Enter the Solution Provider
Alignment at the Nanometer Level

Galen D. Powers and Sid Ragona
EXFO Burleigh Products Group

Introduction

Call it the Photonics Paradox. The prolonged slowdown in the telecommunications industry could prove to be a catalyst for automation in photonics component manufacturing. Indeed, reduced demand has created pricing pressure on optical components. The few buyers in the marketplace are necessarily demanding significant discounts on products. This new market reality, in turn, is forcing component manufacturers to review their assembly processes in efforts to lower costs, increase throughput and improve yields. Enter the solution provider role for makers of automated photonics component assembly equipment.

The well-established semiconductor and electronic component automation industries provide somewhat useful models for the fledgling photonics component manufacturing industry. There are, however, two major differences in the manufacturing processes. First, photons do not travel like electrons; they must be guided. Each connection must have some degree of alignment — up to the nanometer level — to achieve minimal photon loss.

Secondly, production volume and component standardization are quite different in the semiconductor/electronic component industries versus the photonics component industry. Without the benefit of volume, costs have to be reduced. Analysis by others has shown that the low cost path is yield improvement[1]. A major contributor to yield improvement is some level of automation. At the base of the all-optical needs pyramid is the capability to align and process optical elements into photonic assemblies.

Market Picture

Compared to the semiconductor and electronic industries models, photonics is in the early part of its manufacturing evolution and now is experiencing the volatility that has been characteristic of the semiconductor world. Semiconductor electronic equipment manufacturers periodically experienced book-to-bill ratios gyrating from 1.5 to 0.5 and back. Since the bursting of the telecommunications bubble, the marketplace rapidly shifted from an excess of money, people, demand perceptions and little attention to costs to low demand but extreme pressure on manufacturing cost for performance. With excess people and money, companies were able to spend resources on expanding intellectual property and span of control. Then the world changed, as the *Wall Street Journal* tallied elimination of more than 500,000 telecommunications jobs since late 2000[2]. The surviving companies are forced to concentrate on the technologies that directly support their products and customers.

One ramification of the recent market change is that the industry has less need for equipment and more need for solutions. Companies no longer have departments responsible for transforming equipment and instrumentation into production lines. They have product development groups that need to fabricate and characterize their prototype products. They have production groups that need to ship reliable products at a fraction of the costs of the recent past. Because volumes currently are very low and technology is evolving so rapidly, production may not even have dedicated lines. It is very difficult for traditional process improvement approaches to wring out costs in this model.

Similar to semiconductors, at this stage of evolution process yields for photonics assemblies are very low. Whether the basic costs arise from huge capital outlays, high material costs or high labor content, low process yields magnify the effect because of the high cost of the scrap. The high scrap rate creates an artificially high demand for material and capacity that gradually adjusts as yields improve. Projections need to accommodate this intrinsic damping of apparent demand. Contrary to the semiconductor model, there does not appear to be extremely high volume potential for any particular assembly. Potential relatively high volume is further diluted by the many options available. The market has not standardized yet.

In the semiconductor past, process development engineers used time and product volume in their successful efforts to reduce the costs. They reduced the noise of the manufacturing system and established cause and effect relationships. The optical assembly industry has the need to lower costs but does not have the volumes of the semiconductor world. One process development approach is to analyze the fabrication systems with an objective of some level of automation that provides extremely flexible systems. These systems must handle relatively low volumes, rapidly changing product and technology, and a shared R&D — manufacturing milieu. Enter the solution provider instead of the equipment vendor.

Solutions

Suppliers to this market are recognizing that they have to provide solutions. The solutions need to meet R&D requirements for alignment of optical elements to characterize and bond the rapidly changing final assemblies. The solutions need to be shared with or readily transportable to manufacturing. Since the products and technology are evolving quickly, a high level of flexibility is needed but without the cost implications normally associated with highly flexible processes. Solution designs must draw upon a wide range of traditional technologies from motion control, alignment systems, bonding systems, optical test and measurement, and optical waveguide operation. Finally, or paradoxically first for the customer, the solution must meet the customer’s need for a working assembly proven by optical performance.

Fundamentally the solution provider must know how to manage photons. This is a major deviation from the semiconductor model, which dealt with electrons that follow paths of least resistance. Photons tend to follow straight paths unless reflected or refracted, hence alignment of three axes and three rotations [six degrees of freedom or DOF] can affect their flow and loss. Understanding wave propagation in traditional optical waveguides, such as multi-mode and single mode fiber [SMF], and solid state planar lightguide circuits [PLC] is essential. Understanding optics, optical test and measurement instrumentation is critical to optimizing insertion loss performance.

Along the Way to a Qualified Optical Assembly

Test Path

Because the key parameter for an optical assembly is optical power loss, we need to measure it. A test path to evaluate a PLC, in this case a strip of arrayed waveguide gratings [AWG] used to separate one multi-frequency input into multiple single frequency outputs, is illustrated in Figure 1. Every element of the measurement system can introduce error or variability. The light source output [tunable laser] must be quantified as to wavelength and power levels over time [stability]. At the collection end, the power meter also must be quantified for stability. Once the end points are established, we can work to minimize error and variation from the measurement path. Each connection affects system insertion loss. Photons can be lost to the Fresnel reflection effect at the index change of glass and air between the input fiber array [IFA] and the AWG and between the AWG and the output fiber array [OFA]. Photons can be lost to the Fabry-Perot interference fringes from reflections between parallel optical surfaces at those same junctures.

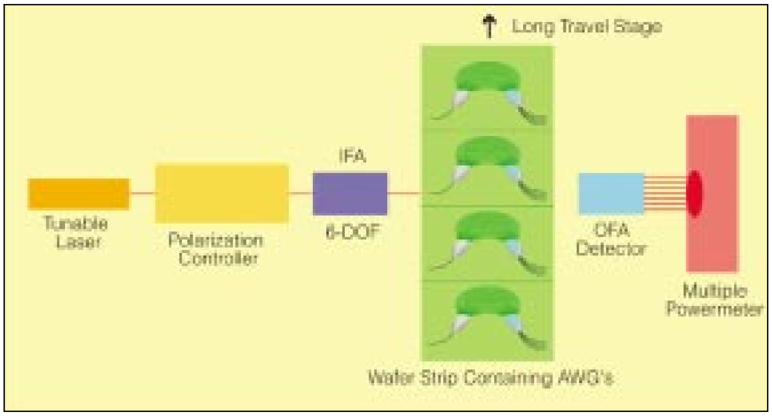

Figure 1: Optical Assembly Test Path

Alignment Issues

Let’s look at aligning a multi-channel PLC to a fiber array [FA] simulation. In Figure 2 we show a tight alignment and the desired uniform insertion loss curves. The third from right channel is slightly attenuated to show that effect on the changes. We know what we want but getting it is another matter. The mechanical scale is about 9 micrometers round cross-section for each SMF core and 5 to 8 micrometers rectangular cross-section for each PLC channel. For context a sheet of paper is about 100 micrometers, human hair about 50 micrometers in diameter. And we will need to hold the alignment for 10 minutes because we need to measure the PLC’s functional performance.

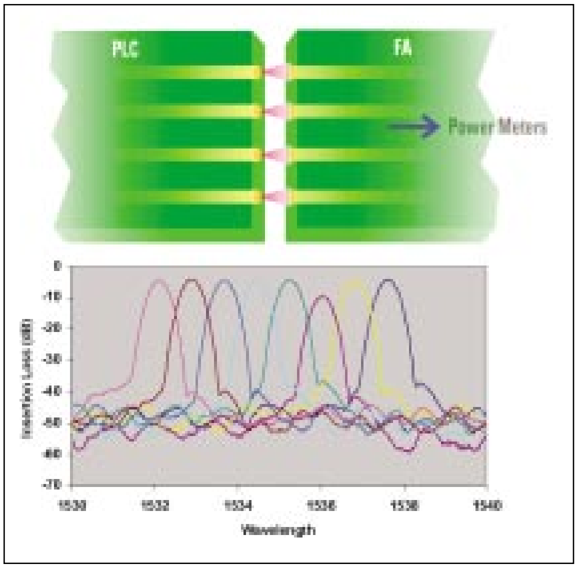

Figure 2: Tight Alignment

What can go wrong? Wrong is being at less than optimal insertion loss for any channel over the critical time period. Figure 3 shows an increase in separation between the PLC and FA. Now there’s cross talk between three channels because the insertion cone has become large enough to cover multiple channels. Insertion loss has increased because fewer total photons are being captured. The spot size has increased but the total number of photons has remained constant thereby decreasing the photon density.

