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Automatic Alignment Fiber Optic Coupling System for Optimal Signal Transmission

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INTRODUCTION

This report describes an automated alignment system developed to aid in the process to evaluate the optical characteristics of waveguides manufactured for research in optical communications. Using the current method of characterizing the waveguides, it can take up to 8 hours to characterize the waveguides on a single silicon wafer. Using the computer automation system developed, the characterization process has been reduced to less than an hour.

Figure 1 shows a picture and a drawing of a silicon wafer containing many waveguides. After the silicon wafer containing the waveguides is manufactured, the waveguides must be evaluated to determine the optical characteristics of the various waveguides on the silicon wafer.

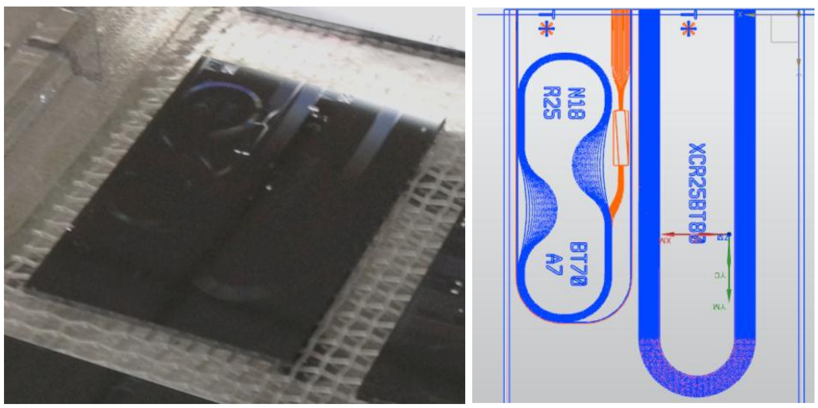

Figure 1. Waveguide and CAD Drawing.

CURRENT TECHNIQUE

Figure 2 shows the current setup used to measure the optical properties of the waveguides on a silicon wafer. The silicon wafer is approximately 1 inch square and can contain as many as 50 separate waveguides that need to be analyzed. In this setup, laser light is passed through an optical fiber into one end of the waveguide. At the other end of the waveguide, another optical fiber is used to capture the light exiting the waveguide and is measured using a power meter. Each fiber is attached to x-y-z stages, which allows for fine adjustment of the fiber along three directions. This fine adjustment is needed in order to get the laser light into the waveguide as well as into the fiber on the exit end of the waveguide. Thus there are six stages used to maximize the laser light passed through the waveguide. In addition to the six stages, there are two stages that are used for coarse adjustments. The coarse adjustments are only along the x-direction and are used for the initial alignment of the two fibers and for the displacement needed to move to the next waveguide.

When a new wafer is placed into the setup, the coarse adjustments are used to get the two ends of the fibers close to the desired location. Next, the six fine adjustments are used to maximize the power through the waveguide. Once the desired data has been gathered, the coarse adjustments are used to go to the next waveguide and the adjustment process is repeated to maximize power through the waveguide. Figure 3 shows a close-up view of the silicon wafer and the optical fibers.

