Application Note 6

Fiber Optics & Photonics

Fiber to Waveguide Alighment Algorithm

Spectra-Physics
A Division of Newport Corporation

Newport
Experience | Solutions

Fiber to Waveguide Alignment Algorithm

Kamran S. Mobarhan, Ph.D., Martin Hagenbuechle, Ph.D., and Randy Heyler

Introduction

In manufacturing of fiberoptic components it is often necessary to attach an optical fiber to a semiconductor device such as a laser diode. This process is commonly referred to as fiber pigtailing. The device could possibly be a laser diode, a semiconductor optical amplifier, an optical switch, or any of the other numerous types of optoelectronic devices typically used in optical telecommunication networks. In any case, there exists the problem of coupling the light that is being emitted from the output end of a rectangular shaped waveguide into the input end of a circular optical fiber or vice versa. Due to the mismatch of the mode structures between these two differently shaped structures (rectangular waveguide versus circular fiber), a large portion of light could easily be lost if the fiber is not positioned in front of the device in an optimum fashion. Since the fiber used for this purpose is a single mode fiber, the alignment tolerances required for optimum light coupling between the rectangular shaped laser waveguide structure and the round optical fiber core are usually very tight, typically in the submicron regime. As a result, high-precision computer controlled motion stages and sophisticated alignment algorithms are required to successfully achieve maximum coupling efficiency.

Initial Light Coupling

The first step in the alignment process is to position the tip of the optical fiber in front of the device in a coarse manner. It is then necessary to ensure that at least some light is coupled into the fiber. The beam of light that is emitted from the output aperture of the rectangular shaped device is typically in the form of a divergent elliptical cone. If the tip of the fiber does not fall within the volume of space overlaid by this cone of light no light will be detected at the output end of the fiber and one cannot begin the alignment process. Through the use of a high resolution imaging system and precision-machined device tooling, it is usually possible to position the fiber in such manner so some light is detected. However, in some cases it is necessary, as a first step, for the fiber to perform a systematic search to find this cone of light. The initial search is in the form of a 2-dimensional raster scan as shown in Figure 1. The fiber is typically encapsulated in a cylindrical metallic fiber ferrule. This metallic fiber ferrule provides the fiber with a metallic housing necessary for rigidity and welding purposes. The fiber protrudes out of the metallic ferrule as little as possible in order to avoid any mechanical instability typical of cantilever structures. The tip of the fiber is also polished into specific geometric shapes in order to maximize the coupling efficiency. For example, in Figure 1 the tip of the fiber is shaped into a cylindrical lens which is suitable for 980 nm EDFA pump laser diode packaging applications in which no external lenses are used between the laser diode and the fiber. The output end of the fiber is connected to a fiber optical detector. A power meter is used to accurately measure and display the optical power level. This optical power meter, as well as other system instrumentation, interfaces through GPIB with a computer that automatically controls the entire alignment process.

Fiber Gripping and Manipulation

In order to successfully perform fiber to chip alignment it is necessary to be able to hold the fiber and move it around in an accurate manner. As mentioned previously, for many applications a small length (a few millimeters) of the optical fiber, near its tip, is metalized and encapsulated in a cylindrical metallic fiber ferrule. The metallic fiber ferrule offers a robust housing for the fiber that one can grip without damaging the fragile optical fiber itself. Newport offers a variety of chucks, grippers, tweezers, and other styles of toolings and fixtures for many applications.