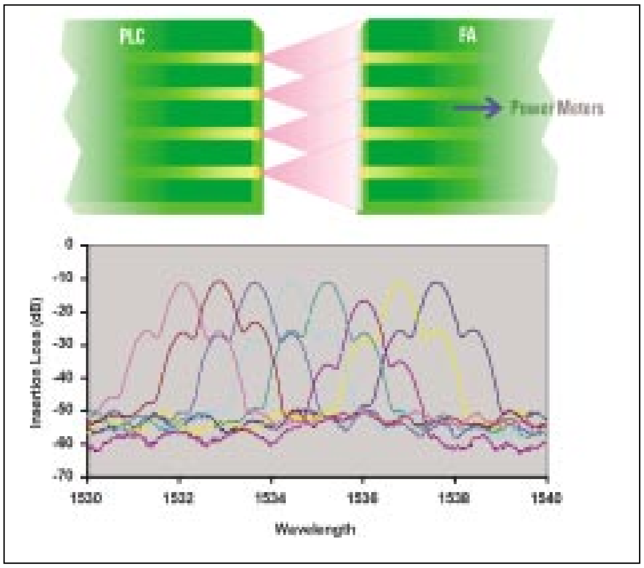

Figure 3: Separation Optical Axis

If separation can occur then a lateral misalignment is possible as shown in Figure 4. The output curves show two cross-talk channels of uniform signal strength. Peak wavelength information is lost. There is also significantly worse insertion loss because of the photon loss into the separation area between the channels rather than into the active channels.

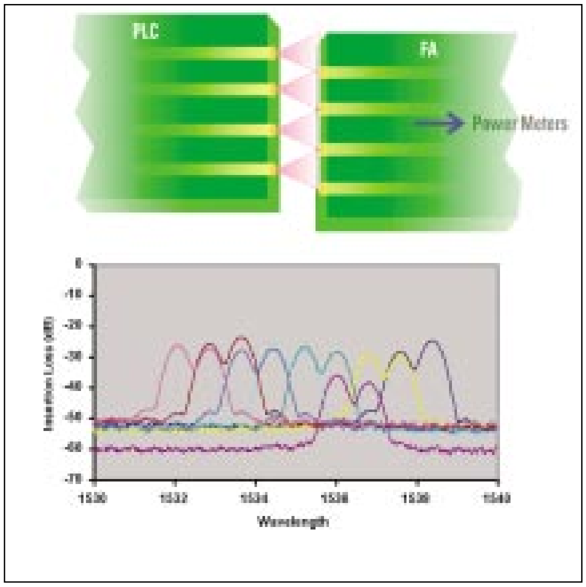

Figure 4: Misalignment, Lateral

What performance effects occur if the alignment angle is incorrect? Figure 5 shows a yaw deviation. Cross talk is present but only as a single side lobe so peak wavelength can still be determined. To further complicate the analysis, the overall insertion loss per channel changes as the separation distance increases for that channel.