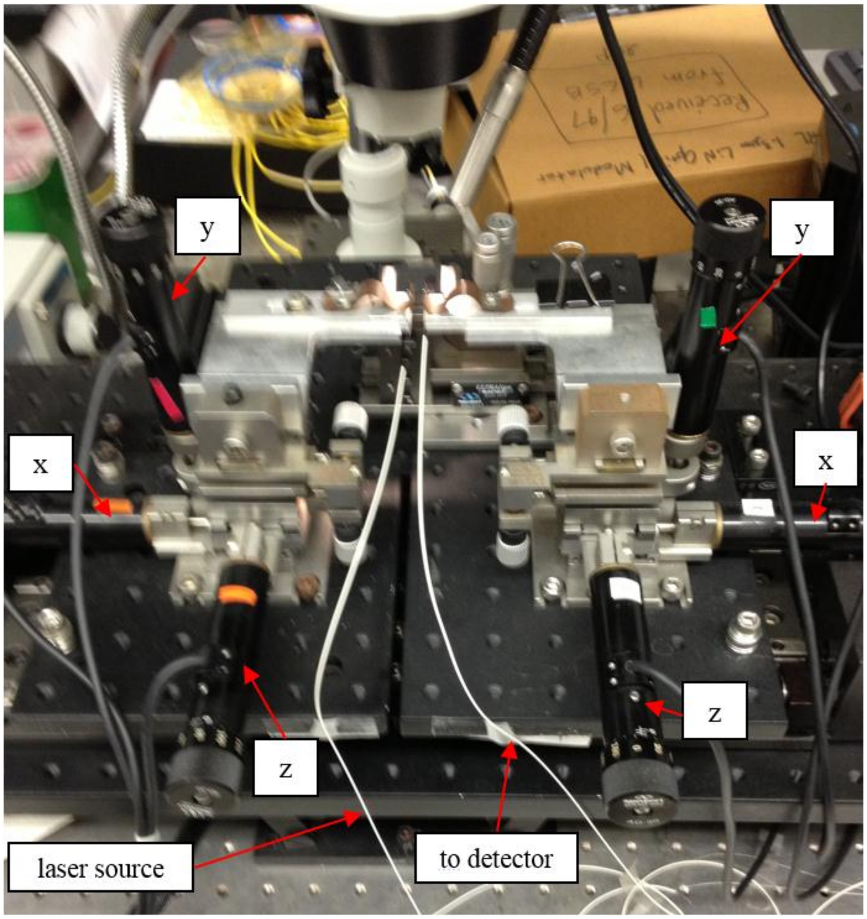

Figure 2. Measurement System Setup.

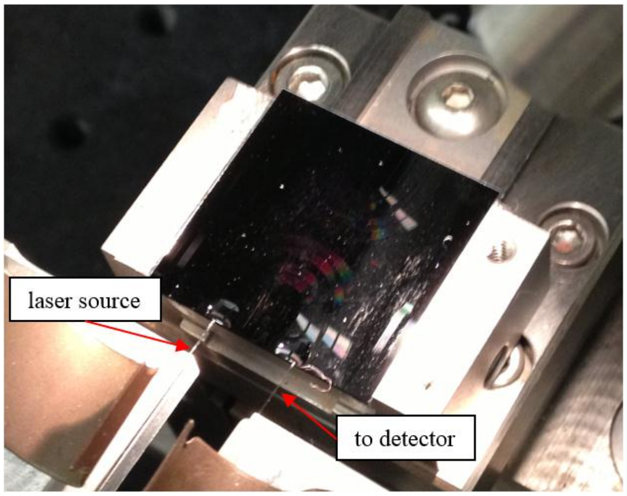

Figure 3. Close-up View.

Figure 4 shows the two Newport controllers that are used to control the x-y-z stages for the two fibers. To make an adjustment, the user has to turn the control knob to the x, y, or z axis and then turn the appropriate knob to make fine adjustments along that axis. The adjustment knobs can make up to 10 turns. Thus the complete process of lining up the fibers is very tedious and requires many adjustments of the knobs on the controllers. In addition, the two coarse adjustment stages are manufactured by Aerotech and are computer-controlled using a software interface that requires motion commands to be entered through the Aerotech computer interface.

Figure 4. x-y-z Axis Fine Adjustment Controllers.

AUTOMATED SYSTEM

The automation of the system to align the fibers to characterize the optical waveguides required the motion control and power measurements to be conducted through a single computer interface. It was decided that the LabVIEW™ software package would be used to design the computer interface. In order to design and develop a LabVIEW interface for the automation, the following tasks needed to be accomplished:

- Control of the x-y-z fine adjustment stages using LabVIEW
- Optical power measurement using LabVIEW
- Development of a LabVIEW algorithm to automatically control fine adjustment stages to maximize power
- Control of Aerotech coarse adjustment stages using LabVIEW
- Development of a LabVIEW interface that automatically characterizes a series of equally spaced waveguides on a single silicon wafer.

Control of the x-y-z Fine Adjustment Stages using LabVIEW

The Newport ESA-CXA controllers contained a BNC input connection for each axis. The BNC connections allowed for a 0-10 volt input analog signal to be applied for the motion control of the x-y-z fine adjustment stages. Using a USB-3103 eight-channel analog voltage output device provided by Measurement Computing, it was possible to control all three fine adjustments for each of the fibers via LabVIEW. Figure 5 shows the USB-3103 with the six connections for the fine adjustment control.

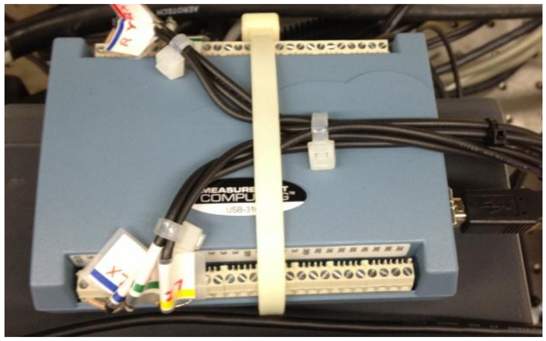

Figure 5. USB-3103.