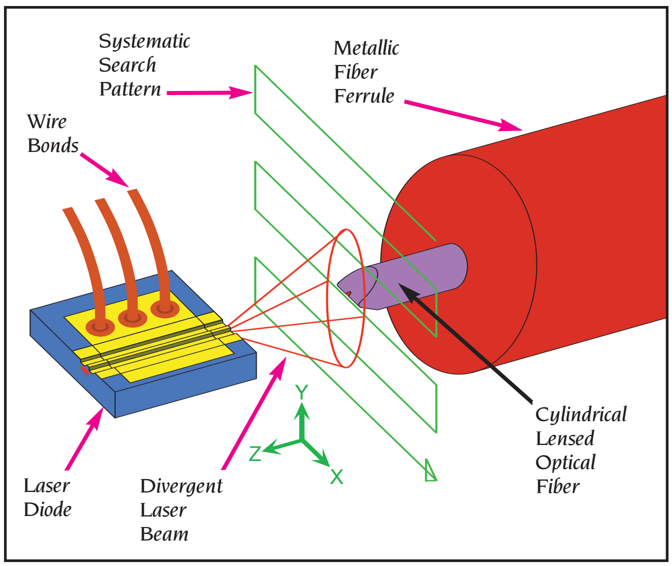

Figure 1. Schematic diagram showing the optical fiber systematically scanning the volume of space in front of the laser diode until some light is detected. In this particular application the fiber is encapsulated in a metallic fiber ferrule and the tip of the fiber is shaped into a cylindrical lens. The parts are not shown to scale in this diagram.

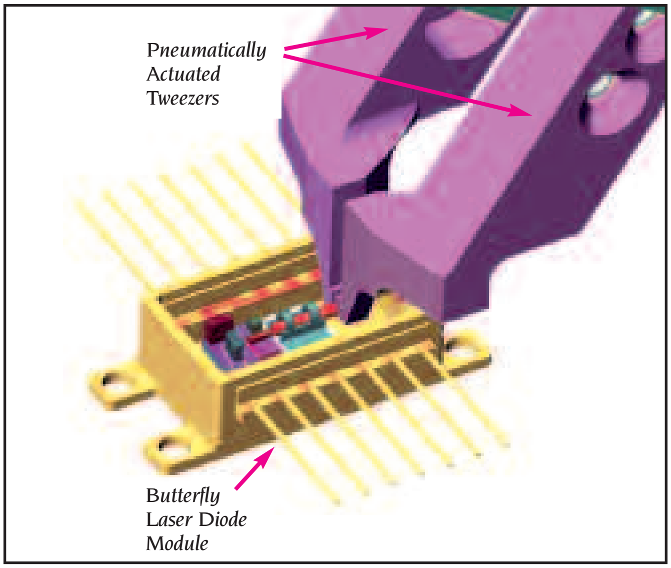

Figure 2. In some applications pneumatically actuated tweezers are used to position the metallic fiber ferrule in the butterfly package and align the fiber tip to the laser diode chip. The narrow profile design of these tweezers makes it possible for the tweezers to reach into tight spaces inside of the rectangular package.

Application Example: 980 nm Laser Diodes

In fiber pigtailing of a 980 nm pump laser diode, a pair of pneumatically actuated tweezers are used to grip and position the metallic fiber ferrule inside a butterfly package laser diode module (Figure 2). These tweezers provide precise gripping pressure control for handling the ferrule. Their narrow profile design makes it possible for the tweezers to reach into tight spaces inside of the rectangular package and hold the metallic fiber ferrule.

Once the pneumatic tweezers have the metallic fiber ferrule in their grip, it is possible to move the optical fiber in x, y, or z directions so that its tip is positioned in front of the laser diode in order to maximize the light coupling efficiency between laser diode waveguide and the optical fiber. The alignment process requires very high precision computer controlled motion capability. This is done using DC servo motion control technology offering absolute bi-directional positioning capability with 50 nm accuracy.

Figure 3 shows the inside of a 980 nm butterfly package pump laser diode module. At this stage of the operation the metallic fiber ferrule has been inserted into the butterfly package and positioned a safe distance away from the front facet of the laser diode chip. The tweezers have the ferrule securely in their grip and, in addition, a saddle shaped weld clip specially designed for this application is placed over the ferrule. After the fiber to waveguide alignment is completed and optimum coupling efficiency is achieved, a laser welding process is used to bond the saddle shaped clip to the base of the package. The metallic fiber ferrule is subsequently welded to the saddle shaped clip thus locking the fiber tip into a fixed secure position in front of the laser diode chip. The details of this process are explained in a separate Application Note.

Figure 4 shows a close-up view of the laser diode chip and the cylindrical lensed optical fiber and its metallic ferrule housing.

The next section describes the details of an alignment algorithm called “Hill Climb”, which is used to align the optical fiber to the waveguide.

