Measure twice, attach once

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Component and device characterisation is an important driver of higher yields and lower costs for optical component manufacturers

Huge product/process technical hurdles must be overcome in optical device manufacturing to achieve the necessary repeatability in optical component assembly. Product and process development must march down a fast path to deliver the operating and economic performance needed for today's optical component manufacturers to be successful.

Optical component architectures are driving down two somewhat independent paths. The semiconductor model points to integrated optical structures that scale to high performance and low cost in large volumes. The hybrid approach is to integrate multiple electro-optical functions in a single package. Both paths seek to deliver on three goals: order of magnitude performance gains, six sigma yields, and large-scale production. Accomplishing all three goals is essential. From a process standpoint, we have a lot of work to do. We are starting from largely manual, non-repeatable assembly processes with insufficiently qualified sub-components and assembly performance that too often falls short of design goals.

SUB-MICRON REPEATABILITY IS ESSENTIAL

An undeniable obstacle in this evolution is repeatable assembly precision. Required tolerances for optical alignment and assembly of optical components are tighter than any other assembly process in any other market. Semiconductor assembly tolerances are about 10µm. Automotive tolerances are as tight as 5µm. Optical attachment tolerances in photonics are as tight as 0.2µm. This is true for monolithic and hybrid architectures, passive and active devices. Few, if any, volume-manufacturing markets currently assemble devices to sub-micron tolerances. There is little established, transferable know-how that could accelerate the march to six sigma yields and low cost.

Sub-micron accuracies add new control dimensions to assembly. Temperature control is essential in the sub-micron world. Electrical and mechanical noise (vibration) is a significant source of process non-repeatability as well. Error budgeting is essential because so little error is allowed. Manufacturing processes must be developed in parallel with product designs. The quest to understand and control non-repeatability requires new precision tools to see and understand these incredibly small numbers. Finally, the know-how gained in the laboratory must be readily transferable to the production floor.

Systematic product and process characterisation is an essential ingredient in reaching these goals. Characterisation is the careful, accurate measurement of key process inputs and outputs of align and attach systems. Typically, characterisation is accomplished with production-grade, high-precision, highly repeatable servo-controlled equipment tailored to the specific needs of a process and product. More than merely inspection or test equipment, characterisation equipment must acquire and log process data – geometric or optical – to feed subsequent part, trend, and cause/effect analysis. Leading-edge manufacturers are measuring the sources of variability in optical system assembly so they can define and implement design refinements, process improvements, and process controls with the goals of simultaneously improving process speed and repeatability. Higher repeatability results in faster processes, higher performance and higher yields. All of which lead to lower prices.

The following examples illustrate the challenges of part/process variability and the role of characterisation in continuous improvement.

FIBRE ARRAYS

Active alignment of one fibre to another is becoming fairly straightforward. Alignment of fibre arrays to planar light circuits (PLCs) such as AWGs present a number of interesting challenges to the manufacturer, however. The PLC is comprised of a number of light channels – as few as two or as many as 80 today. Channels are spaced at a standard distance – typically 250µm – in a horizontal plane. Manufactured with semiconductor processes, the variability in location of those channels is typically under one micron.

Manufacturers will want to optically couple the PLC with a fibre array, typically produced by a different manufacturer in a different location using similar but different processes. A silicon v-groove fixture, produced with lithography methods, will locate each of the array fibres. The v-grooves have both vertical and horizontal errors from perfect geometric fibre location. The fibre introduces additional sources of error in both the cladding diameter and core concentricity. The tolerance on fibre diameter is nominally ±1.0mm, while the core-clad concentricity is on the order of 0.5mm. Each channel from 1 to n has identical error sources (but different errors) with typically normal distributions. The result is an extremely complex system with significant channel center errors both horizontally and vertically. Figure 1 shows typical horizontal/ vertical deviations for a 16-channel fibre array.

Alignment of planar light chip to fibre array with repeatable coupling efficiency across all channels is impossible without additional process control. Figure 2 shows a typical insertion loss, by channel. Careful understanding of system component geometric errors though characterisation processes builds understanding of achievable coupling efficiencies at the system level. Furthermore, it can predict system performance for a given device pair, absent higher precision parts.

LASER DIODES

Semiconductor laser components are some of the highest volume parts currently manufactured for optical communications networks. Manufacturing processes have benefited from experience in industrial and medical applications, driving part-to-part consistency to higher levels than other components.

Laser components do exhibit significant differences in performance, however, from one part to the next. Due to a variety of reasons, lasers produce very unique output signatures at a local level, almost like our own fingerprints.