Optical Power Measurement using LabVIEW

The optical power meter, PM100D manufactured by Thorlabs, contained a USB interface that allowed it to be connected to the computer, and power measurements could then be made using LabVIEW. Figure 6 shows the PM100D power meter.

Figure 6. PM100D Power Meter.

LabVIEW Algorithm to Automatically Adjust Fine Adjustment Stages to Maximize Power

To optimize the power through the waveguide, two techniques were investigated: the hill-climbing method [1] and the Simplex method [2], [3].

Hill-climbing Method

The hill-climbing method is the most widely used algorithm in the current photonics automation industry. In the hill-climbing method, each movement is based on the comparison between current and previous output light intensity measurements. Motion continues along a particular direction as long as the measurement increases. When the measurement decreases, motion is stopped and then moved to the previous position where the measurement was a maximum. Then the process is repeated for the next direction.

To implement this technique into the automated system, we began with maximizing the power by adjusting the x-y-z directions for the fiber that supplied light to the waveguide. Next the x-y-z directions for the fiber collecting light from the waveguide were maximized. This process was repeated for a total of three iterations. The distance moved between measurements was decreased with each iteration. This allowed the algorithm to move quickly to the location where the maximum power existed and to move closer to the maximum location with each increase in the iteration. Figure 7 shows the LabVIEW algorithm (Virtual Instruments, or VI) used to implement the hill-climbing method along a single direction. Figure 8 shows the implementation of the VI in the main LabVIEW VI to optimize power through the waveguide.

Simplex Method

A simplex is defined as a convex hull with N+1 vertices in an N-dimensional space. These vertices satisfy the nondegeneracy condition that the volume of the simplex hull is nonzero. Each dimension corresponds to a variable or factor in the optimization procedure. Thus, a two-dimensional simplex is seen to be a triangle while a three-dimensional simplex is seen to be a tetrahedron. The Modified Simplex Method (MSM) is an iterative algorithm starting from an initial simplex. Iteration k begins by ordering and labeling the current set of vertices as the best point (B), the next to the worst point (NW), and the worst point (W). The MSM allows the simplex to expand and contract to conform to the topography of the response surface, with the new vertex, named R.

King's MSM improves the convergence ability and the efficiency of the MSM. It is different from the standard MSM in that it reintroduces reflection from the next-to-worst vertex to encounter a failed contraction. When the initial reflection produces a point whose response is less desirable than the point B or NW, a contraction is in order. A contraction may be either positive or negative. A positive contraction (named PC) is marked when the refection point R gives a more favorable response than W. When the response at PC is still better than the response at NW, the point is substituted for W and the entire procedure is repeated. If the response at PC is worse than the response at NW, this point is substituted for PC, and a new reflection point R is marked based on the response at NW. In this case, the new reflection point R is used to form the next new simplex. This situation is called a failed contraction. On the other hand, a negative contraction (named NC) is marked when the response at R is less favorable than that at W. When the response at NC is better than the responses at NW, the point is substituted for W and the entire procedure is repeated. If the response at NC is worse than the responses at NW, the point is substituted for NC, and a new reflection point R is marked based on the response at NW. In this case, the new reflection point R is used to form the next new simplex. This situation is still called a failed contraction. The process is repeated until B stops changing [2].

Figure 9 shows a simulation of the simplex method. The algorithm used in the simulation was then used to generate a LabVIEW VI for the simplex method. The entire VI is too large to show here but the main part of the VI is shown in Figure 10. Figure 11 shows the implementation of the VI in the main LabVIEW VI to optimize power through the waveguide.

