Preparing for the mass production of photonic devices

Advances in active alignment approaches enable the efficient testing and assembly of photonic components.

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Over more than half a century, the pace of innovation in electronic communication and computing has consistently increased, giving rise to progressively smaller silicon microchips with enhanced processing power. This achievement is attributed to the exponential growth in the density of integrated circuit (IC) transistors – a development predicted by Intel co-founder Gordon Moore in 1965, commonly referred to as Moore's Law. However, there are inherent limits to reducing the physical size of silicon structures before quantum effects begin to influence their functionality.

Fortunately, photonics has complemented electronics by enabling the integration of miniaturized optical devices into various applications, from sensors in wearable devices to lidar and ADAS cameras in autonomous vehicles. Photonics has the potential to surpass traditional electronics by combining data throughput and efficiency with miniaturization, sparking a true revolution in the telecommunications and data communication sectors. To sustain this growth, it is essential to address the remaining challenges and bottlenecks in photonic device manufacturing. The implementation of additional automation solutions, particularly those ensuring fast and precise component alignment, is crucial to meet the demands of future advancements.

Limitations of labor-intensive device assembly

The assembly process of photonic devices typically involves the careful alignment, bonding and curing of a combination of light sources, fibers, lenses, gratings, and chips with array I/Os and active and passive elements. Each of these individual components must be accurately positioned to ensure the intended functionality and perfor-

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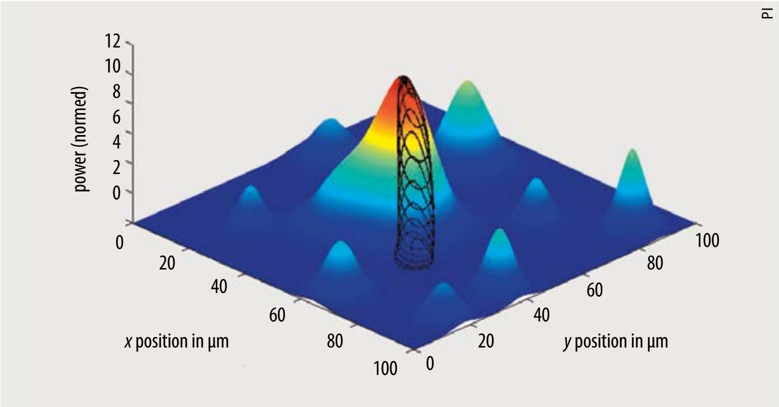

Fig. 1 Optical power distribution of a photonic component and a simulated hill-climb algorithm (gradient search).

mance of the final product, as even slight misalignments – on the order of less than a millionth of a meter – can severely impact device efficiency.

Despite technological advancements, many manufacturers still rely on manual alignment techniques. Beyond being time-consuming, these methods often require specialized labour that is both costly and difficult to find.

The manual assembly of complex devices can take up to twenty minutes, creating a significant bottleneck in the production process at the component-positioning stage. Traditional approaches to precision assembly (jigs, tooling, fixturing, etc.) fail to meet the stringent optical tolerances required. An alternative alignment strategy is necessary to precisely define component positioning.

Optical feedback to guide automatic alignment engines

A key characteristic of photonic devices is the direct correlation between their efficiency and the alignment of individual components. This means that the output strength dynamically changes in real time with component positions. Until now, the varying signal strength has served as a guide for iterative positional adjustment processes, resulting in a precisely aligned assembly. Today, as discussed below, novel technology allows these processes to be performed in parallel, typically reducing process times by 99 %.

To assess component drift, fluctuations in photonic output strength can be monitored during the gluing and curing processes. However, manually performing this method on complex devices with numerous inputs and outputs becomes impractical. Optimizing one connection can result in movements – physical or optical – affecting others, necessitating constant readjustment to achieve global consensus. An automated solution is essential to address this challenge, enabling a practical production process that eliminates time-consuming back-and-forth adjustments.

