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NOVEL APPLICATIONS FOR MICROSTRUCTURED OPTICAL FIBERS

CHRISTOPHER M. GEORGE
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Reviewed and approved* by the following:

Eric Mockensturm
Associate Professor of Mechanical Engineering
Thesis Supervisor

Matthew Mench
Associate Professor of Mechanical Engineering
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Microstructured Optical Fibers are small fibers containing one or more holes running axially through their length. They were originally developed for various optical properties, but their size, shape, flexibility and strength precludes them to mechanical uses as well. The explored applications are thrusters for the so-called nanosatellites, flexible capacitors, simple pipe flow cooling device, pulsating heat pipe, and neutron detector waveguide. The thruster design shows promise, but requires more extensive testing to determine the accuracy of the theory. A cyclindrical capacitor with an anode in the center of a single-channel optical fiber, and the cathode on the outside, has far too low of an energy density to be of use, but more complex geometries may be more efficient. Simply forcing water through the tubes results in a very highly effective heat transfer device. The pulsating heat pipe design is simple to build, but its small size makes it challenging to observe its behavior, and tests should be repeated with more powerful optical and thermal equipment. The neutron detector design is also promising, though a much larger scale test is required to determine more quantitatively the effectiveness of the system.

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Chapter 1

Background

Microstructured optical fibers are a type of silica optical fiber formed with air holes within the structure that run axially along the length of the fiber. They were originally developed in an attempt to decrease the loss of light passed through the fibers, and the structures were created such that they modified the total internal reflection in a way that successfully decreases losses. Extensive research has been done on potential photonic applications of these fibers, and optimization of the shapes for various functions has created a wide variety of microstructured optical fibers (Eggleton, Kerbage, Westbrook, Windeler, & Hale, 2001).

As these devices are being used in more and more photonics systems, they have become easily obtainable, and their variety and availability makes them good candidates for researching further applications. Due to their small size, flexibility, strength, and high manufacturing consistency, they are potentially well suited to a variety of mechanical uses.

Miniature Satellite Thruster

For Earth-orbit research, NASA has been increasingly relying on “nanosatellites,” which are satellites much smaller than those used over the past few years. They often weigh between 10 and 20 pounds, and therefore need smaller thrusters than are commonly used on today’s spacecraft. An alternative method to provide thrust currently being researched is hydrogen peroxide, whose decomposition is triggered with a catalyst (Roylance, 2009). Unfortunately, the testing done so far has used MEMS structures, and analysis of the exit plume has shown incomplete decomposition. Various potential reasons for this incomplete decomposition have been suggested, including low Reynold's number effects, surface tension effects, or thermal effects (Zhou & Hitt, 2003). For all of these issues, the solution is to increase the length of the thruster, providing more catalyst surface area on which the hydrogen peroxide can react. Due to the cost and resources required for increasing the size of the catalyst bed, further experimentation has focused on changing the bed's geometry to created better mixing conditions (Zhou & Hitt, 2005).

This paper will explore an alternative to the above catalyst bed technique. Instead of changing the MEMS geometry to get better mixing conditions, a microstructured optical fiber with a platinum catalyst coating along its channel may provide an alternate method to utilize H_2O_2 propellant. The simpler geometry decreases the amount of mixing, but the significantly longer fiber may provide enough area for complete decomposition of H_2O_2.

Flexible Capacitor

Electronics is a major industry in today's world, with circuitry technology advancing quickly. Miniaturization is the most visible element of this growth, and it can be seen in the ever-smaller cell phones, laptops, and music players on the market. However, the limiting factor for this trend is the size of batteries or other energy storage devices. Significant research is being done on various new types of batteries and capacitors that increase energy density, so that energy source can be better-integrated into the devices.

An alternative approach, however, could be to find new form factors for the energy storage elements. This paper will explore the use of microstructured optical fibers of various sizes and geometries as a basis for building flexible, durable capacitors.

Heat Transfer

As mentioned above, miniaturization is the trend with personal electronics. Smaller components have higher surface area to volume ratios, and therefore have better heat dissipation. However, since there is such a strong emphasis on making the smallest device possible, the components are placed extremely close to each other, and overheating becomes a potential issue. To combat this, many devices, particularly laptop and desktop computers, have fans to increase air circulation and provide cooling.

Fans are efficient cooling devices, but have the downsides of being bulky and noisy when operating. Therefore, alternate heat dissipation methods would allow these devices to become smaller and quieter. The microstructures in the optical fibers may be useful as heat transfer devices. The simplest implementation along these lines is placing the fibers in or on a heat source, and forcing cool liquid through the fiber. Its small diameter would give a large surface area to volume ratio, and will hopefully provide a high rate of energy removal for the small amount of liquid passing through it.

A related heat transfer device that could be built of microstructured optical fibers is an oscillatory heat pipe. An oscillatory heat pipe is a heat transfer device consisting of one or more loops of narrow tubing with a heat source on one side of the loop and a heat sink on the other. The tube is chosen such that its internal diameter is small enough that the working fluid will always form droplets that completely fill the cross section of the tube; i.e., they will create “plugs” in the pipe, rather than droplets on the side. The high temperature will cause plugs on the hot side to evaporate and expand, therefore pushing other plugs toward the heat sink. The vapor, then, will condense into new plugs on the side of the heat sink. This alternating between plugs and vapor sends pressure waves through the length of the pipe in a chaotic fashion, causing the plugs and vapor bubbles to move back and forth, and thereby carrying energy from the heat source to the heat sink, effectively acting as a heat pipe (Dobson, 2004). This device, while much harder to model and predict, is an entirely passive transfer device that does not require a pump or any other external driving force besides the heat gradient.

Neutron Detector

In nuclear reactors, neutrons are used as a way to monitor reactions and check for issues. Because neutrons do not interact with many other particles, neutron detectors must use indirect detection methods, lowering the resolution of images. They consist of a mixture of a boron-containing material and a phosphorescent material, commonly zinc sulfide (ZnS). Whenever a neutron collides with a boron atom, an alpha particle is emitted. This alpha particle can then cause the ZnS to emit a photon. Since this is a two-step process, and the particles are not emitted in exactly the same direction as the incident particle, the images tend to have low resolution, and optical devices are needed to create a cleaner image (Goulding & Schlacter).

As mentioned previously, the optical fibers have excellent waveguiding properties, and their geometry and optical properties could be used together to increase the image clarity for neutron detectors. If the detection materials were to be placed inside the channel in the fiber, the photons may be channeled along the length of the fiber, focusing the image and preventing scattering.

Chapter 2

Theoretical Calculations

For all theoretical calculations, analytical methods were used when possible, with the assistance of Mathematica.

Miniature Thruster

The purpose of the miniature thruster is to create a small impulse, or change in momentum, that will cause the orbit of the miniature satellite to change. The maximum impulse for a decomposing liquid is given by the equation:

$$I_{sp}^{max} = \sqrt{\frac{2\gamma R T_{stag}}{\gamma - 1}}$$

Where γ is the ratio of specific heats of input and output, R is the gas constant, and T_{stag} is the stagnation temperature of the decomposed gas. For 85% hydrogen peroxide, I_{sp}^{max} = 185 sec (Zhou & Hitt, One-Dimensional Modeling of Catalyized H2O2 Decomposition in Microchannel Flows, 2003). From here, thrust can be obtained from the fact that $F = I_{sp}\dot{m}g$. This assumes that the fuel is fully consumed, and that material properties do not vary significantly.

To determine the length necessary to assure full decomposition, see (Zhou & Hitt, Numerical Modeling of Monopropellan Decomposition in a Micro-Catalyst Bed, 2005). For now, a 0.25 m length of coated tubing will be considered long enough to ensure complete combustion.

A thrust of 145 μN is given as representative of the scale required for these nanosatellites. This gives a flow rate of 80 μg/s. Given the density of hydrogen peroxide, this equates to a volumetric flow rate of 5.46×10^{-11} m^3/s (Zhou & Hitt, One-Dimensional Modeling of Catalyized

H2O2 Decomposition in Microchannel Flows, 2003). Assuming the larger of the microstructured optical fibers is used (ID of 320 μm), this relates to a mean velocity of $6.79*10^{-4}$ m/s. To find the pressure required to achieve this velocity, the Reynold's number must be found. The equation for Reynold's number is $Re = \frac{\rho U D}{\mu}$, and in this situation, Re = 0.0256, an exceptionally low number, and therefore highly laminar. For laminar, fully-developed pipe flow, the friction factor is $f = \frac{64}{Re}$, so in this situation, f = 2,500. The pressure loss across a tube with a friction factor of f is $\Delta P = f\rho \frac{L\,U^2}{2D}$ (Cengel & Cimbala, 2006). In this case, the pressure required is 660 Pa, a completely reasonable pressure to achieve in a simple laboratory setting.

Capacitor

The simplest implementation of the microstructured optical fibers as a capacitor is using a single-channel fiber, with a conductive core and coating, making it a basic cylindrical capacitor.

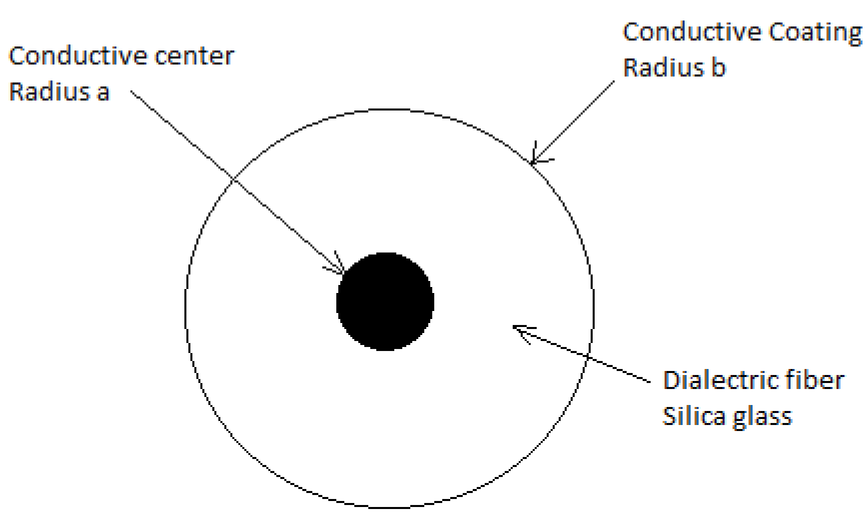

Figure 2.1 – Simple Cylindrical Capacitor

This setup is simple to model. Given a charge per unit length, $\lambda = \frac{Q}{L}$, where Q is charge and L is length, then the voltage across a cylindrical capacitor is $V = \frac{\lambda}{2\pi\varepsilon} \ln\frac{b}{a}$. Once the voltage is known, the capacitance can be calculated from the fact that $C = \frac{Q}{V}$. Therefore, in this capacitor, $C = 2\pi\varepsilon L \ln\frac{a}{b}$. From here, the energy stored by the capacitor can be found, since for any capacitor, $U = \frac{QV}{2}$ or $\frac{CV^2}{2}$. Therefore, for our cylindrical capacitor, $U = \frac{\lambda^2 L}{4\pi\varepsilon} \ln\frac{b}{a}$.

Now, the critical values for the use of a capacitor are its maximum voltage and its energy density. The expression for electric field strength in a cylindrical capacitor is $E(r) = \frac{V}{r \ln{}^{b}/_{a}}$. It is easy to see that the maximum electric field in the dielectric would then be $E_{max} = \frac{V}{a \ln{}^{b}/_{a}}$. All dielectrics have a maximum breakdown strength, and with this knowledge, the maximum voltage a capacitor can handle can then be given as $V_{max} = E_{max}\, a \ln\frac{b}{a}$, where E_{max} is the dielectric's breakdown strength. The maximum energy stored, then, is $U = \frac{C\, V_{max}^2}{2}$ (Eren, 1999).

The fibers are made of fused silica, so they have the following properties: $\varepsilon_r = 3.8$, $E_{max} = 30 * 10^6$ V/m (CERAM Research Ltd, 2001). Therefore, for the sample fibers used in experiments, they would theoretically have the following electrical properties if turned into capacitors:

ID (μm)	OD(μm)	C/L (pF/m)	V_{max} (kV)	U_{max}/L (μJ/m)	U_{max}/V (kJ/m^3)
75	205	212.5	1.13	135.9	4.11
320	450	72.0	1.63	96.5	0.607

Table 2.1 – Theoretical values for fiber capacitances

Unfortunately, these results are not very promising. While the V_{max} is much higher than traditional capacitors (which often have maximum voltages on the order of 1-100 V), the energy density is much lower. Traditional electrolytic capacitors have energy densities on the order of 100 kJ/m^3, and ultracapacitors exceed 1,000 kJ/m^3 (Lachapelle & Garcia, 2008).

One proposed method to increase the energy density of the fibers was to optimize the ratios of inner diameter to outer diameter. The optimization attempts are described in Appendix A: Optimization of Capacitor Geometry.

Heat Transfer

Simple flow through pipe

As an initial estimate of the usefulness of the fibers as a heat transfer device, calculations will be done assuming the fiber is long enough and has a high enough surface area that at the end of the tube, the liquid has fully boiled and has reached the temperature of the heat source.

Working fluid: Water							
Diameter	$\dot{V}$	Density	$C_{p\ liq}$	$C_{p\ gas}$	ΔH_{vap}	T_{min}	T_{max}
5 µm	$1.67*10^{-8}$ m^3/s	1000 kg/m^3	4.2 kJ/(kg K)	2 kJ/(kg K)	2270 kJ/kg	25^o C	300^o C

Table 2.2 – Values for flow calculations

From these values the mass flow rate can be calculated. The result is $2.78 *10^{-7}$ kg/s.

The amount of power absorbed to bring the temperature of the fluid is given by the equation $q_{liq} = m * c_{p,liq} * (T_{boil} - T_{min})$, The energy to boil all the liquid is $q_{boil} = m * \Delta H_v$, and the energy to raise the temperature of the vapor to the max temperature is $q_{gas} = m * c_{p,gas} * (T_{max} - T_{boil})$. If the mass is replaced with mass flow rate in the above equations, the equations are added together, and all other values are assumed constant in time, then the resulting equation is total power removed by the working fluid at steady state (Incropera & De Witt, 1981). Doing this yields the equation:

$$\dot{q} = \dot{m}(\Delta H_v + c_{p,gas} * T_{max} - c_{p,liq} * T_{min} + (c_{p,liq} - c_{p,gas}) * T_{boil})$$

Plugging in the values from Table 2.1 yields a maximum heat transfer rate of 49.75 W per fiber. This is an extremely good heat transfer rate, especially considering the small size and simplicity of the object, so further experimentation will be done to find how close a physical system is to this theoretical maximum.

Pulsating Heat Pipe

Pulsating heat pipes (PHPs) are very difficult to model analytically, due to their highly chaotic nature (Dobson, 2004). An additional proposed limit to PHP performance was a theoretical minimum diameter of $D_{min} = 0.7\sqrt{\frac{\sigma}{(\rho_{liq} - \rho_{vap})g}}$ for a given working fluid (Yu-Hsing, Shung-Wen, & