INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book. These are also available as one exposure on a standard 35mm slide or as a 17" x 23" black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
Transmission of quartz capillary optical fibers as a function of diameter and refractive index fluid

Hwang, Chan Joo, M.S.
The University of Arizona, 1989
TRANSMISSION OF QUARTZ CAPILLARY OPTICAL FIBERS
AS A FUNCTION OF DIAMETER AND REFRACTIVE INDEX FLUID

by

Chan Joo Hwang

A Thesis Submitted to the Faculty of the
COMMITTEE ON DEPARTMENT OF PHYSICS
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF SCIENCE
In the Graduate College
THE UNIVERSITY OF ARIZONA

1989
STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: [Signature]

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

[Signature] W. S. Bickel
Professor of Physics

Date
ACKNOWLEDGMENTS

I would like to thank and acknowledge various persons for their help, suggestions, and support in the research and writing of this thesis. First, I wish to thank my parents for their support and understanding throughout my college career.

My best wishes to my advisor, Dr. William S. Bickel, for the original suggestion for the thesis topic and for equipment used in the experiment. My thanks to Jeha Kim and Sukmock Lee for support, advice, and useful comments about the experiment and Lih Sin The and Yuan Hu for computer aid.

I would also like to thank all the people that helped in one way or another that were not mentioned by name.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>5</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>6</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>7</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>8</td>
</tr>
<tr>
<td>2. SAMPLE PREPARATION</td>
<td>10</td>
</tr>
<tr>
<td>Fiber</td>
<td>10</td>
</tr>
<tr>
<td>Determination of Fiber Quality</td>
<td>12</td>
</tr>
<tr>
<td>Refractive Index of Fluid</td>
<td>12</td>
</tr>
<tr>
<td>The Optics of the Fiber</td>
<td>15</td>
</tr>
<tr>
<td>3. PROCEDURE</td>
<td>18</td>
</tr>
<tr>
<td>4. EXPERIMENTAL DATA AND ANALYSIS</td>
<td>22</td>
</tr>
<tr>
<td>5. CONCLUSION</td>
<td>33</td>
</tr>
<tr>
<td>LIST OF REFERENCES</td>
<td>34</td>
</tr>
</tbody>
</table>
LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Photograph of a cut end of 100 μm fiber</td>
<td>13</td>
</tr>
<tr>
<td>2.</td>
<td>Photograph of the intensity distribution of the transmitted beam taken with a strip of photographic paper</td>
<td>14</td>
</tr>
<tr>
<td>3.</td>
<td>Maximum entrance angle definition of critical angle $\theta_e$, half-angle $\theta$ and numerical aperture $NA = \theta$</td>
<td>16</td>
</tr>
<tr>
<td>4.</td>
<td>Diagram of the optical and detector system used in the experiment</td>
<td>19</td>
</tr>
<tr>
<td>5.</td>
<td>Diagram of the top and end view of the optical fiber filled with refractive index fluid</td>
<td>21</td>
</tr>
<tr>
<td>6.</td>
<td>Transmitted intensity as a function of beam insertion point for 530 μm ID fiber</td>
<td>23</td>
</tr>
<tr>
<td>7.</td>
<td>Transmitted intensity as a function of beam insertion point for 320 μm ID fiber</td>
<td>24</td>
</tr>
<tr>
<td>8.</td>
<td>Transmitted intensity as a function of beam insertion point for 250 μm ID fiber</td>
<td>27</td>
</tr>
<tr>
<td>9.</td>
<td>Transmitted intensity as a function of beam insertion point for 200 μm ID fiber</td>
<td>28</td>
</tr>
<tr>
<td>10.</td>
<td>Transmitted Intensity as a function of beam insertion point for 100 μm ID fiber</td>
<td>29</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Specifications of flexible fused silica fibers</td>
<td>11</td>
</tr>
<tr>
<td>2. Refractive indices of fluids</td>
<td>11</td>
</tr>
</tbody>
</table>
ABSTRACT