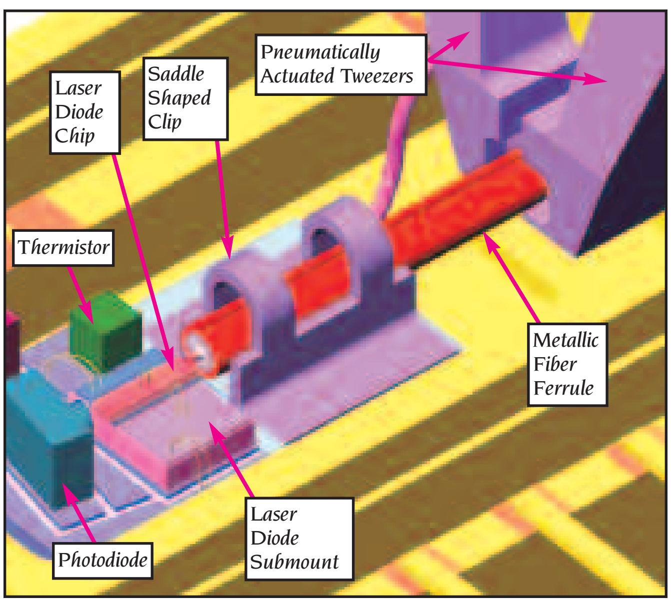

Figure 3. Close-up view showing the internal components of a 980 nm butterfly package laser diode module. The pneumatic tweezers hold the metallic fiber ferrule in their grip, and move the optical fiber in x, y, or z directions so that its tip is positioned in front of the laser diode in order to maximize the light coupling efficiency between the laser waveguide and the optical fiber. At this stage of the assembly process neither the saddle shaped weld clip nor the metallic fiber ferrule are welded to each other or to the package.

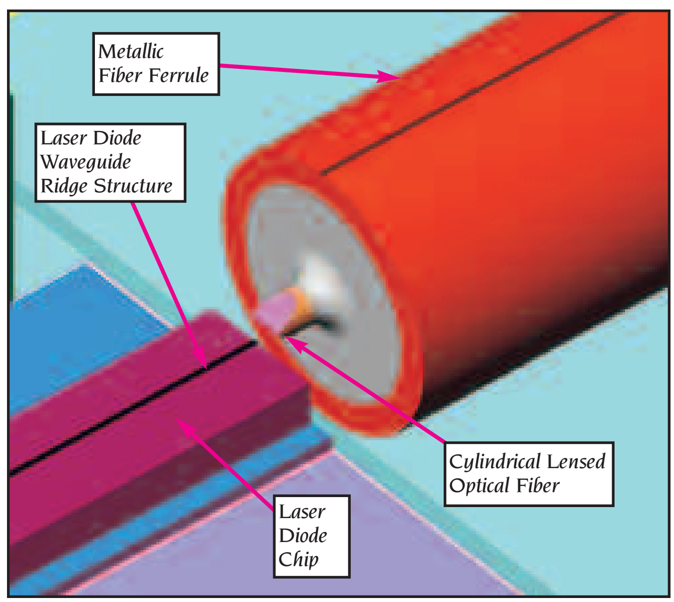

Figure 4. Close-up view showing the cylindrical lensed tip of the optical fiber aligned to the laser diode waveguide ridge structure in a 980 nm pump laser diode application.

Hill Climb Alignment Algorithm

Hill Climb is a process for performing 2-dimensional alignment along the X and Y axes (i.e. directions perpendicular to the optical fiber) a fixed distance away from the light emitting facet of the waveguide.

As mentioned previously, first a raster scan is performed in order to have the tip of the fiber positioned within the volume of space containing the divergent cone of light. Once initial light coupling is achieved, the computer, using a sophisticated motion control system, executes the Hill Climb alignment algorithm based on predetermined initial parameters. Typically the 2-dimensional Hill Climb process is executed first along the X axis, then along the Y axis, and once again along the X axis. This is referred to as the XYX scan method. Alternatively, it is possible to select YXY sequence depending on the application and the particularities of the device.

The main objective of the Hill Climb process is to position the fiber at a location in space where maximum amount of light is coupled into it. Figure 5 schematically shows the process in which the tip of the fiber moves closer and closer towards a location in space where maximum amount of light is coupled into the fiber. Typically the beam of light emitted from the waveguide (e.g. laser diode chip) has a Gaussian profile. However, it is also possible that it has various spatial side modes in addition to the main peak. If necessary, as part of the the Hill Climb process, it is possible to perform a complete beam profiling scan resulting in a full 3-dimensional graph (Figure 6). In this manner the existence, or lack of, side modes or any other irregularities can be clearly established.