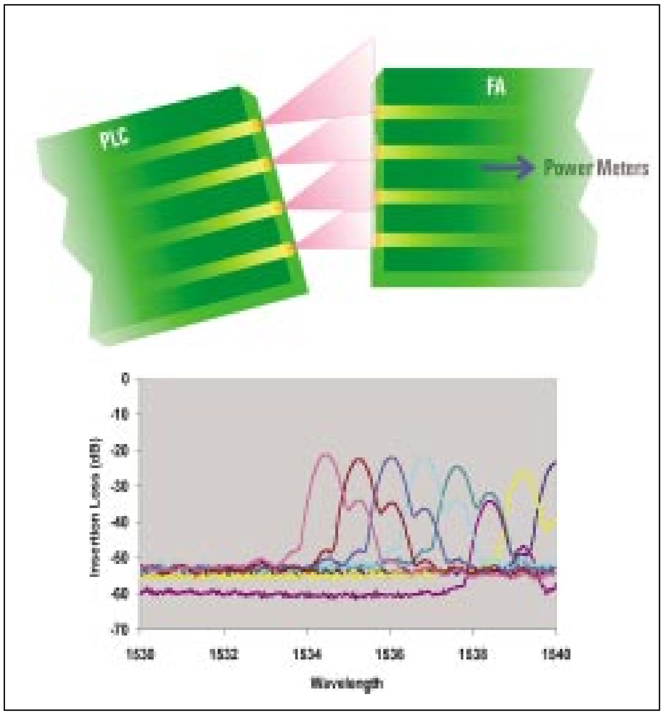

Figure 5: Misalignment, Angular

Stability Effects

Each degree of freedom can change over time and consequently affect insertion loss. Xu's[3] normalized Figure 6 illustrates radial movement away [X and Y axes] from the optical axis and Figure 7 illustrates separation along the optical [Z] axis. For single mode fiber [SMF] coupling to SMF, the insertion loss is about 0.1 dB at the 800 nanometer displacement point and rapidly falling another 0.25 dB for the next 800 nanometer displacement. Index matching fluid, oil for testing or adhesive for bonding, adds a small effect. The fiber separation along Z axis, Figure 7, highlights the Fabry-Perot effect mentioned above. The generation of fringes at half the insertion wavelength intervals can add 0.4 dB to the uncertainty of the insertion loss. This effect disappears with the use of index matching fluid, the top graph in Figure 7. Further complications can be expected when adding the elliptical Gaussian mode from rectangular PLCs to the coupling requirements.

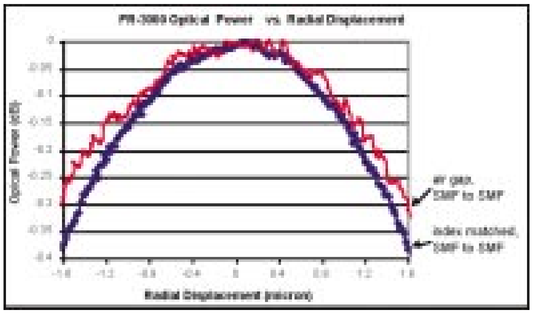

Figure 6: Optical Power Displacement

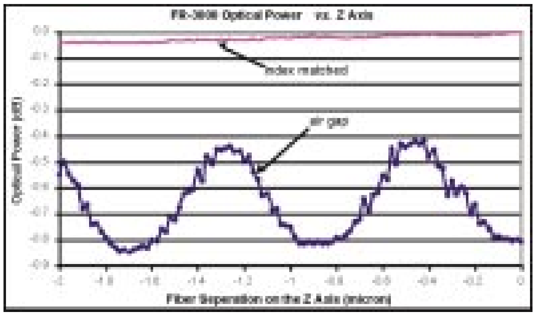

Figure 7: Optical Power Gap Displacement

Why do we care? No system is absolutely stable, hence it will move and some insertion loss change will occur. Movement can be a function of the mechanical mechanisms, changes in temperature, and vibration to name the main contributors. The solution provider must understand the sources and methods to minimize these effects on insertion loss of the optical assembly.

Bonding Considerations

After all the aligning and measuring we still do not have a solution [product]. We have performance data. The optical elements are deemed acceptable or not. If acceptable then the final part of the solution is bonding the good part into an assembly. Some method must be chosen to permanently join the critical elements. For discussion purposes, one approach is an organic adhesive cured with photons. Figures 8 and 9 show the ProBond adhesive bonding station for EXFO's ProAlign™ 5000 component assembly workstation.