Recent experiments with optical fibers have reached a remarkable development for optical communication spectroscopy as well as a medical technology. Hollow optical fibers are required for optical communications. The measurement of the transmission of light through fibers can provide information about the fiber quality and about the far-field energy which radiates from the fiber end. We used five flexible hollow fused quartz fibers to study laser beam propagation down the fiber axis. Five different refractive index fluids were prepared and inserted into the fiber core to measure the transmitted intensity as a function of core property. The plots of the normalized, relative transmitted intensity measured as a function of the beam insertion point show the dependence of the transmitted intensity as a function of fiber diameter and refractive index fluid.
CHAPTER 1

INTRODUCTION

A flexible hollow core fiber is one of the most promising waveguides to satisfy the demand that the initial laser mode be preserved while the beam is focused to a small spot size. Although the air core refractive index is smaller than the cladding refractive index, this waveguide still confines most of the transmitted power to the air core because of the total internal reflection of the waves from the dielectric or metallic cladding.\(^2\).

A new type of middle-infrared optical fiber was proposed in which quartz is used as the cladding material to define a hollow core. Quartz has refractive index close to unity in the IR frequency range near 100,000 Å due to the nearby resonance of molecular vibrations. Therefore the total reflection of the incident laser light from air to quartz surface occurs, creating a hollow-core optical fiber with quartz functioning as the cladding while exhibiting small transmission loss.\(^3\)

The small transmission loss permits the quartz fibers to be used for optical communication with a transmission wavelength (\(\lambda_t\)) ranging from ultraviolet (UV) to near infrared (0.20 < \(\lambda_t\) < 2 μm). Fibers for the longer wavelength regions have been widely developed, while those for the shorter wavelength regions such as vacuum ultraviolet (VUV) light or soft x rays remain undeveloped.\(^5\)

The lens-coupled connector is one of the basic type of connections between two single fibers. Spring-loaded connectors press the fiber ends into a low-loss optical lens. The lens is immersed in a viscous fluid whose refractive index matches
the core index of the fiber. The fibers are therefore aligned optically rather than mechanically\(^4\).

The most frequent measurement in all of fiber optics is a simple and direct power measurement of the total radiation emanating from an optical fiber. Far-field scanning of the \(\theta\)-dependent optical power output from the fiber is an infrequent measurement. This is unfortunate because a great deal of diagnostic information can be learned about the fiber with this straightforward but more cumbersome technique\(^6\).

We decide to measure the fiber transmitted beam as a function of the energy insertion point along the fiber diameter. It is well known that improper coupling or misalignment can cause severe losses at fiber junctions. In the optical region, laser beams can be prepared into the desired polarization state and focused precisely to spots of the desired size and solid angle. This energy can be totally accepted by the entrance aperture of the fiber. In the VUV and x-ray region this high quality control is not available and compromises must be made at the insertion and coupling points. We will show how the insertion point location affects transmission through the fiber. This will guide the development of optical fiber couplers for VUV and x-rays.
CHAPTER 2

SAMPLE PREPARATION

Fiber

The five flexible fused silica fibers used in these experiments were supplied by Polymicro Technologies. Their specifications are shown in Table 1. The hollow fibers are made of fused quartz (SiO₂) and are coated with an epoxy outer jacket for protection because they are brittle. For these experiments, the fibers were cut to lengths of 8 to 12 cm with a standard NRC silicon carbide blade fiber cutter.

Two different techniques were used to cut the fibers and produce high quality ends. One, "the roll cut with pull", goes as follows: put the carbide cutter on the fiber perpendicular to the fiber length, press the cutter very gently and roll the fiber approximately one turn. This creates a fine scratch. Then remove the cutter from the fiber and pull on the fiber to apply a force along the fiber length. The fiber will break at the scratch point. This technique works well for fibers smaller than 200 \( \mu m \) ID. The other technique, "roll cut with bend" was used to cut the larger fibers. Here the carbide edge is placed near the end of a cut fiber while the fiber is rolled. The fiber is then bent near the cut mark causing it to break cleanly and smoothly.