Automating the adjustment process involves closing the feedback loop between device output and positioning hardware, allowing intelligent software solutions and control modules to handle fine-tuning. These systems utilize areal scan algorithms to characterize the assembly, identifying the approximate location of peak photonic output. Multiple gradient searches are then conducted to precisely determine the global optimum. Specialized piezo nanopositioning devices, capable of adjusting several connections simultaneously, guide the components into perfect alignment in an innovative process known as active alignment. Integrated features, including compensation factors, eliminate the need for constant iterative readjustment. Complete

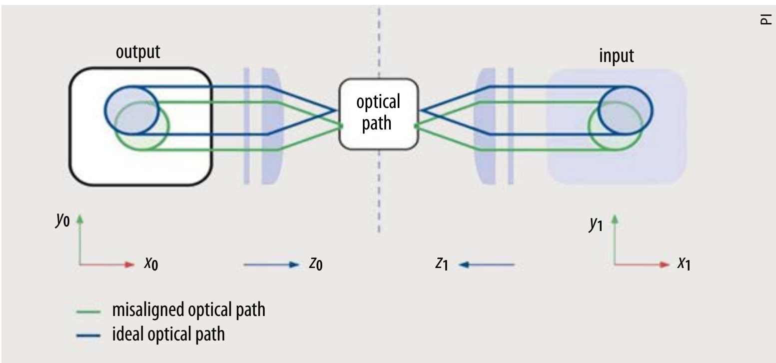

Fig. 2 Testing and packaging modern photonic devices can pose significant challenges across multiple degrees of freedom. The alignment of multichannel devices, such as fiber-optical arrays, used to be a slow and repetitive process until modern parallel algorithms were developed.

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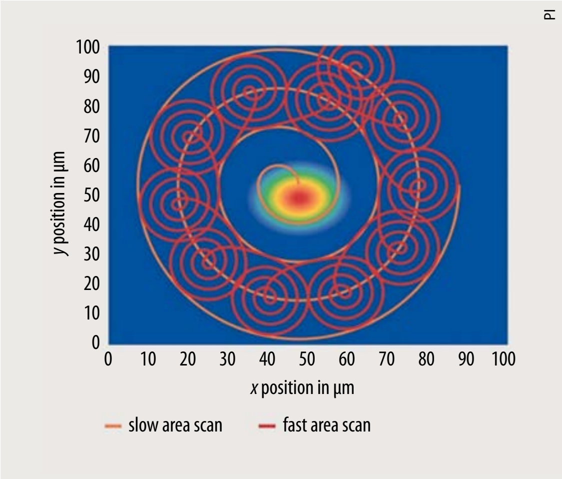

Fig. 3 Optical feedback is crucial for automated alignment. A fast, traditional method of finding "first light", followed by a gradient search for optimal coupling efficiency, is shown here – a double spiral scan using a hexapod/piezo approach. The hexapod performs a coarse spiral scan (coarse meaning single-digit microns), while the piezo stage fills in the gaps with high-speed submicron scans. Both fine and coarse scans can be performed simultaneously.

modular solutions are now available, significantly reducing photonic device manufacturing times while maintaining sub-micron precision. For instance, Physik Instrumente's Fast Multichannel Photonic Alignment (FMPA) technology can perform multiple alignments, such as inputs and outputs, across multiple degrees of freedom in parallel, reducing assembly time by a factor of one hundred or more.

Solving the first light capture problem

Since alignment is the primary cost driver for photonic device manufacturing, addressing it has been PI's focus since the award-winning Fast Multichannel Photonic Alignment (FMPA) technology in 2016. By optimizing multiple channels, components, and degrees of freedom in parallel and achieving coupling repeatability to typically 0.02 dB, FMPA reduces the time and cost of manufacturing and testing photonic devices while improving yield. However, before the optimization process can begin, an optical signal above the noise level must be detectable – a process called first light capture. This step is particularly time-consuming in devices with inputs and outputs, where both sides must align to achieve even a threshold amount of coupling. Finding first light has historically been a time-consuming procedure in all industrial photonics alignment applications, including wafer probing and device packaging.