Moving along one direction (either X or Y axis) the Hill Climber begins its ascend up the hill and towards the peak as shown in Figure 5. The Hill Climber represents the tip of the optical fiber and its vertical altitude, at any location on the hill, corresponds to the amount of light coupled into the fiber as detected at the output end of the fiber. The optical power is measured using an optical detector and power meter. At the start the Hill Climber takes one step in an arbitrary direction along the X axis. If it detects a drop in optical power it realizes that it has moved away from the peak. As a result it will reverse course and begin moving in the opposite direction.

The Hill Climber takes equal steps of predetermined value. After each step it stops and the level of the optical power, (i.e. the altitude of the hill) is measured. If the newly measured value is larger than the previous measurement the Hill Climber knows that it is still going up the hill. A decrease in optical power indicates that it has passed over a peak. However, the peak that is crossed over could be a local maximum associated with one of the side modes of the divergent beam of light. In order not to mistake a local maximum with the absolute peak, the Hill Climber continues along its course and takes a predetermined number of steps along the downward slope of the hill to ensure that the hill does not begin to rise again. In this manner the Hill Climber continues its journey up the hill until it crosses a peak whose altitude is determined to be higher than any of the local maxima encountered throughout its journey along the X axis.

Once the highest peak (i.e. absolute maximum) in the mountain range (i.e. optical beam profile) is identified, the Hill Climber will try to stand on top of this peak as

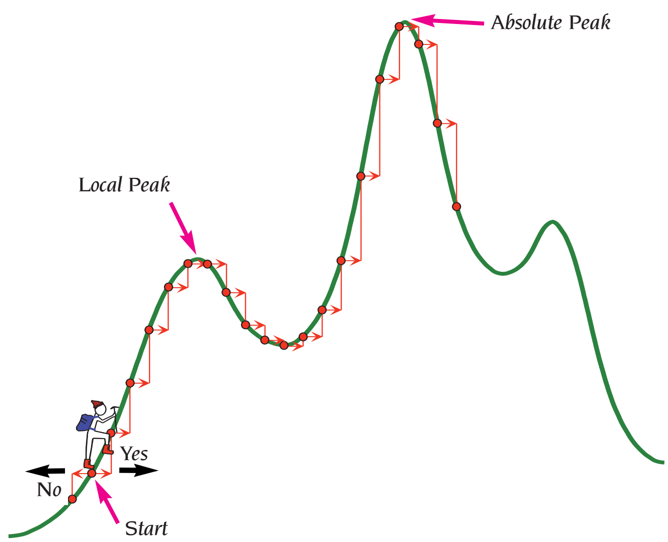

Figure 5. Schematic diagram showing the approach of the Hill Climber towards the absolute peak in incremental steps. If at the start point, a drop in optical power is detected, the Hill Climber realizes that it is moving in the wrong direction. As a result it will reverse course and move in the opposite direction. In order not to get trapped at local peaks, the Hill Climber checks several steps beyond each maximum point to ensure that the curve does not begin to rise again. In this diagram the vertical axis represents optical power, and the hill shaped curve represents the optical profile of the laser beam. The horizontal axis is along either the x or y directions (i.e. directions perpendicular to the optical fiber).

