



Manufacturing Low Insertion Loss Fiber-Lens Elements

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Introduction

Throughout the fiber optics industry, one is constantly hearing that without substantial improvements in production efficiency, new markets for fiber optic technology will remain elusive. It is therefore a common goal throughout the fiber optics industry to continually improve production processes. We propose a scalable improvement for a production step found in a wide range of fiber optic components, fiber-lens and fiber-array alignments.

Fiber-lens alignment is a required production step for numerous fiber optic components. This is because light from the end of a bare fiber is highly divergent, and substantial power will be lost in the fiber optic component unless a lens is used to collimate the beam. A fiber-lens pair is needed whenever light from the fiber must pass through an optical element such as a grating, filter, or mirror. After the light has interacted with the elements, the light is put back into a fiber, using a lens coupled to the destination fiber. The lens, such as a gradient index (GRIN), gradium, and aspheric, can either be contact bonded to the fiber, or can be precision aligned in close proximity. (See figure 1 below) Both the rotation and linear alignment of the fiber is critical prior to bonding the lens to the fiber.

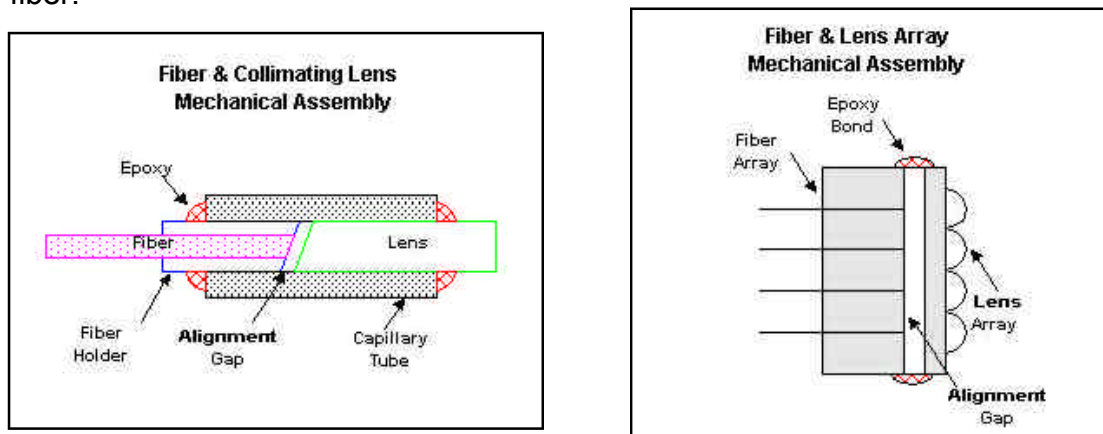


Figure 1: Sample GRIN Lens and Lens Array Assemblies

The goal in fiber-lens alignment is minimizing the insertion loss as the light passes through the fiber-lens pair. Components that use fiber-lens pair to remove light from a fiber to re-insert elsewhere include filters, Mux-DeMux elements, and optical switch elements.

Limitations of the Back-Reflection Technique

To produce fiber-lens elements for minimal insertion loss, a back reflection technique is often employed, as shown in figure 2. A mirror reflects the light from the lens back into the fiber. A power meter is coupled to the fiber to measure the back reflected light. The coupling of the fiber lens pair is adjusted, often manually, until the back reflected light is a maximum. To a certain degree, the insertion loss due to the fiber-lens pair can be determined by the reading of the power meter.