A breakthrough has been achieved in form of a novel, built-in search-and-alignment algorithm (patent pending) that promises to revolutionize this field. The algorithm, called PILightning, runs embedded on PI's advanced controller. It enables highly dynamic mechanics, such as piezo scanners or direct-drive air-bearing stages, to achieve significant production-economics gains over previous first light search algorithms. This new process is fully automated and virtually instantaneous, eliminating the need for extensive calibration or manual intervention. PILightning is based on a new search method with integrated AI-based real-time executive functionality. It replaces fine-pitch scanning with high-frequency data sampling, significantly increasing alignment speeds. It drastically reduces the time required to acquire first light in single- and double-sided couplings and in loopback (omega) waveguide configurations.

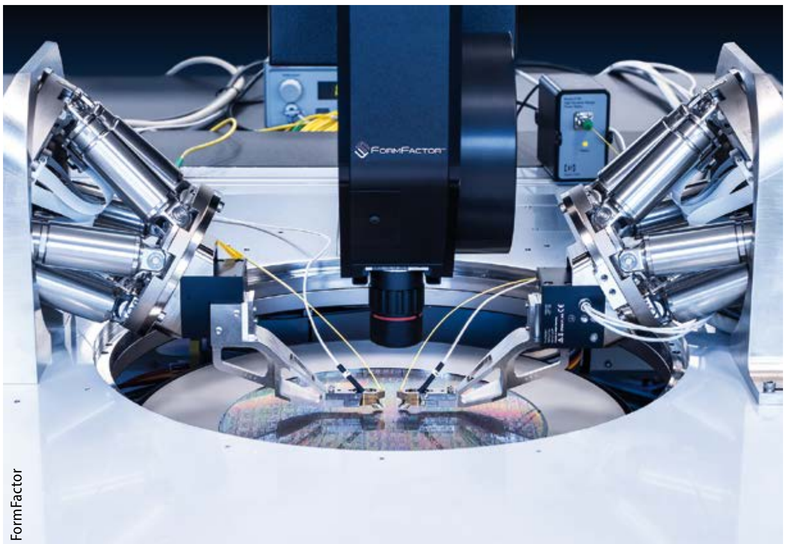

Fig. 4 The F-712 double-sided, 18-axis fast multichannel photonics alignment engine enables rapid NxM alignment of SiP devices in wafer probers. The hexapods provide six degrees of freedom, while a compact 3-axis piezo scanner achieves nanometer resolution and scanning frequencies up to 100 Hz, ensuring the fastest possible alignment. Cascade Microtech's pioneering CM300xi photonics-enabled engineering wafer probe station integrates PI's Fast Multichannel Photonics Alignment engines for high-throughput, wafer-safe, nano-precision optical probing of on-wafer silicon photonics devices.

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Fig. 5 A PILightning-algorithm-enabled dual-sided, air-bearing-based alignment system.

Once first light is detected, the FMPA fast gradient search algorithm takes over, utilizing real-time feedback control to swiftly optimize alignment in parallel across degrees of freedom and channels. Depending on the application, a tracking algorithm can also be activated to maintain maximum coupling efficiency – important, for example, during curing situations.

Modular solutions based on multiple drive technologies

The photonics market is advancing rapidly, with substantial growth projected in numerous sectors incorporating this technology over the next decade. Anticipating devices with hundreds or even thousands of individual components and connections, manufacturers will require parallel optimization, making active alignment the optimal choice to meet production demands.

Additionally, as photonic devices gain traction across various sectors, the development of increasingly specialized devices will require customised production processes. Manufacturers aiming to stay competitive and adapt to evolving demands need flexible combinations of hardware and software that can be easily reconfigured.

In addition to "monolithic" hexapod-based 6-axis alignment engines, modular alignment solutions – exemplified by those developed by PI – are characterized by the flexibility and scalability required for production operations. These solutions include friction-free air-bearing-based motion systems that require zero maintenance and provide superior speed and longevity, as well as linear and torque motor-driven solutions with precision mechanical bearings, and economical systems based on traditional screw drives and stepper motors.

Common to all these modular systems is a high-performance EtherCAT-based motion controller with embedded advanced alignment routines and an integrated high-speed optical power meter, providing a quick path to success.

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