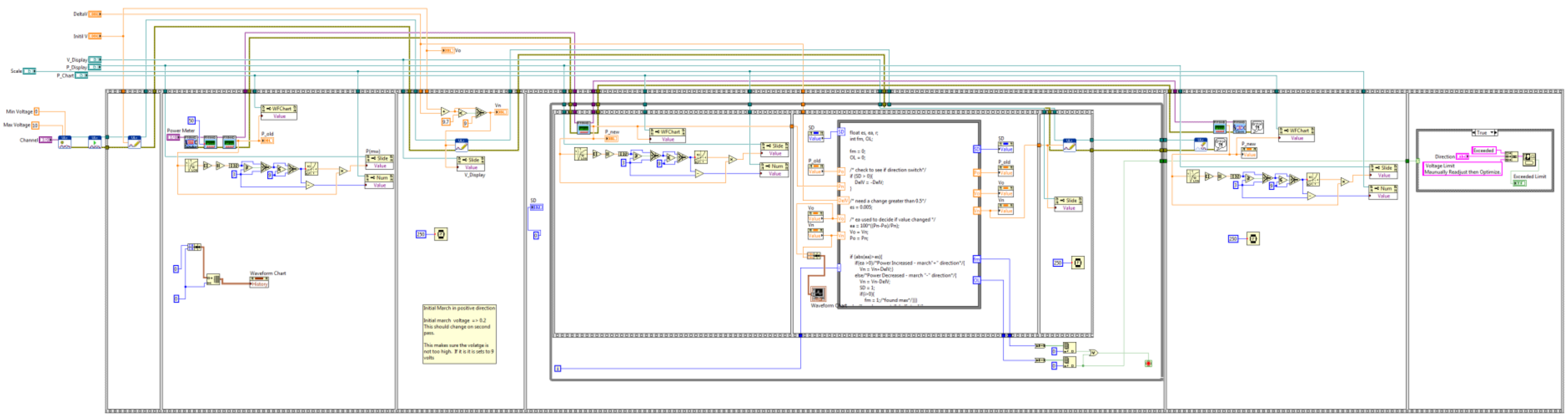

Figure 7. Hill-climbing Method.

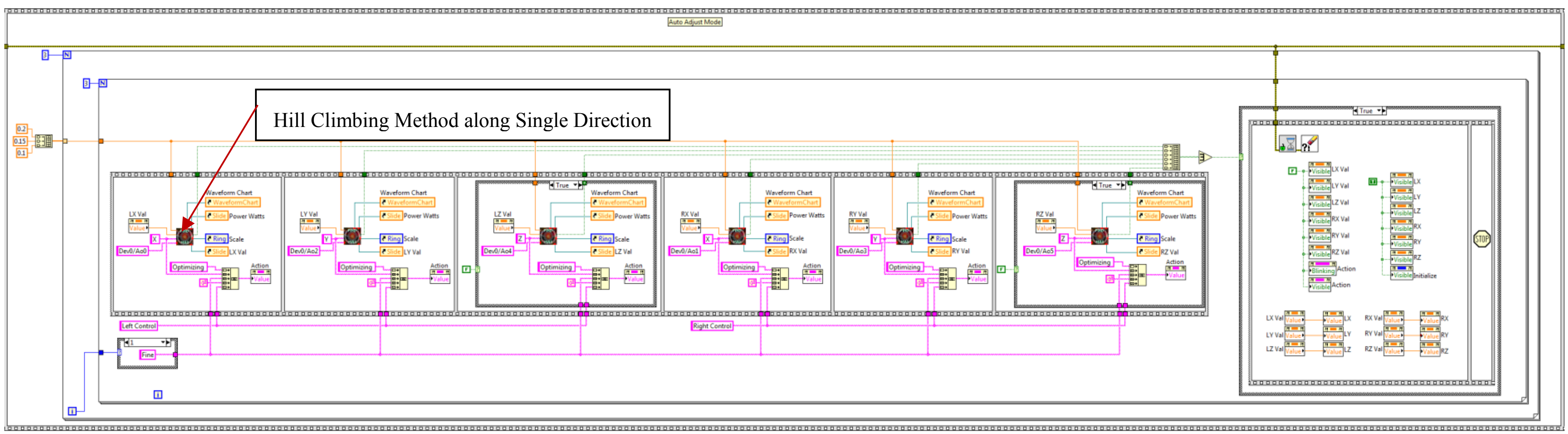

Figure 8. Implementation of Hill-climbing Method along Fiber x-y-z Directions.