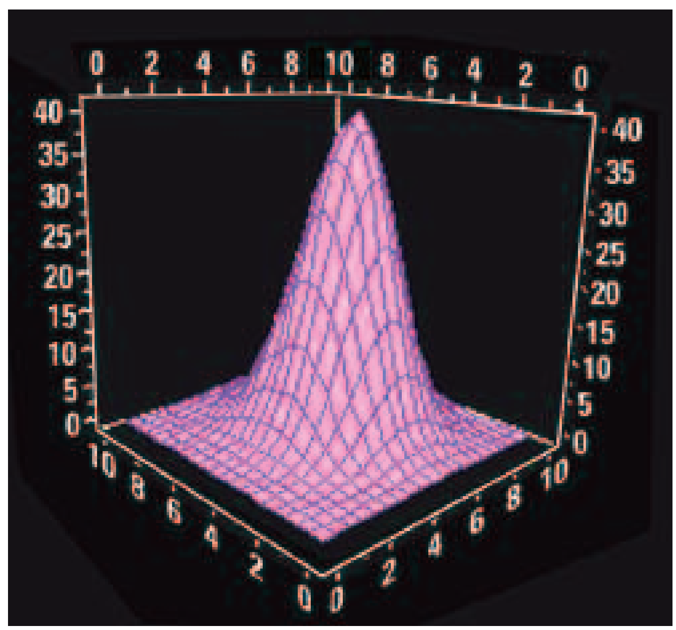

Figure 6. This 3-dimensional graph shows the beam profiles along the x and y axes (i.e. directions perpendicular to the optical fiber) generated using half a micron (500 nm) incremental steps. The vertical axis in this diagram represents the optical power, in units of micro Watts, as measured at the output end of the optical fiber. In this particular case no side modes are present.

precisely as possible. The use of a motion system with 50 nm bi-directional repeatability and absolute position control makes it possible for the Hill Climber to come extremely close to the mathematical absolute maximum point of the peak thus resulting in an optimum optical power coupling efficiency. This is done through a series of iterations in which the Hill Climber reduces the size of its steps and repeatedly passes over the peak of the hill several times.

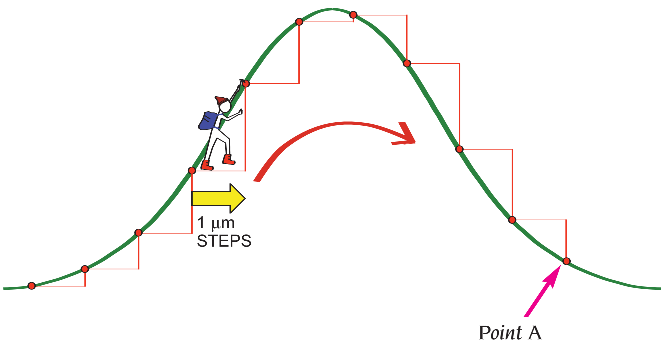

Figure 7. At the early stages of the climb the Hill Climber goes up the hill in relatively large steps. Once over the peak (i.e. when a drop in optical power is detected), it checks a predetermined number of check points (4 points in this case) to ensure that the curve does not begin to rise again. At point "A" it reverses course and climbs back towards the peak.

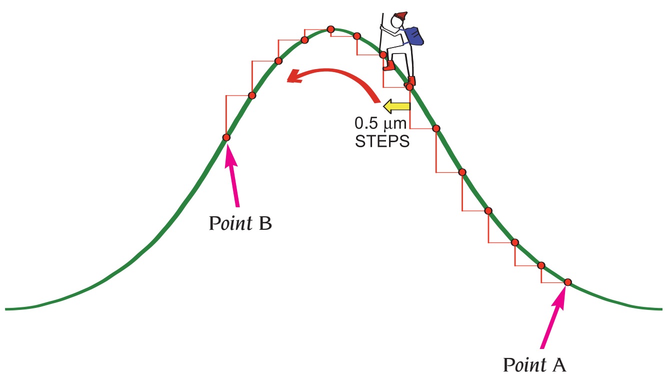

Figure 8. Once the Hill Climber determines that it has gone over the peak, and also that the peak is not a local maximum, it turns around and approaches the peak in steps half as small as the initial step size. This is called an "iteration".

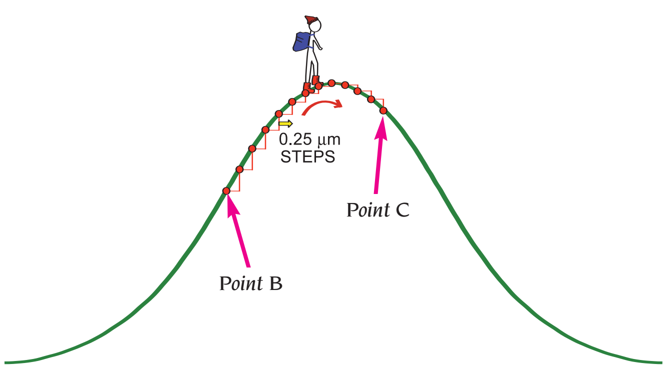

Figure 9. The Hill Climber passes the peak and turns to climb towards it in incrementally smaller steps. Each cross over the maximum point results in the step size to be reduced by a factor of 2. Points "B" and "C" mark the spots where the Hill Climber reverses its direction of travel.