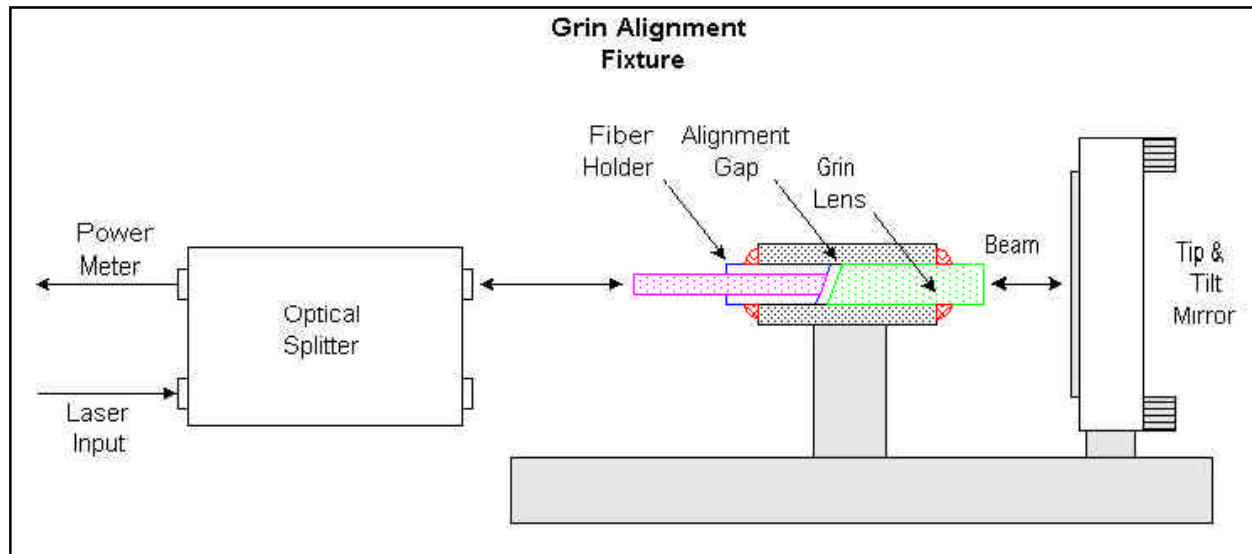


Figure 2: Typical apparatus for back reflection technique.

This back reflection technique is common throughout the industry, but suffers from the following problems:

- ◆ The mirror is usually manually adjusted by the operator and makes the entire process open to variations and dependent on operator skill.
- ◆ It is difficult to determine a robust algorithm for optimal coupling. This is why this technique is often performed manually. Active alignment is difficult and slow in this step.
- ◆ It is difficult to further quantify the process other than simply minimizing the loss.
- ◆ Parameters that may be critical to the coupling of the fiber-lens pair, such as pointing of the beam, are only inferred. In fact, one can only determine if a fiber-lens pair is “lossy”, but has no way of determining the source of the loss.
- ◆ The process does not lend itself to a high degree of repeatability, since at best, only one parameter is quantified.
- ◆ Low insertion loss does not necessarily indicate good optical performance due to a host of optical alignment issues.

In contrast to the back-reflection method, we show that profiling the light as it is emitted through the fiber-lens pair provides a quantifiable, repeatable, and most crucially, a means to automate and improve this process.

More Efficient Fiber-Lens Coupling Through Beam Profiling

Profiling the light emitted from the lens-fiber pair provides more information than the back-reflection technique. This information is important for developing processes that can be automated and have a high degree of repeatability. Finally, the cause of a poor fiber-lens alignment can be identified and tracked from the profile data, allowing for the appropriate corrective actions to be taken, before additional value is added to that assembly or process.