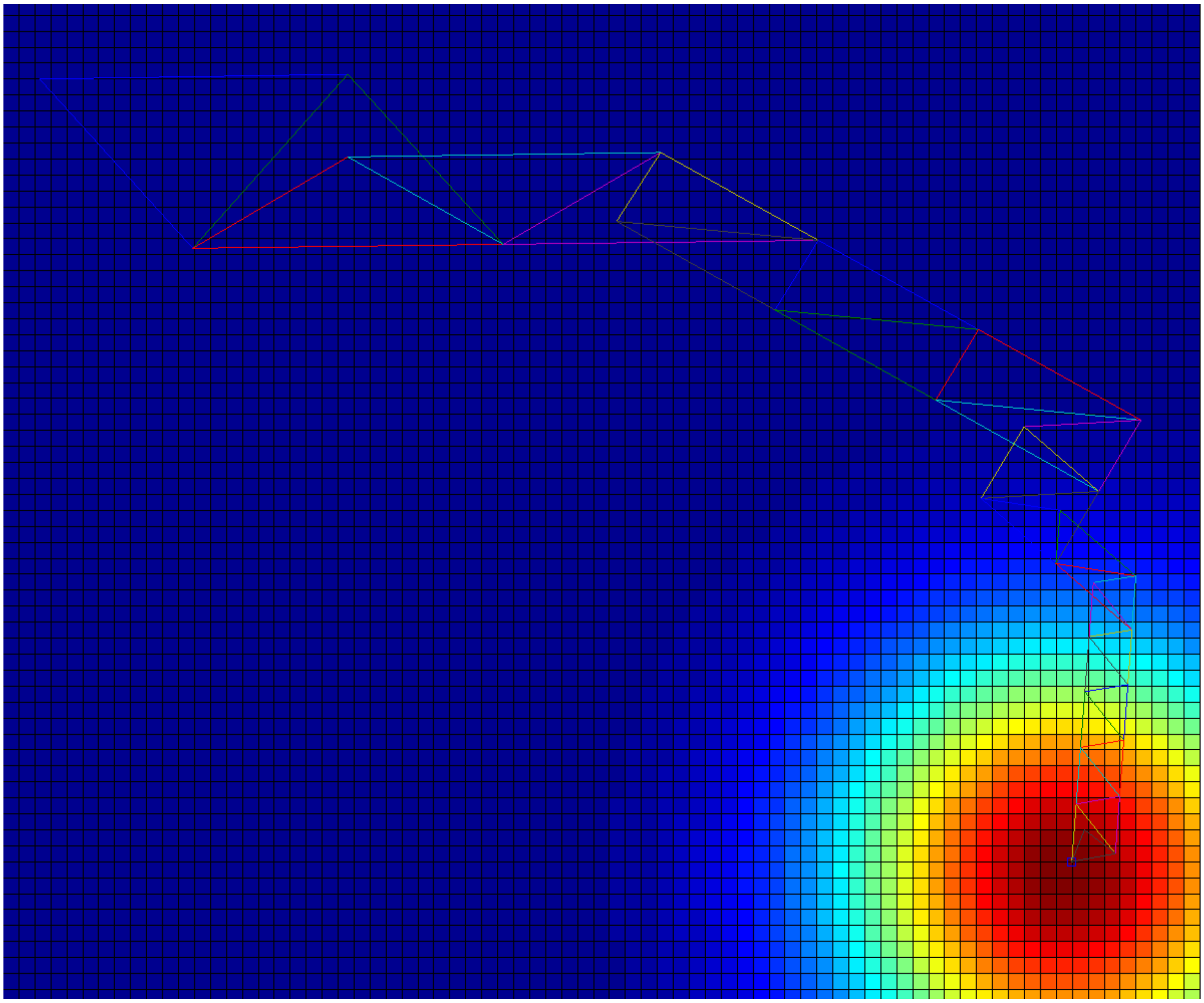

Figure 9. MATLAB Simulation of the Simplex Method.