Both techniques require practice, careful treatment and gentle application of forces to pull and bend. If too many rolls are made or if the starting and end points do not match, the break will be nonuniform. This will cause a fractured end, chipped surface or a rough nonperpendicular end. If this occurs, the fiber is recut. Using these techniques, many fibers were cut to the desired length all of which had
### Table 1. Specifications of flexible fused silica fibers

<table>
<thead>
<tr>
<th>Fiber No.</th>
<th>Inside Diameter (µm)</th>
<th>Nominal Coating Thickness (µm)</th>
<th>Outside Diameter (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>530 ± 24</td>
<td>15</td>
<td>660 ± 50</td>
</tr>
<tr>
<td>2</td>
<td>320 ± 12</td>
<td>15</td>
<td>450 ± 40</td>
</tr>
<tr>
<td>3</td>
<td>250 ± 12</td>
<td>15</td>
<td>365 ± 30</td>
</tr>
<tr>
<td>4</td>
<td>200 ± 12</td>
<td>15</td>
<td>300 ± 20</td>
</tr>
<tr>
<td>5</td>
<td>100 ± 12</td>
<td>15</td>
<td>200 ± 12</td>
</tr>
</tbody>
</table>

### Table 2. Refractive indices of the fluids and quartz at λ = 6328Å

<table>
<thead>
<tr>
<th>Number of Fluid</th>
<th>Refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5806 ± 0.005</td>
</tr>
<tr>
<td>2</td>
<td>1.5600 ± 0.005</td>
</tr>
<tr>
<td>3</td>
<td>1.5584 ± 0.005</td>
</tr>
<tr>
<td>4</td>
<td>1.4582 ± 0.005</td>
</tr>
<tr>
<td>5</td>
<td>1.3995 ± 0.005</td>
</tr>
<tr>
<td>quartz</td>
<td>1.4571 ± 0.005</td>
</tr>
</tbody>
</table>
high quality ends which were flat, perpendicular to the fiber axis and free of chips. When the fibers were cut, the epoxy coating was removed from about 5 mm from each end by putting the end in a bunsen flame. The epoxy was left on the rest of the fiber to keep it strong.

**Determination of Fiber Quality**

After the fiber was cut, visual, photomicrographic and photographic observations were used to assess the fiber quality. All fiber ends were observed with a Nikon HKW microscope equipped with a Minolta camera. Visual observation permitted a quick check of the quality of each end, while photomicrographs were used to record the good fiber ends that were used in the experiments. A photograph of a cut fiber end is shown in Fig. 1. The end is flat and free of serious defects. The intensity distribution of a beam transmitted down the axis of the fiber taken with a strip of photographic paper placed at the detector location 3 cm from the fiber and perpendicular to its end is shown in Fig. 2. A perfect fiber would create a uniform intensity $I(\phi)$ distribution. The lack of uniformity indicates that one or both of the ends of this fiber are not perfect. However, this test is very sensitive to end imperfections. We found that fibers could have very high transmission properties even through the $I(\phi)$ distributions were not perfect.

The outer surface and cladding material were examined at several places along the fiber to determine its radius and assess its surface quality, paying special attention to surface and internal defects such as air bubbles and scratches.

**Refractive Index Fluid**

Five refractive index fluids were prepared to insert into the core of the
Fig. 1. Photograph of a cut end of 100 μm ID fiber
Fig. 2. Photograph of the intensity distribution of the transmitted beam taken with a strip of photographic paper placed at the detector location.
fibers for the experiments. Three Cargille oil immersion liquids having different refractive indices were mixed in the proper proportion to create five liquids with the refractive indices, shown in Table 2. The refractive index of each prepared liquid was measured with a Bausch and Lomb Abbe-3L refractometer at the Optical Sciences Center. The goal here was to produce three fluids which respectively had refractive indices equal to, less than and greater than the refractive index of quartz (n = 1.4571) at the He-Ne laser wavelength $\lambda = 0.6328 \, \text{Å}$. 