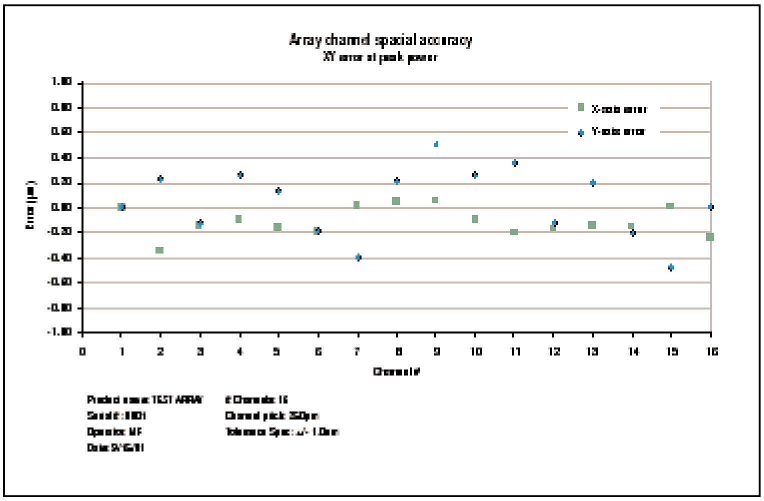

Figure 1. Example of optical channel geometric deviations from nominal in a 16-channel fibre array

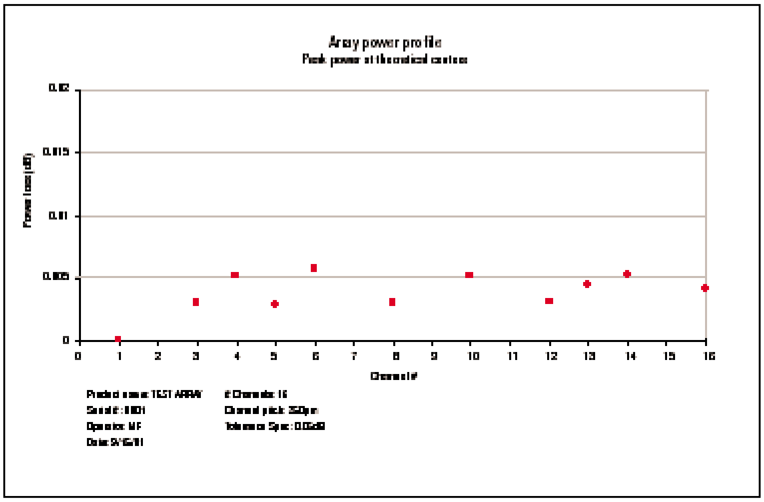

Figure 2. Insertion losses due to geometric deviations in Figure 1

This variation can produce coupling challenges as well as assembled device performance/ yield problems.

Global and local characterisation of laser output early in the manufacturing process improves process understanding and production yields. At the simplest level, this can be a go/no go test of performance against predetermined output parameters such as output power. More sophisticated algorithms map the laser output. Local and global peaks can be mapped and measured (Figures 3 and 4, respectively). Alignment problems can be isolated independent of global output problems prior to assembly. The experience gained by 100% inspection of diode components can be used to track component performance as manufacturing

