Application Note

AN004: Fiber Coupling Improvement

Introduction

AgilOptics' mirrors increase coupling efficiency into a 4 µm diameter fiber by 750%.

Industrial lasers used for cutting, welding, drilling, engraving, and ablation require high power and a sharp focus. A sharper focus allows for precision cuts and will drill smaller holes. A sharper focus also increases the power density which maximizes the fiber coupling efficiency. Increased power density means less time spent cutting or welding and requires less laser power at less cost. Money can be also be saved by allowing the use of fiber cables with smaller core diameters, and by eliminating the need for expensive optics to correct wavefronts.

A sharper focus can be achieved by removing undesired aberrations in a laser beam. These aberrations are caused by the optics, the laser itself, and by the surrounding environment. The best focus that can be obtained is based on the diffraction limit of the system. By introducing a wavefront beam corrector into the system, aberrations can be removed to obtain a sharper focus.

Figure 2 25mm Multi™

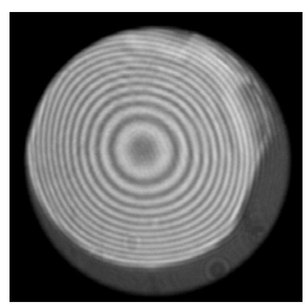

Figure 1 25mm Multi™ active at 90V

A 25 mm diameter Multi™ and Clarifi™ were used to correct the wavefront. Clarifi™ is a Windows™ based application that is used to drive the Multi™. Experiments were conducted with the Clarifi™ software and a 25 mm Multi™ DM in a closed loop system to improve the free space laser fiber coupling efficiency. A 75 mm focal length lens was used to couple laser light into a multi-mode fiber optic cable with a 4 µm core and a single-mode fiber optic cable with a 50 µm core diameter. Clarifi™ optimizes the photodiode detector output by adjusting the Multi™ to achieve the best focus at the fiber. The Multi™ DM can remove aberrations and simultaneously keep the beam pointed on the fiber when the laser drifts.

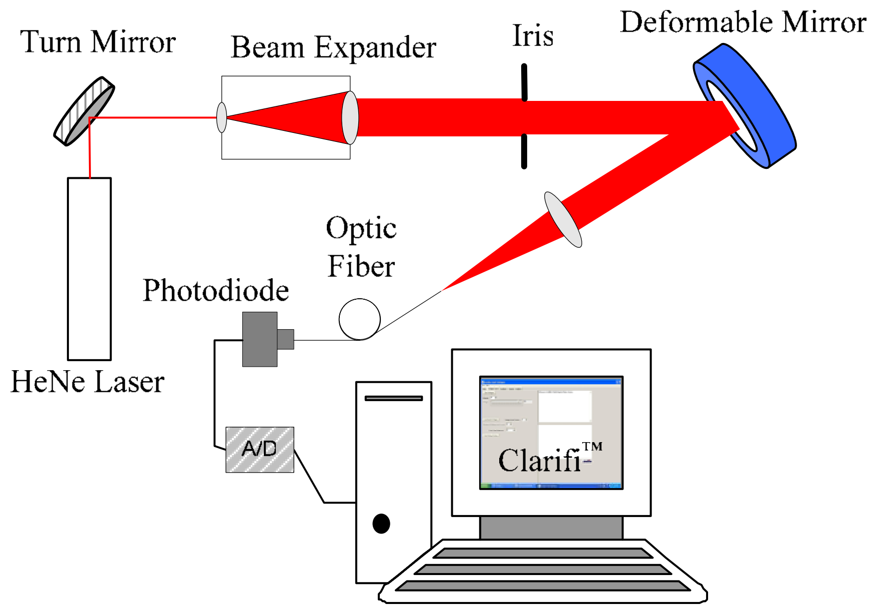

Figure 3 Experimental Setup

Figure 3 illustrates the experimental configuration. Fiber coupling efficiency is also limited by manual fiber alignment. Fiber coupling is especially difficult for lasers with poor beam quality caused by increased thermal distortions as the power is increased.