Before the Hill Climb alignment algorithm can be executed three key parameters need to be set by the process engineer. These parameters include: initial Step Size, number of Check Points, and number of Iterations.

The Step Size determines the magnitude of motion along each axis. For example, if the initial Step Size is set to 1 micron, the Hill Climber moves along the X axis in 1 micron incremental steps.

Check Points is the parameter that specifies the number of steps the Hill Climber takes past each maximum point in order to check to see if the hill would begin to rise again or not.

After locating the absolute peak of the hill the Hill Climber will reduce the size of its step by a factor of two and repeats the pass over the hill process as many times as indicated by a parameter referred to as Iterations. This is done in order to fine tune the alignment.

Figures 7, 8, 9, and 10 show the various steps of the Hill Climb process with the three key parameters preset to the following values:

Step Size = 1 micron

Check Points = 4

Iterations = 3

In Figure 7 the Hill Climber is going up the hill with its step size set at an initial value of 1 micron. At some point it detects a drop in the power level indicating that it has crossed a peak. Since the Check Points parameter is set to 4, the Hill Climber takes 4 steps to check whether the hill begins to rise again or not. It detects no increase in power level and decides that the peak it had just crossed is an absolute maximum. At point "A" it stops, reverses course, and begins to climb the hill back towards the peak using a step size half as large (0.5 micron).

In Figure 8 the Hill Climber passes over the peak for the second time. A drop in power level prompts the Hill Climber to start counting its check point steps. The Hill Climber takes four steps, stops at point "B", reverses its direction of travel and begins heading up the hill taking steps that are now only 0.25 micron in magnitude.

The Hill Climber passes the peak for the third time, as shown in Figure 9. It takes four steps to point "C" where it turns around and climbs back up the hill using a step size with magnitude set to a value twice as small (0.125 micron).

Upon arrival to the top of the peak for the fourth time the Hill Climber no longer crosses over it. This is because the Iteration parameter, in this case, was initially set at 3 and the Hill Climber has already completed three passes over the hill. At this stage the Hill Climber concludes its ascend of the mountain and comes to rest at the top,

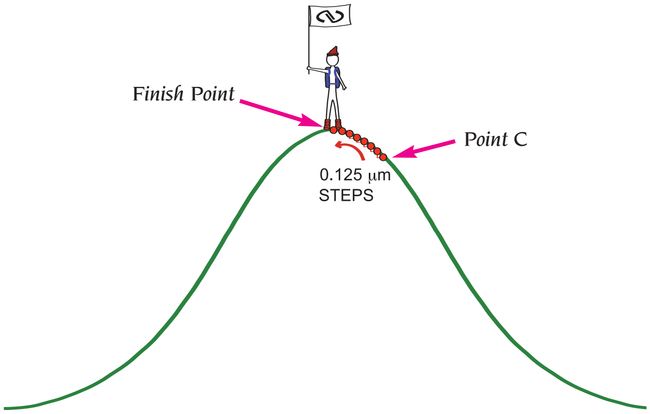

Figure 10. The Hill Climber reverses course at point "C" and makes its final approach towards the peak taking 0.125 micron size steps. Since its 3 iterations are now completed the Hill Climber concludes its climb at the peak.

within a 0.125 micron distance of the absolute maximum point (Figure 10).

The back and forth motion of the Hill Climber over the peak can be repeated until either no detectable increase in power is observed or the step size required reaches the resolution limit of the translation stages being used. Once the Hill Climb process, performed in the manner described above, is completed along the X axis, it is repeated along the Y axis and after that once again along the X axis. Figure 11 shows the resultant Hill Climb graph that is typically generated after the above outlined XYX Hill Climb process sequence is concluded.