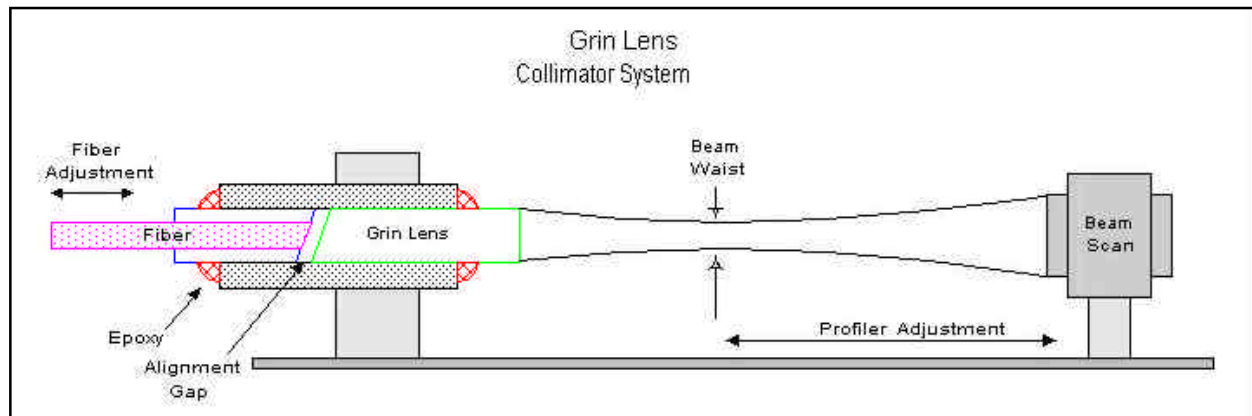


Figure 3: Sample Beam Profiler Set-up

Beam profile measured parameters that quantify the fiber-lens coupling are:

- ◆ Beam Width
- ◆ Beam Position, or equivalently, Beam Pointing
- ◆ Beam Collimation, or Beam Waist Along the Optical Axis
- ◆ General features of beam profile, including Gaussian fit.
- ◆ Beam Power

Following is a brief description as to what these parameters indicate about fiber-lens alignment.

Beam Width

The beam width is a strong function of the distance between the fiber and the collimating lens, when measured at positions along the optical-axis of the beam. In some cases, beam width at a given distance from the lens quantifies the coupling and correlates to the insertion loss of the lens coupling.

Beam Position or Beam Pointing

Clearly, if the light emerges for the fiber-lens pair at an angle to the optical axis, much of the light power will be lost in the device. Beam pointing is especially critical for MEMS based optical switching applications, where the alignment of the light beam onto the reflecting mirror is very critical. Measuring this parameter and accurately computing the optimal alignment position is very desirable for manufacturing high quality components. It is important to note that a component with low insertion loss but incorrect beam pointing often fails to deliver optimum system performance.

Collimation of the Beam, or Beam Waist along the Optical-axis

Measuring the beam width at points along the optical path indicates the collimation. For a collimating lens, collimation directly measures the performance of the lens and its alignment with the fiber. In addition, coupling of light between two fiber-lens pairs is a maximum when the positions of the waists overlap. Collimation measurement can be automated by mounting the beam profiler to a motorized stage. This allows for accurate and quick positioning of the profiler while collecting the required collimation data.

General features of the profile, including Gaussian fit

A profile that deviates significantly from a Gaussian may indicate either a defect in the lens, or poor alignment between elements. A non-Gaussian profile may indicate the presence of higher order modes in the beam. As different modes propagate at different speeds, mode dispersion will increase the bit-error rate introduced by the optical component.

Beam Power

In addition to beam profile characteristics, beam power can also be by some profiling instrumentation. Thus, transmitted power and the beam profile are measured simultaneously.