Improved Coupling Efficiency into a 4 μm Fiber Core

This experiment shows an incredible increase in coupling efficiency between the ranges of 250% to 750% into a single mode 4 μm fiber core using a closed loop system with Clarifi™ and a 25 mm Multi™ DM. The 4 µm fiber has a 0.13 NA and a cladding of 125µm. Figure 3 shows the results of this experiment.

The percent coupling increases is defined as the corrected detector output, P_{DC}, minus the initial detector output, P_{DI}, divided by the initial detector output shown in **Equation 1**.

$$\frac{P_{DC} - P_{DI}}{P_{DI}} \qquad \textbf{(1)}$$

The DM was initialized at 90 volts. Then the optic fiber was realigned for maximum detector voltage readings. The normalized initial and corrected power curves use the left axis. The initial power is the power incident on the detector from the 4 μm fiber core without correction. The corrected power is the power incident on the detector after closed loop system had improved the coupling. The percent improvement curve uses the right axis.

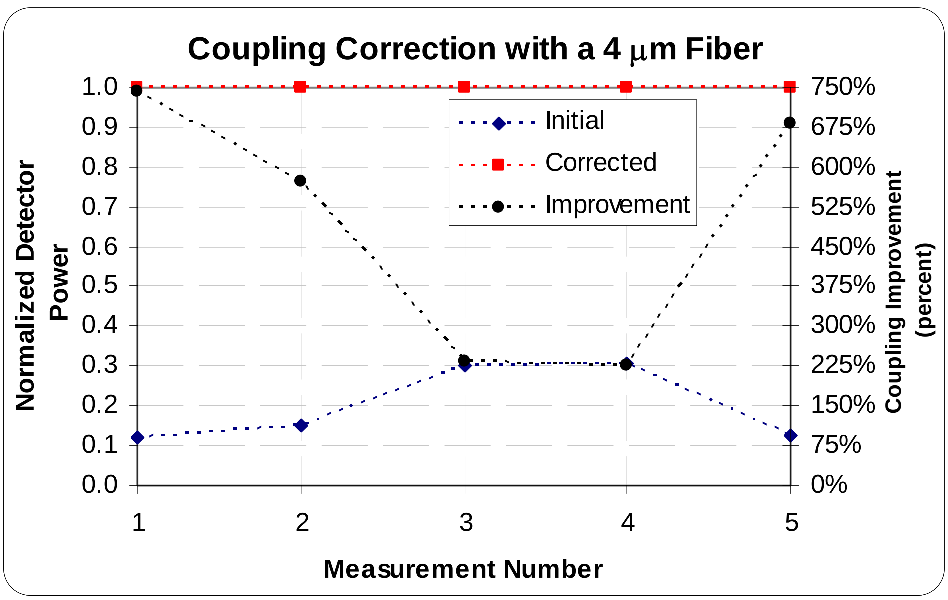

Figure 4 Coupling Correction on a Single Mode 4 µm Fiber Core

Improved Coupling into a 50 μm Fiber Core

This experiment illustrates the capability of the closed loop system to improve the coupling efficiency after a manual fiber coupling alignment for the 50 μm fiber. The chart in Figure 4 below shows the experimental results. The improvement ranged from 5% to 7.5% during the five measurements.