Figure 12 shows the variations of optical power along the 3 major axes after a Hill Climb process has been successfully completed in an application where an

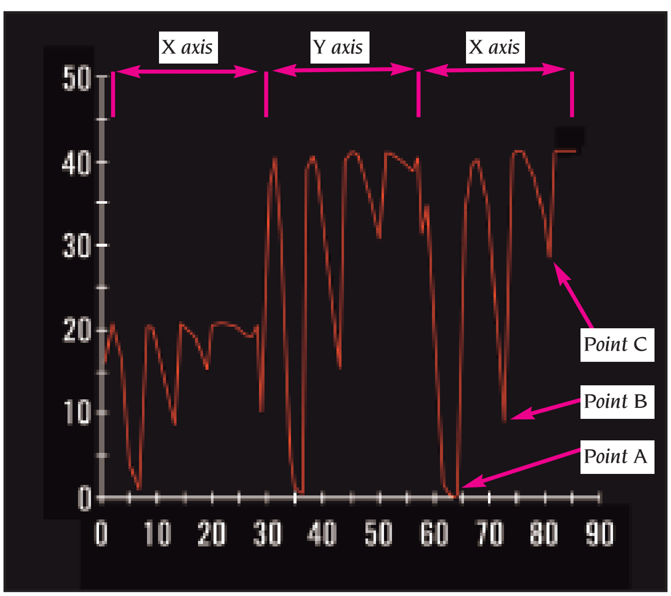

Figure 11. This graph represents the result of the Hill Climb algorithm having been executed along the X-Y-X axes with the number of iterations parameter set to 3 (i.e. the Hill Climber crosses over the maximum peak 3 times). The vertical axis in this graph represents the optical power in units of micro Watts. The horizontal axis marks the number of data points collected in the process (in this case about 90 points). The minimum points A, B, and C correspond to the turning points A, B, and C as shown in Figures 7, 8, 9, and 10.

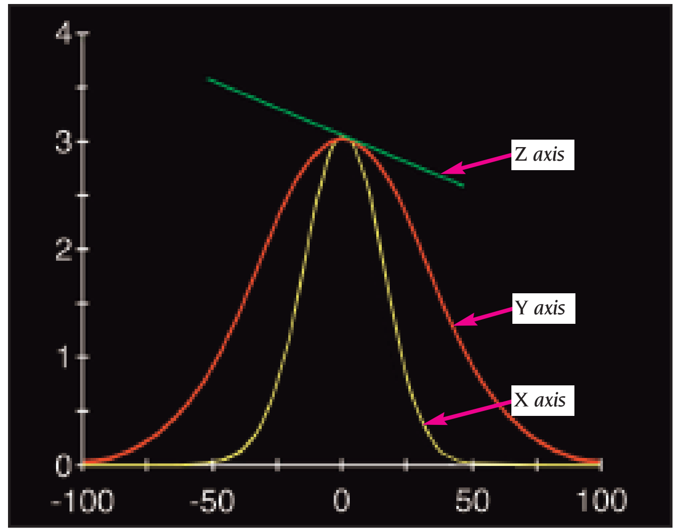

Figure 12. This graph shows the beam profiles along the x, y, and z axes. Horizontal axis is marked in units of microns. The maxima of the x and y axes curves coincide when optimum alignment is established. The curve associated with the z axis (i.e. the axis parallel to the optical fiber) does not peak at a maximum point. This is due to the fact that the graph shown here represents an application in which a bare fiber tip is being aligned to a waveguide without the use of any lens. Consequently the light coupling efficiency is increased as the tip of the fiber is brought closer and closer to the light emitting aperture of the waveguide.

optical fiber with as cleaved facet was being aligned to a planar waveguide.

In conclusion, Hill Climb is a powerful alignment algorithm with useful applications in the alignment of optical fibers to planar waveguide structures such as laser diodes, semiconductor optical amplifiers, switches, or Arrayed Waveguide Gratings (AWG). It offers sophistication, versatility, and speed all in one easy to execute

Figure 13. The image of the computer screen, as seen by the operator, when executing the Hill Climb alignment process.

package. In most cases, the entire fiber alignment process takes approximately from 30 to 90 seconds, depending on the application. The Hill Climb process is developed with automation in mind and is an integral part of the Process Control Software (PCS) used in Newport's automated manufacturing systems. Figure 13 shows a typical PCS screen associated with the Hill Climb alignment process.

Newport Corporation
Worldwide Headquarters

1791 Deere Avenue
Irvine, CA 92606

(In U.S.): 800-222-6440
Tel: 949-863-3144
Fax: 949-253-1680

Internet: sales@newport.com

Newport
Experience | Solutions

Visit Newport Online at: **www.newport.com**

BSI REGISTERED
ISO 9001
FM 27207

Newport Corporation, Irvine, California, has been certified compliant with ISO 9001 by the British Standards Institution.

DS-03002 (12/04)
Printed in the USA