*The Optics of the Fiber*

The optics of a hollow fiber is described by the equations relating Snell's law, the half-angle and numerical aperture (NA). For a step-index fiber, light rays from the core strike the cladding at various angles of incidence, as shown in Fig. 3. When $\theta$ reaches a certain critical angle $\theta_c$, all the light will be reflected. Because of this total internal reflection, the light will be confined to the core and will follow a zigzag path down to the core to the other end. We are considering only focused rays injected at a point on the center of the fiber core. From Snell's law, the critical angle is given by

$$\sin \theta_c = \frac{n_2}{n_1}$$

provide that $n_1$ is greater than $n_2$. This can be rewritten

$$\theta_c = \sin^{-1} \frac{n_2}{n_1}.$$ 

The total internal reflection will occur only for those rays incident at angles equal to or greater than the critical angle.

Light rays strike the insertion point of an optical fiber at many different
Fig. 3. Maximum entrance angle definition of critical angle $\theta_c$, half-angle and numerical aperture $\text{NA} = \theta$
angles. However, for a ray to be propagated down a fiber without reflection loss, it must enter the end of the fiber within an angular region called the acceptance cone, also shown in Fig. 3. A light ray not within the cone will enter the cladding. If it strikes the outer protective coat, it could be absorbed and never make its way down the core. The half-angle of this cone is $\theta$ and is defined for step-index fibers as

$$\sin \theta = n_1 - n_2 .$$

This angle is the maximum angle with respect to the fiber axis at which ray can be accepted for transmission through the fiber.

The amount of energy coupled into a fiber from a source is dependent on the fiber's numerical aperture, which is a measure of the light-gathering or collecting power of an optical fiber. The larger the numerical aperture (NA), the greater will be the amount of light accepted by the fiber. Thus, as the NA increases, the greater will be the possible transmission distance for the same amount of inserted light. NA is a function of the refractive indices of the fiber and is always less than 1. For a step-index fiber,

$$\text{NA} = \sqrt{n_1^2 - n_2^2} .$$

Since the fiber accepts only rays contained within the cone defined by maximum angle, an input coupling loss occurs if the source of light for the fiber emits at angles greater than $\theta$. Analogously, if the detector at the receiving end of the fiber is not large enough to cover all angles of light emission up to $\theta$, power will be lost. Optical energy can also be lost between two fibers with dissimilar NAs. Matching numerical apertures is therefore important to optimize source-to-fiber and fiber-to-fiber coupling.
CHAPTER 3

PROCEDURE

The system for measuring the optical transmission of $\lambda = 6328 \, \text{Å}$ laser beam through hollow optical fibers consists of a laser, mirror, microscope objective, fiber, DC motor, detector, digital multimeter and x-t strip chart recorder. The total intensity transmitted through the hollow optical fiber was measured as a function of input beam insertion point along the fiber diameter. A diagram of the optical and detector system used in this experiment is shown in Fig. 4.

The monochromatic input beam was supplied by a Spectra Physics model 120 He-Ne laser at $\lambda = 6328 \, \text{Å}$ wavelength with a 5 milliwatt (mW) maximum output. A mirror directed the beam through a microscope objective which focused the laser beam to a waist radius of 4.7 $\mu\text{m}$ at the one end of the fiber.

A 0.25 inch OD stainless steel tube holding the fiber on its axis was placed on the XY-translator. Both ends of the tube were fit with a plastic tip having a small hole at the center through which the fiber was loaded to keep it on the fiber axis. The beam transmitted through the fiber was detected with a solid state photoelectric detector (United Detector) located on the axis, 3 cm away from its end which received the total transmitted intensity.

In order to measure the transmitted intensity as a function of the beam insertion point along the fiber diameter, the fiber was translated along its diameter parallel to the incident laser beam with a 1 rpm Hurst DC motor connected to the XY-translator stage. As the fiber moved in the $\pm x$ direction (see Fig. 4), with the
Fig. 4. Diagram of the optical and detector system used in the experiment
objective lens and the detector fixed, the intensity of the transmitted light through the fiber was measured by the detector. Its signal was converted into a DC voltage which was monitored by a voltmeter and measured with the chart recorder (Huston Instrument model 4523). Signals for all the fibers with different ID and OD and different index cores were taken this way.