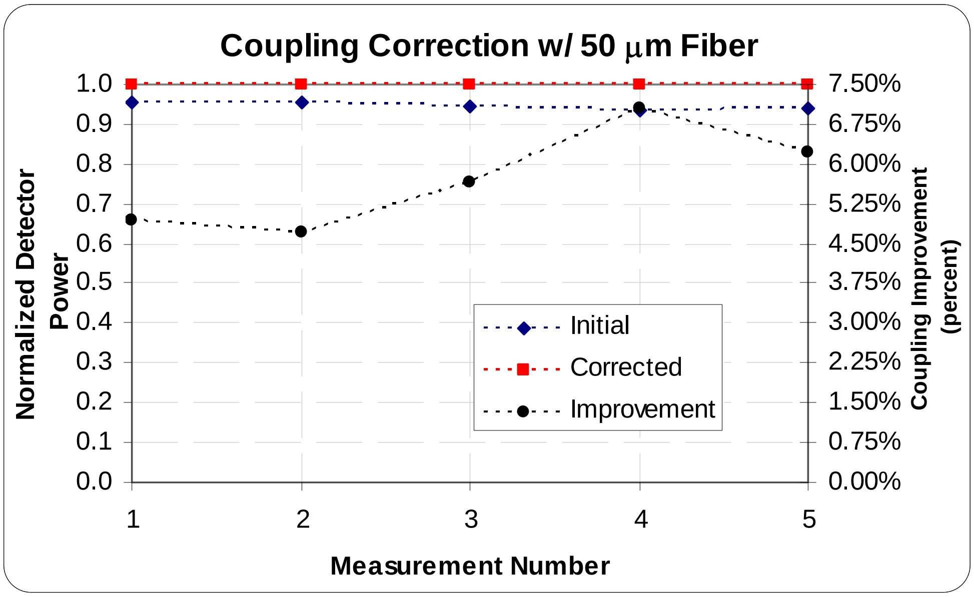

Figure 5 Coupling Correction on 50 µm Fiber Core

This implies that all of the light exiting the lens was not being coupled into the fiber before correction. No increased coupling was detected with the initial voltage state of the deformable mirror set to zero.

Experimental Configuration

The optical components used for this experiment are a Spectra-Physics 632.8 nm HeNe laser, a 20x beam expander, an iris diaphragm, a 25 mm Multi™ DM, 50 mm diameter by 75 mm focal length achromatic doublet lens, a 61 cm 50 μm multi-mode fiber optic cable, a 2 m single mode 4 µm fiber optic cable, and a photodiode detector. The optical configuration is shown in Figure 1. The shaded portion in Figure 2 is the feed back loop. The Multi™ DM uses 37 electro-static actuators and has a 1 µm thick membrane. Figure 5 is a digital image of the configuration. The shaded area in Figure 5 is the closed loop system.

Laser light from the HeNe laser is directed into a beam expander by a turn mirror. The beam is expanded and collimated to approximately 25.4 mm in diameter. The beam diameter exiting the beam expander is stopped down to 19 mm before it reaches the DM which utilizes 67% of the DM's active area. The DM directs the light through the 75 mm lens. The distance from the DM to the lens is 55.25 cm. The angle of the incident beam to the output beam at the DM is approximately 45°. The 75 mm lens couples the laser light into the fiber core at its focal length. The fiber optic is mounted on a tip-tilt stage attached to a xyz translation stage. The fiber delivers the light to the photodiode detector. The detector output is converted to a voltage through a variable resistor in parallel. The output of the resistor is fed into a 12-bit A/D converter connected to a PC USB port.

The voltage corresponds to the power incident on the detector which is the detector voltage divided by the detector responsivity and the resistance shown in **Equation 2**.

$$P = \frac{V_D}{\Re(\lambda) R_{LOAD}} \qquad \textbf{(2)}$$

Where P is the power at the detector, V_D is the voltage from the detector, $\Re(\lambda)$ is the responsivity at the wavelength, λ , R_{LOAD} is the resistance. $\Re(\lambda)$ is approximately 0.4 at λ = 632.8 nm.

The photodiode current is converted into a voltage Clarifi™ uses to optimize the beam quality. The amount of beam correction is limited by the fiber core diameter. Once all of the energy is directed onto the fiber core, no more correction is possible even if the diffraction limit has not been reached. To improve beam quality, a smaller fiber core is required.

To achieve 100% laser coupling into the fiber, the fiber numerical Aperture NA = D/2f = 0.127 is required. The diffraction limited spot diameter is 2.44 λf/D = 6.08 μm. Ideally, the 75 mm focal length lens has the capability for 100% coupling of light into a 0.127 NA fiber core or greater. The 0.13 NA of the 4 µm fiber and the 0.22 NA of 50 µm fibers used in these experiments are capable of coupling with the 75 mm focal length lens.