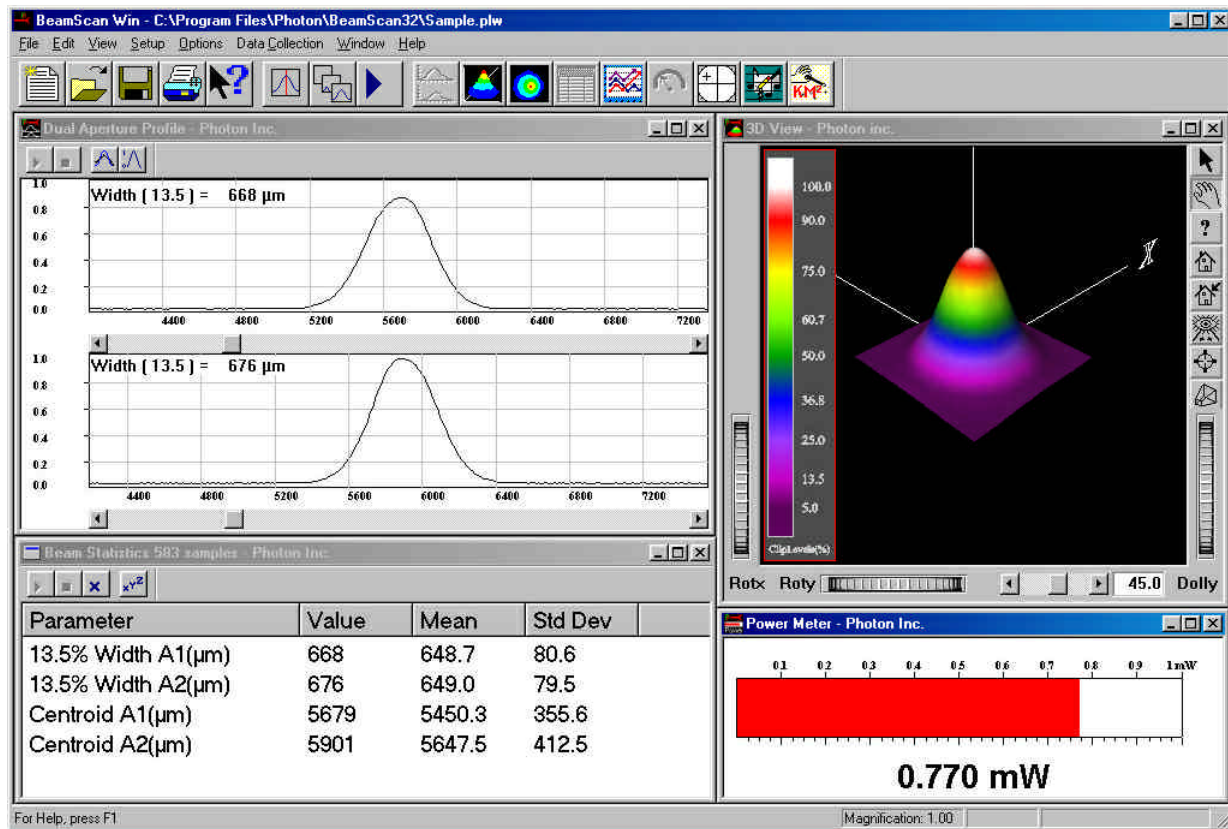


Figure 4: Example of Beam Profiler data, indicate orthogonal profiles, beam width and position data, power level, and 3-D representation of beam.