Next, the hollow fiber was filled with index fluid. Capillary action drew a small amount of the refractive index fluid into the core of the fiber. Care was taken to avoid forming bubbles inside the core which could prevent filling and distort the transmitted signal. When the core was filled, the refractive index fluid used as a core material had to be prevented from flowing out of the fiber. The index fluid was kept in the fiber by a pair of pre-cleaned microscope slides placed perpendicular to the fiber axis and almost in contact with the fiber ends. When properly adjusted, the fluid remained in the fiber and the microscope slides formed two flat, parallel surfaces which effectively terminated the ends of the optical fiber. After each measurement for a particular fluid, the refractive index fluid was removed from the core of capillary by blowing it out with a pressurized hypodermic needle. A diagram of the top view and end view of the optical fiber filled with the refractive index fluid is shown in Fig. 5.
Fig. 5. Diagram of the top and end view of the optical fiber filled with refractive index fluid
CHAPTER 4

EXPERIMENTAL DATA AND ANALYSIS

The transmission curves for the hollow quartz fibers as a function of insertion point are shown in Fig. 6-10. The relative intensity is normalized to the maximum intensity transmitted by each fiber and is plotted as a function of the insertion point. The \( x = 0 \) point was located at the center of the fiber. The horizontal scale was calculated from the motor rotation speed and screw pitch on the XY-translator. Hence, the strip chart signal could be related to a definite insertion point position along the fiber diameter. All data were taken with a strip chart recorder and then loaded into a computer where all curves could be normalized, analysed and plotted on the same scale. The intensity distributions vary the fiber having the same ID and refractive index fluid less than 10 percent.

In these experiments, the beam is focused onto the fiber end with a short focal length microscope objective lens. The He-Ne laser beam has an initial width of 1.0 mm. The focal point is located at the input end of the fiber. Since the waist radius of the focused beam is smaller than that of the core diameter, the total intensity is therefore injected into the fiber. With this in mind, we can explain the differences in transmitted intensity for various ID fibers and refractive index fluid.

When the core of fiber is filled with refractive index larger than that of quartz, all input beams have incident angles larger than the critical angle. Total internal reflection occurs at the interface between index fluid core and inner quartz wall. Therefore, the maximum transmission and output is received. For a hollow
Fig. 6. Transmitted intensity as a function of beam insertion point for 530 μm ID fiber
Fig. 7 (a). Transmitted intensity as a function of beam insertion point for 320 µm ID fiber.
Fig. 7 (b). Transmitted intensity as a function of beam insertion point for 320 \( \mu \text{m} \) ID fiber.

SOLID : NO FLUID (\( n = 1.003 \))

DASHED : FLUID (\( n = 1.4582 \))
Fig. 7 (c). Transmitted intensity as a function of beam insertion point for 320 μm ID fiber
Fig. 8. Transmitted intensity as a function of beam insertion point for 250 µm ID fiber

n₀ = 1.4571

SOLID: NO FLUID (n = 1.003)
DASHED: FLUID (n = 1.5584)
Fig. 9. Transmitted intensity as a function of beam insertion point for 200 μm ID fiber
Fig. 10. Transmitted intensity as a function of beam insertion point for 100 μm ID fiber.
fiber with no fluid in its core, the total internal reflection occurs at the interface between the quartz outer surface and air. When the light is incident into the boundary between quartz and air, the input rays which have angles larger than the critical angle pass into the air or are absorbed by the epoxy coating. The signal transmitted through the hollow fiber is therefore lower than that for the case where it is filled with index fluid which has a refractive index greater than that of quartz.

For 530 μm ID fiber, as shown in Fig. 6, the overall intensity signals are approximately symmetric. The main difference between the signal with and without index fluid is the change of the maximum intensity of the flat top at the center region of the profile. For a fiber without index fluid, the intensity profile shows two peaks at the edge. This peak occurs when the focal point of the input beam is located at the cladding. As soon as the focal point moves off the cladding, the transmission drops rapidly.