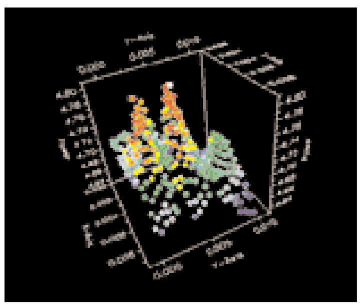

Figure 3. Global output profile for laser diode

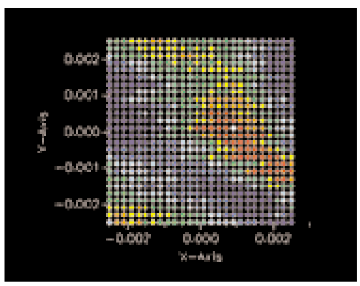

Figure 4. Local output profile for laser diode

processes are adjusted and improved. Like the fibre array example earlier, the

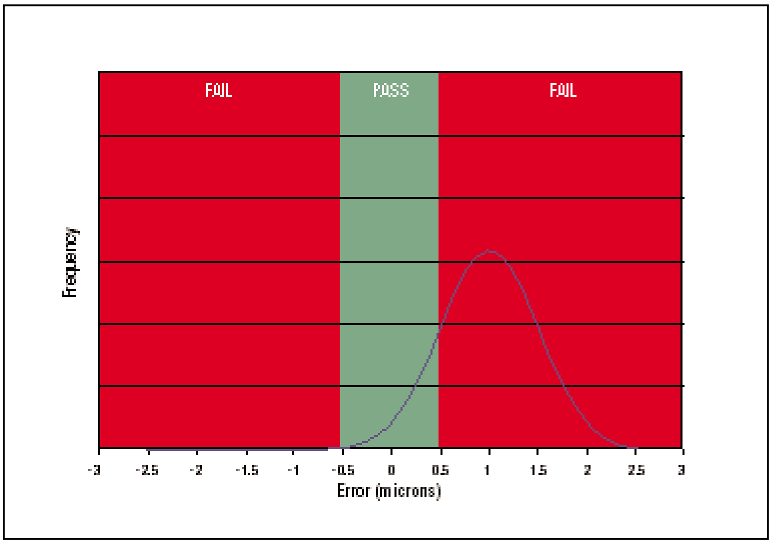

Figure 5. Attachment geometric shift in laser welding

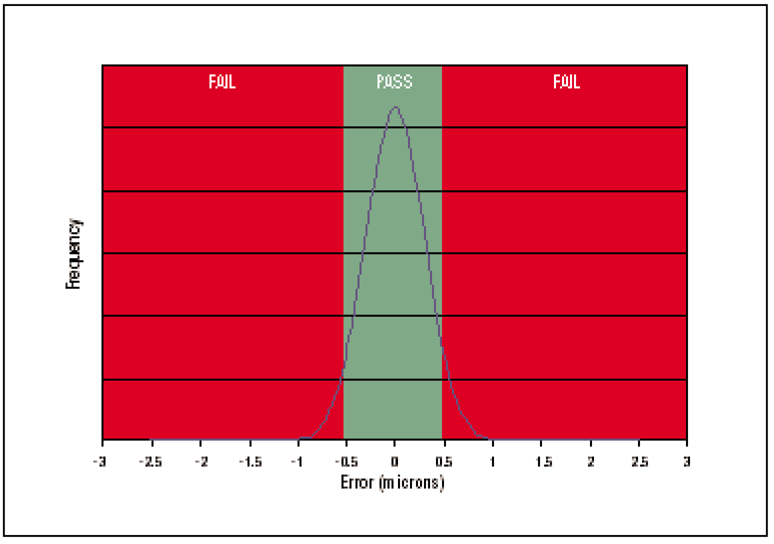

Figure 6. Ideal attachment process repeatability

high power microscope opens our eyes to component issues that affect system performance in a meaningful way.

HYBRID ASSEMBLY

Both active and passive components are trending towards hybrid architectures. The laser diode of yesterday is being packaged with a modulator, collimating lenses and focusing lenses into transmitters and receivers today. Tomorrow, dozens of tunable transmitters may be packaged with PLCs and VOAs into DWDM modules. The goal is fewer components, lower packaging costs and higher efficiency.

Unfortunately, our ability to design these devices outstrips our ability to produce them to high yields quickly and economically. Multiple parts must be actively aligned prior to attachment as part of the yield recipe. Attachment must be accomplished with an acceptable post-bond shift in alignment location or be adjusted later (adding cost). The shift from manual stages to servo-controlled alignment systems helps in process accuracy and repeatability. However, active alignment is but one small element in the complex systems required to attach fibre and bulk-optical devices into a hybrid structure.

Attachment processes introduce errors. Every weld, solder, or bond attachment introduces a geometric shift in alignment from the pre-alignment location. Figure 5 is a typical distribution of shift for attachment processes. Manufacturers currently invest in clever schemes to compensate for shift and scrap the assembled devices that fall short. Realignment of welds, whether mechanically or thermally, improves yield, but at an intolerable cost. Re-flow of solder joints can statistically yield an acceptable coupling, but it may take ten or more reflow iterations. Adhesive bonding is often shunned as an attach approach because realignment is difficult. Few assembly tools in use today collect the shift data necessary to ferret out cause-and-effect. The measurement of shift displacements as a function of other process variables is simply not done accurately and systematically to yield quality diagnostic data on manual and early stage automation equipment.

Component manufacturers are now implementing more sophisticated, high-accuracy servo-controlled characterisation tools to automatically gather shift data in the lab. In manufacturing, new assembly tools incorporate the inherent process repeatability and data gathering functionality to capture process data on each attachment. The result is a growing body of data and knowledge on shift relationships that, over time, will yield process performance improvements as illustrated in Figure 6.

SUMMARY

Accurate product and process characterisation is essential to improving process repeatability, yields, and optical component costs. Achieving high speed, sub-micron optical assembly tolerance requires continuous incremental improvement in process understanding and control. Automated, highly repeatable characterisation tools must replace manual and other non-repeatable methods to build this body of knowledge. Careful, accurate process measurement will, over time, yield continuous improvement in yields and process speed, resulting in more economical deployment of optical networks. ●