics devices.

PI's broad, modular toolkit allows unparalleled functionality as shown in 6DOF double-sided planar test.

The breakthrough

A foundational breakthrough occurred with the introduction in the late 2000s of an on-the-fly version of the digital gradient search, CyberTrack, developed by Physik Instrumente, capable of performing entirely metrical and limitable alignment processes using continuous motion patterns. The alignment technique was also compatible with the astigmatic and asymmetrical coupling profiles increasingly prevalent in emerging devices. This in turn led to the ability to perform simultaneous, concurrent alignments and tracking optimization of multiple inputs and outputs to a photonic device, each in multiple degrees of freedom. The ability to align N inputs and M outputs in P degrees of freedom is now virtually independent of N, M, and P, yet the process remains entirely metrical and limitable.

The new NxM alignment optimization technology is automatic, transparent, real-time, and at the same time very easy to use and implement, and it provides fab-worthy alignment performance, repeatability, and speed.

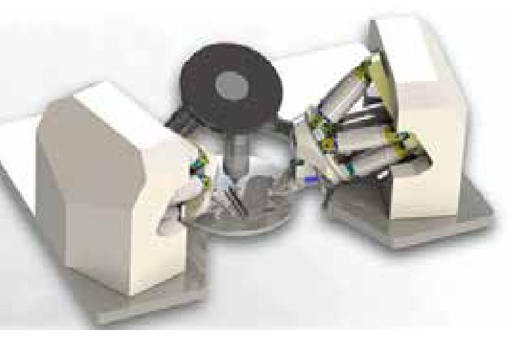
Figure 3: The FMPA fast alignment controller offers high-speed, integrated, firmware-based scanning and peak finding algorithms, automatic centroid fit strategies for Gaussian, tilted, top-hat distributions, and simultaneous real time tracking.

Quantum leap in speed: 10 times faster for sip production and packing automation

The latest generation incorporates the proven technology inside a new high-performance digital hybrid motion controller along with a faster

■ **Figure 4: This micro-hexapod 6-D aligner offers extreme flexibility along with very high dynamics, stiffness and stability due to its parallel kinematics design with extremely low moving masses. Another advantage of the hexapod design is the randomized pivot point, programmable with one single command.**

hybrid alignment mechanism. The hybrid piezo/servo-motor approach was employed to achieve the required coarse travel ranges without sacrificing stability, resolution or alignment speed. A performance improvement up to 10X was made possible because the scanning and alignment algorithms are embedded inside the controller's modular firmware – cutting out any communication delays between a host computer and the motion controller – and at the same time, stiffer and faster alignment mechanics along with a faster piezo scanner were implemented. Now fast, simultaneous alignment and tracking of multichannel couplings can be achieved in fractions of a second, enabling the fastest throughput for a spectrum of applications from undiced wafer to final package. The long-travel, closed-loop piezo scanner ensures reliable reproducibility.



■ **Figure 5: Wafer level alignment with double sided 6-axis hexapod aligners and 3D piezo scanners.**

Flexibility: 3 to 6 degrees of freedom, multiple alignment options

For complex parts, there is a hexapod aligner option to accommodate any application up to 6 degrees of freedom per coupling. Alignment options include a new multidimensional gradient search for aligning and tracking any number of input and output couplings, even if they interact. Scanning and modeling functionalities identify global maxima and accurately determine the centroid of quasi-Gaussian, tilted-Gaussian, top-hat, and tilted top-hat couplings at high speed. Typical alignment modalities complete within a few hundred milliseconds, and time for gradient search alignment and tracking is virtually independent of the number of couplings and degrees of freedom.

The advanced digital controller is complemented by high-speed coarse/fine XYZ aligner mechanisms. A large field, closed-loop, XYZ piezoelectric scanner with 1 nanometer resolution and a generous 100x100x100 micron nanopositioning field was used, covering more than 10 times the area of conventional scanners. The closed-loop approach eliminates hysteresis, drift, and greatly improves accuracy when characterizing beam profiles since the absolute position of all axes is always known and controlled.

Closed-loop, servo-precision, long-range stages provide 1 inch or more travel with 100 nanometer resolution and high, 20 mm/sec speeds. With this system, a typical full-field areal scan is complete in as little as 250 msec, and typical gradient search optimization completes within seconds for single-mode waveguide couplings on both input and output simultaneously.

Compatibility with modern and legacy fabrication automation computers

The new parallel NxM technology capability offers comprehensive advantages over traditional serial alignment. A high-level ASCII command set and high-speed TCP/IP, USB, and RS-232 interfaces provide universal compatibility, even with legacy fab automation computers. In addition, sophisticated dynamic libraries compatible with modern Windows, Linux, and OS X computers facilitate quick development of applications in any language.

Users demand flexibility and easy adaptability which is provided through extensive Windows LabVIEW libraries together with both source-code and compiled versions of an ActiveX-compatible graphical user interface utility capable of both fast, interactive input/output XY and Z optimization for waisted couplings, such as used when aligning waveguides to lensed probe fibers and also scriptable operation via MATLAB, Python, and other platforms.

The combination of advanced, fully-integrated functionality with fab-proven hardware and comprehensive software lights the path for high-throughput production of silicon photonics devices today and into the future.

PHYSIK INSTRUMENTE L.P.

Physik Instrumente L.P. (PI) is a leading manufacturer of nanopositioning, linear actuators and precision motion-control equipment for photonics, nanotechnology, semiconductor and life science applications. PI has been developing and manufacturing standard and custom precision products with piezoelectric and electromagnetic drives for over 40 years. The company has been ISO 9001 certified since 1994 and provides innovative, high-quality solutions for OEM and research. PI has a worldwide presence with 10 subsidiaries and over 750 staff.

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