Figure 8: ProBond Dispenser

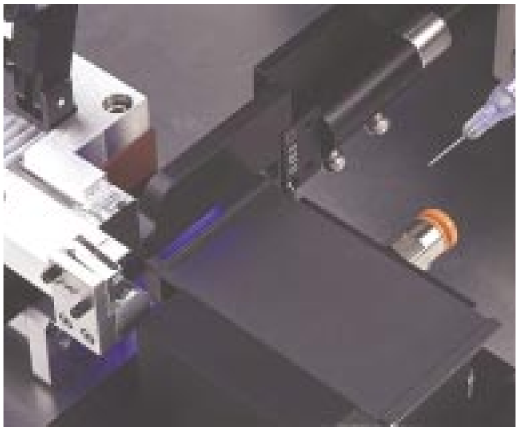

Figure 9: ProBond Curing

The precisely aligned components must now be separated and rejoined for the bonding process. What upsets can be expected? Since the adhesive is not an identical material to the FA nor to the PLC it will differentially change dimension with temperature and with curing to generate some level of stress. A good approach is to evenly distribute the dimensional effects by a symmetrical bond design. Practically this usually means a uniform film on the mating faces of the FA and PLC. A bead of adhesive along the top will cause misalignment from the stress mismatch. The assembly has to separate to allow room for the adhesive dispensing. The adhesive must be distributed in a uniform and repeatable manner [Figure 8]. The mating surfaces must be returned to their previous precise alignment and stabilized during the cure cycle to obtain the insertion loss from the initial characterization. Key performance criteria for adhesive application are repeatable volume and location dispensing.

To finish the assembly the adhesive needs to cure. Figure 9 shows an EXFO Novacure UV curing wand flooding the joint with photons. Adhesives change dimensions during curing, which in turn can affect insertion loss. Martin's[4] Figure 10 shows the shrinkage effect from six different time-photon density profiles. The proper amount of the correct wavelength photons needs to interact with the adhesive over the curing time to achieve reproducible results. Key performance criteria for adhesive curing are wavelength, photon density control and uniformity of illumination onto the bond area.

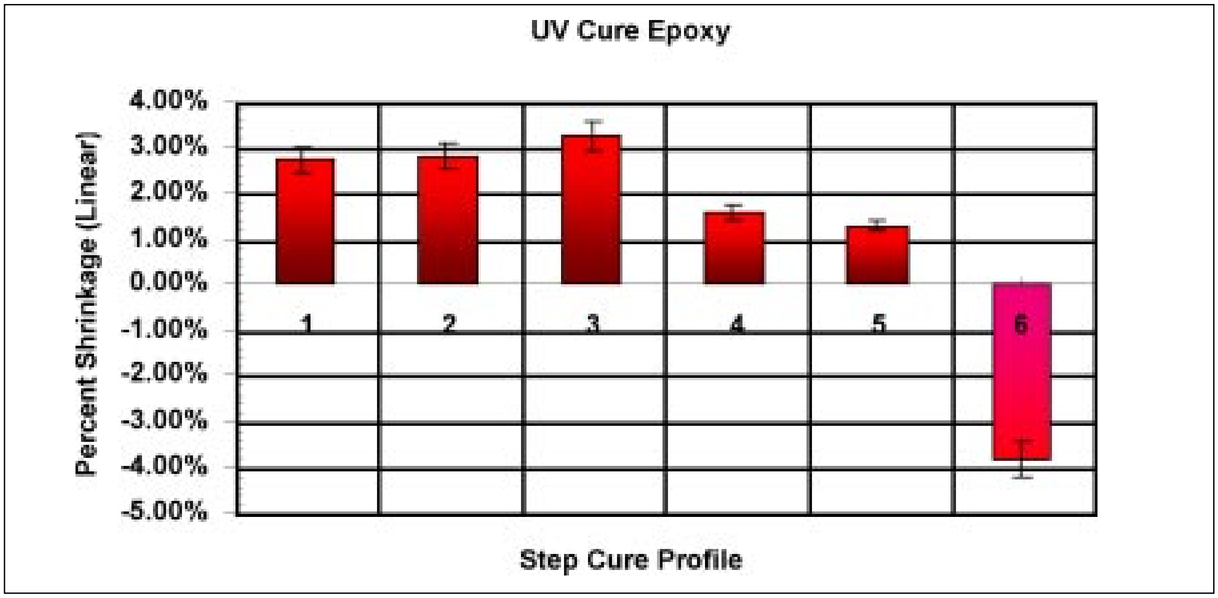

Figure 10: Curing Cycle Effect

Summary

With the need to shepherd photons and little production volume to help in the cost reduction process, the photonics industry is looking for solutions unlike those produced by its older cousin semiconductors.. Multiple technologies must be blended to provide solutions in the form of insertion or optical power loss at the assembly level. Flexibility of the assembly configuration, precision and repeatability of the processes are the fundamental building blocks of the solution provider.

Authors

Galen D. Powers
Manager Advanced Product Development, Photonics Automation
EXFO Burleigh Products Group gpowers@burleigh.com

Sid Ragona
Senior Product Manager, Photonics Automation
EXFO Burleigh Products Group sragona@burleigh.com

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