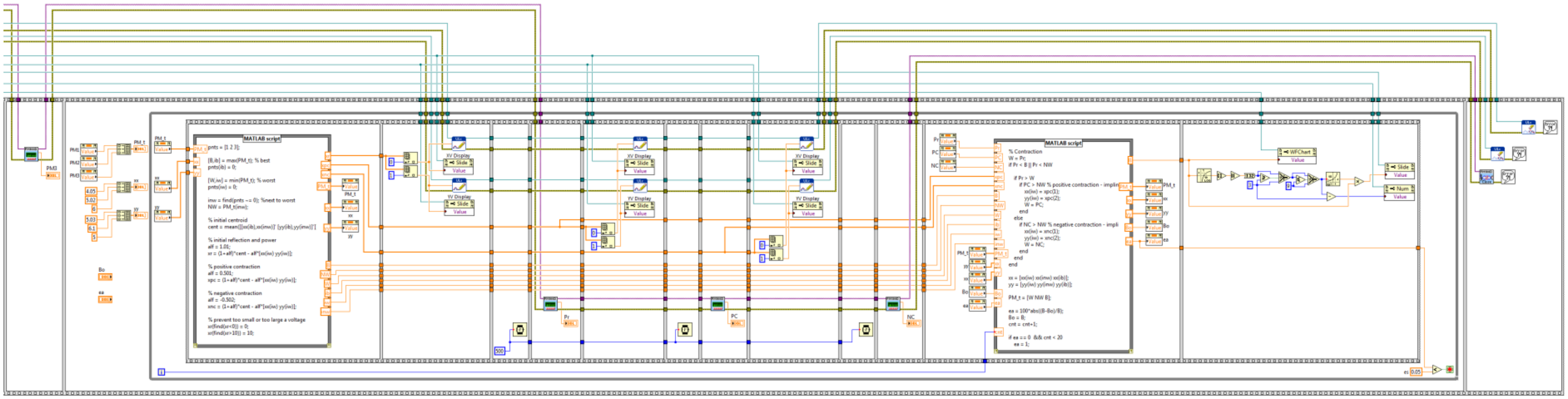

Figure 10. Simplex Method.

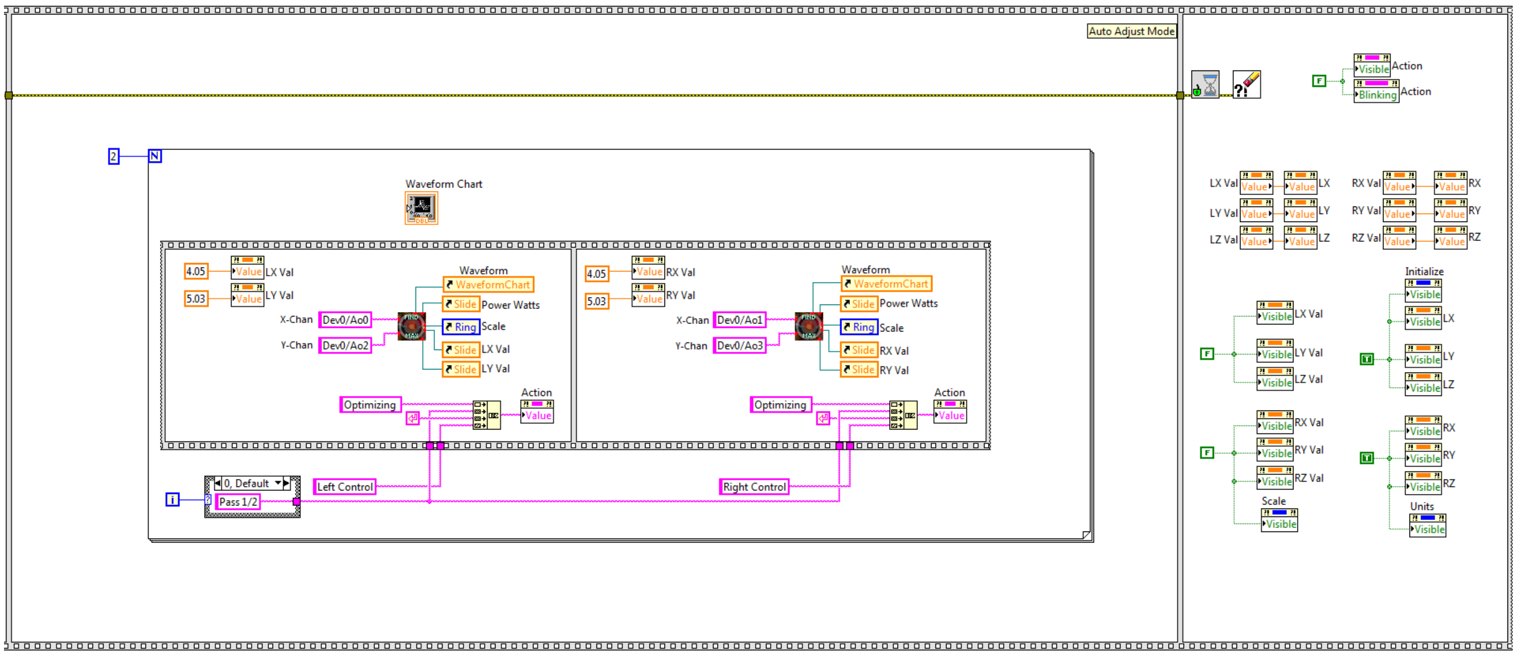

Figure 11. Implementation of Simplex Method along Fiber x-y-z Directions.

Selection of Method

While investigating the different methods, it was determined that once the two fibers were lined up initially along the z-direction full motion of the z-axis, fine adjustment had little effect on the power reading. This meant that it was not necessary to adjust the z-axis of the fibers to maximize the power through the waveguide. The main difference between the hill-climbing method and the simplex method is that the hill-climbing method works with only one axis at a time while the simplex method uses two axes at once. Because of this, the simplex method should locate the desired fiber positions that resulted in maximum power quicker than the hill-climbing method. In testing the two methods, it was determined that the simplex method was very sensitive to the values of the parameters used to determine new points for the vertices of the triangles. By making small changes, it was possible for the method to locate the desired position, but when a new starting position was used the method would often fail and the parameters had to be changed to find the desired location. The hill-climbing method on the other hand was more robust and was much more successful at locating the desired fiber positions for maximum power. In terms of time to converge, the simplex method was about twice as fast as the hill-climbing method in locating the desired position. It took the simplex method about 15 seconds to locate the maximum position, and it took the hill-climbing method about 30 seconds to locate the maximum position. This was considered to be a small time difference and was not a factor when determining which method to select. The hill-climbing method was selected as the method to use for optimizing the power through the waveguide because of its robustness and ability to consistently locate the maximum power position.

Control of Aerotech Coarse Adjustment Stages using LabVIEW

The main difficulty with the Aerotech stages had to do with hardware issues. The current Aerotech system being used was manufactured in 1995 and the computer interface board on the computer was an ISA (Industry Standard Architecture) board. This meant that the LabVIEW software version needed for the USB devices was not supported by the computer with the ISA board. Computers capable of running the LabVIEW software version did not contain the ISA slot needed for the interface board. After locating a PCI version of the interface board, it was possible to install the interface board and software version of LabVIEW needed for the USB devices on a single computer. Once the system was up and running, it was possible to control the Aerotech stages and fine adjustment stages using LabVIEW.

LabVIEW Interface to Characterizes a Series of Equally Spaced Waveguides on a Single Silicon Wafer

Figure 12 shows the LabVIEW interface for the manual adjustment of the Aerotech stages. This interface is used to initially line up the fibers along the x-direction. The alignment only needs to be close enough to register a small amount of light through the waveguide. The hill-climbing method can then be used to find the desired position for maximum power. Figure 13 shows the final LabVIEW interface for the characterization of the waveguides on a silicon wafer. There are three modes of operation. The ***Manual*** mode allows the user to manually fine adjust the x-y-z axis stages of the fibers. The ***Optimize*** mode is used to optimize the power through the waveguide. This mode would be used if only a single waveguide is being studied. The ***Auto Scan*** mode is used to characterize more than a single waveguide. Utilization of the two interfaces shown in Figures 12 and 13 will significantly reduce the time and effort needed to characterize the waveguides.

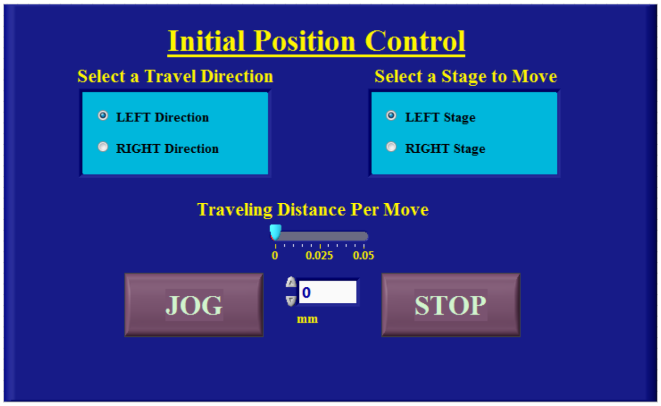

Figure 12. LabVIEW Interface - Coarse Motion Control.

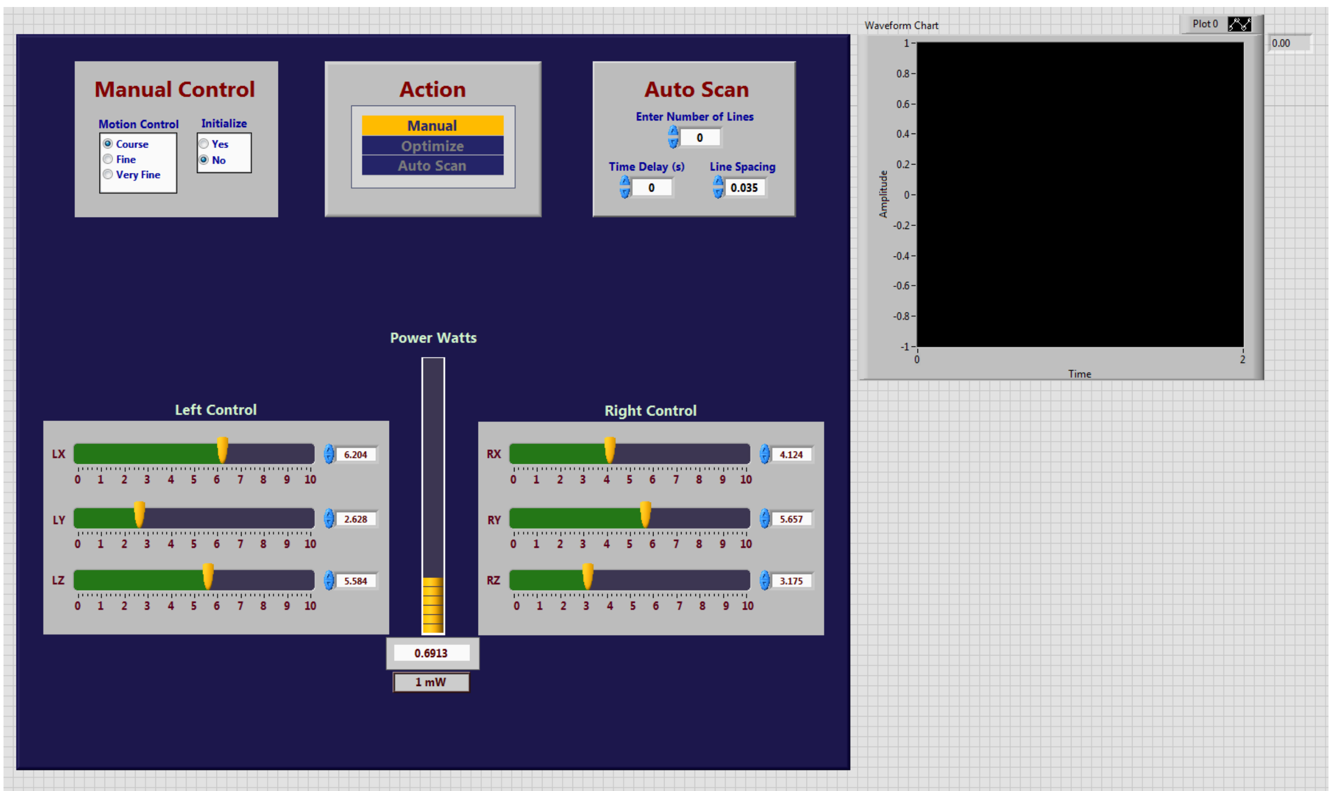

Figure 13. Main LabVIEW Interface for Characterization of Waveguides.

FUTURE WORK

Using the current method of characterizing the waveguides, it can take up to 8 hours to characterize the waveguides on a single silicon wafer. Using the computer automation system developed, the characterization process has been reduced to less than an hour. In addition, once the ***Auto Scan*** mode is started the process is fully automated, allowing personnel to work on other activities.

The current automated system will stop running and report an error if a command is given to move a fine adjustment stage beyond its voltage limits. When the error is given, it is possible to automatically adjust the coarse adjustment stage such that the error is not encountered during optimization. Because there are only stages for coarse adjustments along the x-direction, an error in the voltage limits for the y-direction will still stop the automated characterization process. With the addition of a set of stages for the y-direction, it will be possible to run the ***Auto Scan*** mode without errors occurring that require the recharacterization of a particular waveguide. In the near future, changes will be made such that the error is recorded and the characterization process proceeds without stopping in the y-direction. For the x-direction, when an error in the voltage limits is encountered, the system will automatically adjust the x-direction coarse stages and reoptimize. In the distant future, coarse stages will be added to eliminate voltage errors in the y-direction.

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14. ABSTRACT

This report describes an automated alignment system developed to aid in the process to evaluate the optical characteristics of waveguides that are manufactured for research in optical communications. Using the current method of characterizing the waveguides, it can take up to 8 hours to characterize the waveguides on a single silicon wafer. Using the computer automation system developed, the characterization process has been reduced to less than an hour.

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