For the 320 μm ID fiber, the overall intensity signals are approximately symmetric. When the core of the fiber is filled with the refractive index fluid (n = 1.5584), larger than that of quartz, the intensity profile shows three sharp peaks. This is seen in Fig. 7 (a). One center peak occurs when the focal point of the input beam is located on the fiber axis. The two side peaks occur when the focal point is located at the cladding. However, when the fiber is filled with the refractive index fluid (n = 1.4582), close equal to that of quartz, the intensity profile shows only one narrow peak. This is seen in Fig. 7 (b). This peak occurs when the focal point is located exactly on the fiber axis. No light is transmitted when the focal point is located at the cladding. When the fiber is filled with the refractive index fluid (n = 1.3995), smaller than that of quartz, the intensity profile shows again only one peak which has greatly reduced intensity. This is seen in Fig. 7 (c). For a fiber without index
fluid, the intensity profile shows the flat top curve.

For the 250 µm ID fiber, as shown in Fig. 8, the overall intensity signals are not symmetric. When the core of the fiber is filled with refractive index fluid (n = 1.5584), the intensity profile shows several peaks. One central peak occurs when the focal point of the input beam is located on the fiber axis and the other several peaks occur due to the nonuniform cross-section of fiber. For a fiber without index fluid, the intensity profile shows the flat top curve. As soon as the focal point moves off the cladding, the transmission drops rapidly.

For the 200 µm ID fiber, as shown in Fig. 9, the overall intensity profiles are approximately symmetric. When the core of the fiber is filled with refractive index fluid (n = 1.5600), the intensity profile shows three peaks. One center peak occurs when the focal point of the input beam is located on the fiber axis. The two side peaks occur when the focal point is located at the cladding. For a fiber without index fluid, the intensity profile shows the flat top and no peak at the edge of cladding. Also, as the focal point moves off the cladding, the transmission falls rapidly.

For the 100 µm ID fiber, as shown in Fig. 10, the overall intensity profiles are not symmetric. When the core of the fiber is filled with refractive index fluid (n = 1.5584), the intensity profiles shows two peaks. These peaks occur when the focal point of the input beam is located at the cladding. For the fiber without index fluid, the intensity profile shows several peaks. One central peak occurs when the focal point of input beam is located on the fiber axis and the other several small peaks in the end of fiber occur due to the nonuniform cross-section of fiber.

There are several critical alignments in these experiments. First, the alignment of the optical device has to keep the laser beam focused by the objective
lens along the direction of the incident beam. The fiber is adjusted to receive the focused beam from the lens. Second, the position of fiber and to be carefully controlled. Because of the small inside diameters of each fiber, the alignment is affected by only a little change of fiber.
CHAPTER 5

CONCLUSION

The experimental results clearly show the potential for using this method in determining the energy transmitted through the hollow quartz fiber as a function of the insertion point along the fiber diameter. The use of better commercially available equipment could increase the accuracy of this experiment.

We learned that the transmitted intensity depends on the refractive index. As the numerical aperture increases, the intensity increases and the loss of power reduces. Also we have information about the intensity transmitted as a function of insertion point along the fiber diameter. We could have the symmetric distribution of intensity signal only if the focal point is located exactly on the fiber axis. The cross-section of fiber end affects the intensity signal very much. If the fiber end is not uniform, we can not have symmetric signal of the transmitted intensity. The waist radius of 4.7 μm of the focused beam is large compared to small ID fibers, the alignment of the optical system with small ID fiber is more difficult that of large ID fiber.

This method can be applied to the transmission through the hollow core quartz cladding optical fiber as a function of the far-field energy for the infrared regions such as soft x rays or vacuum ultraviolet (VUV) light.

This procedure should provide another useful tool in the examination of the energy transmitted through the hollow fiber across the diameter.
LIST OF REFERENCES