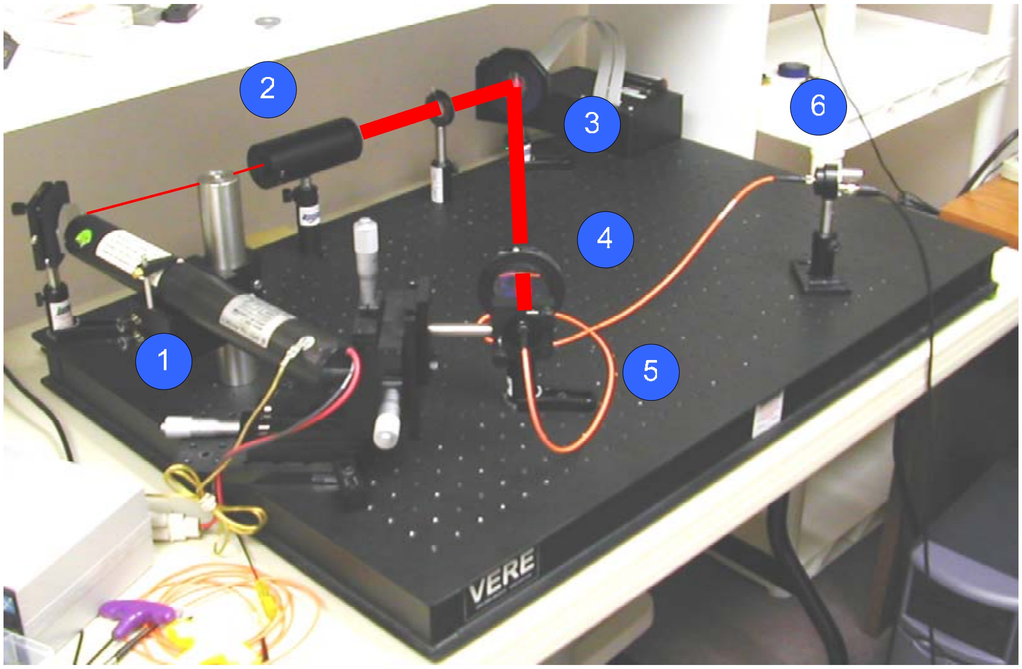

Figure 6 Digital Image of Optical Configuration

1. HeNe Laser
2. Beam Expander
3. AgilOptics' 25mm Multi DM
4. 75mm Lens
5. Fiber Optic Cable
6. Photodiode

These experiments start with an initial preload bias of 90 volts on the deformable mirror membrane. This pulls the membrane in towards the actuators and gives the membrane a radius of curvature of about 15 m. This allows the membrane to apply wavefront corrections in either direction. Figure 1 shows the interferogram of the DM in this state.

Control Algorithms

The Clarifi™ algorithms used to optimize the coupling efficiency are the focus scanning, the Zernike dithering, and the Guided Evolution with Simulated Annealing (GESA).

Dithering is a type of control algorithm in which actuator voltages or sets of actuator voltages are raised and lowered one at a time to the voltage that minimizes the error function. GESA is a genetic control algorithm using 10 sets of child voltages generated from each parent, with the difference between parent and child steadily decreasing in each iteration to cause an annealing effect.

The combination of all three algorithms was utilized for each measurement. No single algorithm seemed to out perform the other two in terms of speed and finding the optimum coupling efficiency.

Conclusions

These experiments showed increased free space laser to fiber coupling efficiency using a 25 mm Multi™ DM and Clarifi™ in a closed loop system. Clarifi™ optimizes the photodiode detector voltage which is directly proportional to the power on the detector. It is assumed that the coupling efficiency is the indicator of how well the beam quality has improved.

A coupling efficiency improvement of 7.5% was seen for a 50 µm fiber core. A 750% coupling efficiency improvement was seen for a single mode 4 µm fiber core with a 0.13 NA. The amount of increase in coupling efficiency for any given fiber coupling system depends on the diffraction limited spot diameter, the fiber core diameter, the NA of the fiber optic cable, the f-number of the lens at the entrance aperture, and the initial alignment.

Optical switches can also benefit from increased coupling efficiency. The 25 mm Multi™ deformable mirror has a beam steering capability also.

This system is now available from AgilOptics as ClariFIBER™.

Results

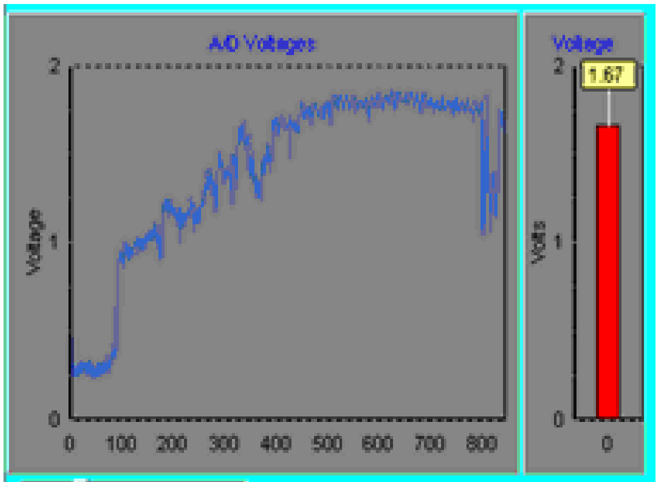

Figure 7 Screen Capture of ClariFIBER™ during operation

ClariFIBER™ is AgilOptics' system for optimizing laser to optic fiber coupling. The screen capture in **Figure 7** shows ClariFIBER™ during operation. The initial voltage output from the photodetector was less than 0.5V. ClariFIBER positioned and focused the laser beam to achieve approximately a 700% increase in the photodetector output.

AgilOptics has refined the ClariFIBER™ system to a minimum set of components, including the software. **Figure 8** shows a standard ClariFIBER™ set up.

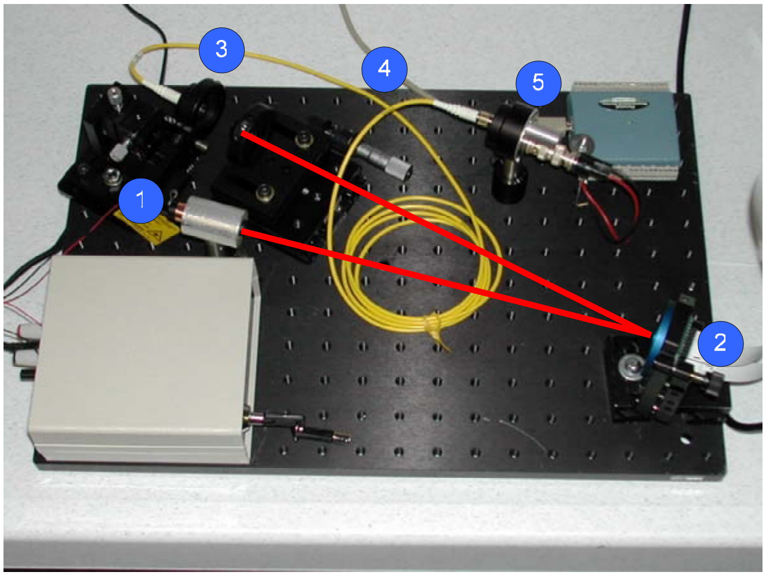

Figure 8 ClariFIBER™ basic set up

1. Laser Diode
2. Deformable Mirror
3. Lens with fiber optic connector
4. Fiber Optic Cable
5. Photodetector

What Can Deformable Mirrors Do?

- Correct Optical Aberrations
- Laser Beam Shaping
- Optical Image Enhancement

Deformable mirrors are revolutionizing laser and optical systems by replacing static components with dynamic optics. Deformable mirrors (DM) are adaptive optics with dynamic faces able to optimize or change the characteristics of reflected light for a specific application. With time-varying control, a DM can focus a beam at several different points at different times or it can replace a lens in an optical system. Deformable Mirrors can improve optical images in telescopes, cameras, and other imaging systems.

For further information and discussion about how deformable mirrors work and how they will solve your optical problems see the manuals for HVDD, Clarifi, and the application notes available on the Web.

http://www.agiloptics.com/AppNotes.htm

http://www.agiloptics.com/downloads.htm