Yield improvements depend on choosing the right approach

Successful implementation of automation systems for photonics components requires scrutinizing technical and business-related factors such as system-performance characteristics, hardware/software interfaces with production equipment, and even vendor experience and installed base.

Implementing automation in the testing and assembly of photonics components is a necessary step to achieve the yield improvements and cost reductions required for future telecommunications applications. Moving from the current state of largely manual test and assembly to full automation, however, presents several challenges.

One of the most significant roadblocks to progress is that few current-generation products were designed for automated manufacturing, and most manufacturers have not sufficiently characterized and stabilized the assembly and test processes to allow full automation. This makes proper identification and specification of the most critical system-performance parameters difficult or impossible. Another issue is whether or not the end-user demand exists to justify large-scale production automation.

Given these circumstances, the primary requirements of a successful automation strategy include matching the automation level to the current state of production, as well choosing an approach that is both flexible and scalable as product mix shifts and volume increases.

**FIGURE 1.** Spatial power distribution of a single-mode-fiber coupling shows less than 0.01 dB attenuation within ±150 nm of peak position. System noise accounts for small perturbations near the peak of the curve.

**Performance requirements**

Most photonics assembly tasks involve the relative alignment and assembly of two or more optical components. Examples include fiber pigtailling of source or pump lasers, mating fiber arrays to planar waveguide structures, or mounting collimating optics or isolators in free-space optical trains. If an automation system is to be of real value, it must be flexible and capable of performing tasks of this type reliably, repeatably, and cost-effectively. So what are the system characteristics required to meet these performance and reliability requirements?

The most basic function performed by such a system is precision alignment. Unfortunately, confusion often arises in specifying alignment system requirements and actual performance. It might seem that the best alignment engine would be the one with the highest specified resolution. But this assumption ignores other critical factors. Resolution is defined as the smallest position increment that a motion system can detect and display. This value is primarily determined by the encoder used to measure position, however, and does not guarantee reliable motion output. A far more important parameter is the minimum incremental motion parameter (MIM), which is defined as the smallest movement a positioning device is actually capable of delivering reliably.

These two terms are not equivalent because a variety of thermal and mechanical effects, such as hysteresis, sticktion, and backlash, limit a system from making a minimum incremental move equal to the resolution. In fact, for some positioners, display resolution is as much as an order of magnitude smaller than the minimum incremental motion. Thus, when defining or selecting a positioning system, the MIM is the most important parameter. For the most demanding photonics automation tasks currently being performed, a minimum incremental motion of about 50 nm is required—50 nm of MIM at the stage results in a typical variation in coupling efficiency for single-mode fiber-to-fiber alignment of approximately 0.01 dB at the fiber, taking into account noise contri-
butions from all elements within the system (see Fig. 1).

Other system qualities of practical importance in a photonics automation environment include load-bearing capacity and travel range. Load capacity is important because tooling can often be heavy and is frequently used in a cantilevered mode, which places additional strain on the stage bearings. Similarly, long travel (in the 25- to 100-mm range) is also required to enable the system to work with a wider variety of components, and facilitates scanning and alignment over large areas or multiple channels.

Software

Another area of tremendous practical importance is the system software because it determines how easy the set-up and operation of the system will be. It also establishes how, and to what extent, the tool can interface with other production hardware and software systems up- or downstream in the manufacturing process. In terms of the software user interface, the system should be simple enough for operation by production-line personnel and contain safeguards to prevent incorrect commands from being executed. It should also be capable of issuing alarms if any manufacturing problems arise.

For the process developer, the software should incorporate a library of pre-engineered process and instrument control routines; the developer can simply string these together to create sophisticated, automated routines (see Fig. 2). This can also be supplemented with a programming language or interface that allows customized routines to address user-specific needs. Ideally, the software is based on an open architecture to facilitate integration with other third-party instrumentation or user-developed software applications. The operating software should also provide for migration to higher levels of automation as production demand increases to save the user’s investment in process development and operator training.

For many manufacturers, instrument software will also be required to interface with existing enterprise software. Statistical process-control and manufacturing-execution system (MES) software, for example, can be used to implement device traceability throughout the production line and to collect statistics for process control and yield management purposes.

Beyond basic performance parameters are the system reliability, availability, and maintainability (RAM) attributes, which ultimately govern whether a given system is economically viable and attractive. These factors can be difficult to assess, and it is wise for the consumer to explore exactly how each vendor has arrived at its published specifications, including the type of reliability testing performed, the number of systems already out in the field, and the demonstrated reliability characteristics of these systems. Another important consideration is whether the vendor has analyzed past failure modes and redesigned its systems accordingly.

Economic implementation

Implementing production automation often involves more than the purchase of a single machine. Automation is typically phased into a production line, for example, focusing in the early stages on those processes with the highest variability, most repetitive tasks, or extremely high levels of precision, like optical alignment. The next phase might include automating more of the bonding or materials-handling processes. In the final implementation, robotic parts-handling equipment could be introduced for complete, unattended operation. Systems introduced at the early stages must provide a clear migration path to preserve the investment in capital equipment, as well as noncapital expenses in areas (such as tooling, training, and process development) as production needs evolve.

It is also desirable to find a single vendor that can supply multiple process solutions. This reduces risk by guaranteeing interoperability throughout the line, minimizes operator training and support requirements, and provides a consistent human interface and connectivity to the MES system (see Fig. 3).

Finally, it is the ability of the equipment vendor to understand the consumer application and supply package design and qualification services, in addition to hardware, that result in a true automation solution that can be successful in volume production. The economics of implementing automation become further enhanced if the vendor can develop a process and do small pilot runs in its own plant before delivering equipment. This enables the consumer to fully assess and validate an automation process before committing to large capital expenditures.

In the end, success requires an initial understanding of the key process variables in order to prioritize where and at what level to automate the manufacturing process. Critical system attributes to specify include incremental motion and bidirectional control (for alignment), system RAM (to ensure reliability and availability), and flexibility in both hardware and software to address different applications, evolving processes, and increasing volumes. Design-for-automation services, fixture design, process development, and pre-sales system validation via prototype and pilot runs will reduce risks and assure a smooth transition and a rapid payback.

![Figure 2](image1.png) Fully automated photonics production tools include parts-handling capabilities for use in integrated production lines or islands of automation. This automated laser-diode characterization system loads parts from Auer boat magazines and replaces them in output magazines after testing and sorting.