Beam Profiling Using the Scanning Slit Technique

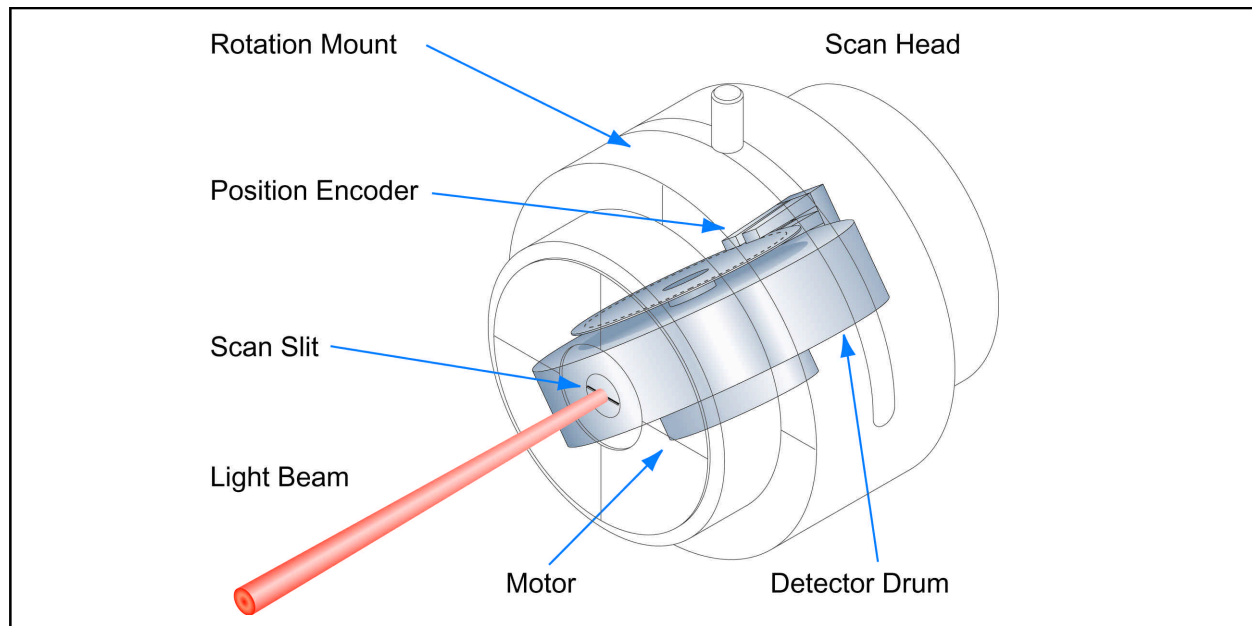


Figure 5: Sample example is scanning slit beam profiler.

Based on our experience with beam profiling instrumentation and the requirements of the fiber-lens alignment process, we recommend the scanning slit technique for profiling in fiber lens alignment.^(1,2) The scanning slit technique uses a slit that passes through the beam. Light emerging through the slit falls onto a photodetector. The photocurrent as a function of slit position generates the profile.

This technique can produce sub-micron accuracy and resolution of beam position and width. Slits can be manufactured as small as 1 micron and data sampling can occur at the sub-micron level. The single detector also helps to ensure a uniform response across the detection plane. Slit-based profilers can also measure beam power with a high degree of accuracy and resolution, providing additional component alignment data and feedback.⁽³⁾

Whatever profiler type is selected, it is critical that the instrument has some means of communication with other components used in manufacturing, such as ActiveX, GPIB command sets, or a software development kit for automation.

Fiber Arrays

Fiber arrays, which are becoming more prevalent, require more than one beam to be analyzed to ensure good alignment. Each beam can be analyzed sequentially. However, faster analysis is achieved by analyzing several beams simultaneously. This is accomplished with a beam profiler with either customized analysis of the data stream to characterize the multiple beams, or from specialized software from the manufacturer. For large complex arrays the beam profiler can be automatically repositioned to collect data from various parts of the array, as well as various working distances. Figure 6 below shows how this is accomplished.

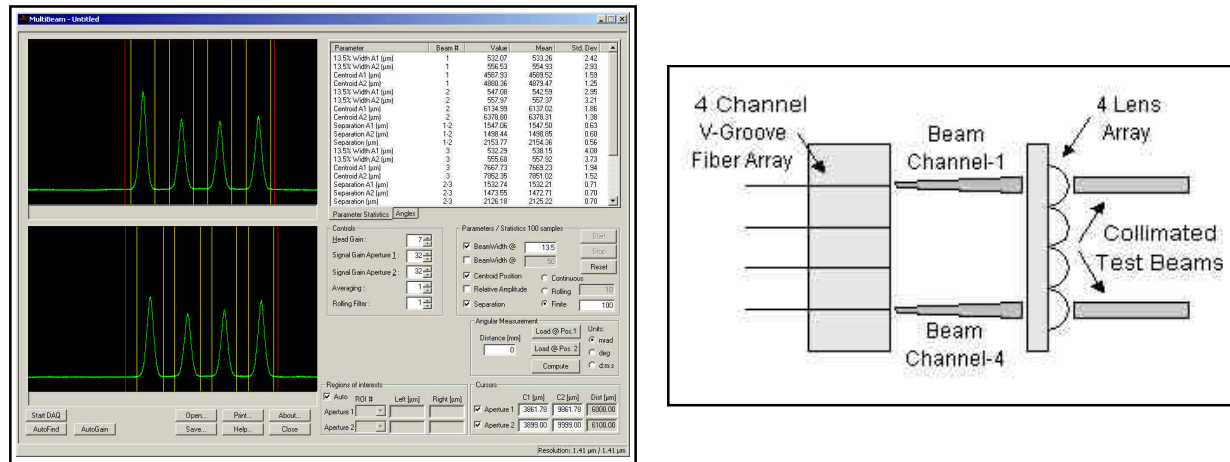


Figure 6: On the left, profiles of four beams with corresponding spatial data. On the right, a general fiber-lens array where multiple beam analysis is desirable.

Using Beam Profilers in the Manufacturing Process

We propose the following process incorporating beam profiling for fiber-lens alignment, based on our experience with beam profiling equipment used for the fiber-lens and fiber-lens array alignment processes.

From an initial position, the fiber or array is illuminated. The beam profile, along with relevant parameters is quickly acquired.

Beam parameters measured from the profile are loaded into an alignment algorithm, which controls the fiber or array position. The alignment algorithm is based on previous empirical results, and can involve, positioning formulas, look-up tables, offset calculations or various combinations of data processing and measurements.

In this closed loop process, the fiber or array is actively positioned until the fiber-lens alignment has attained predetermined acceptance criteria based on the beam profile and positioning data.

Once the beam profile meets quality assurance limits, epoxy is applied to fix the alignment. During the curing process, profile data is sent back to the positioning system to maintain accuracy. The components are completely cured before the finished assembly is removed from the alignment tool for the next production step.

This alignment process has three major attributes:

Scalability

This process can have varying levels of automation, depending on the required throughput and maturity of the process. The fiber alignment can be performed manually, or automated using positioning mechanisms. As the process is better understood or factors dictate improving portions of this process, additional automation can be introduced. Because this process is scaleable, innovations from the lab are brought through development and onto the production floor more smoothly.

Repeatability

The process produces repeatable components because more than just low loss data is used in the alignment. Fiber-lens pairs or arrays may have low loss, but could still produce different beam widths or beam pointing, and therefore, would act differently in larger optical assemblies. Several parameters can be used to quantify the alignment using beam profilers; the fiber-lens pairs or arrays can be optimized and accomplished much more controllably day to day.

Production Process Feedback

When a fiber-lens pair or array fails the process, the cause can be quickly understood by analyzing the beam data collected with that part. Contrast this with the back-reflection method, which simply fails a part for unacceptable loss, with no further information to guide the process engineer. In addition, the fiber-lens alignment process is monitored over time. If the process is slowly varying towards a point of numerous product failures, continual monitoring of the process allows the process engineer to intervene before a catastrophic number of failures occur. Conversely parts that show unusual high quality can be quickly analyzed and the overall process improved.

The Path For Manufacturing

As the fiber optic industry continues to evolve, production efficiency of fiber optic components must improve. Currently, there is an industry wide debate as to best path to travel for automated production. While some preach standardization, others closely guard their proprietary methods. Many in the investment community predict production efficiencies in the fiber optic industry to follow the high volume manufacturing transformation in the semiconductor industry, but the jury is still out regarding whether an industry built on electrons has something to offer an industry built on photons. Whatever the outcome of the lively debate, we expect beam profiling instrumentation to play a significant role.

References

1. "Measurement of the absolute accuracy (to <0.5%) of a clip-level beam profiler using Fresnel diffraction by a wide slit", T.F. Johnston, Jr., and J.M. Fleischer, 1995 Proceedings of the Society of Photo-Optical Engineers, vol. 2375, page 234.
2. "Calibration standard for laser beam profilers: method for absolute accuracy measurement with a Fresnel diffraction test pattern", T.F. Johnston and J.M. Fleischer, Applied Optics, vol. 35, no. 10, page 1719-1734, 1996.
3. Further information in regards to the measurement issues involved in scanning slit profilers can be found at www.photon-inc.com/appnotes.shtml

A similar version of this paper was published in the February 2002 issue of Photonics Spectra Magazine.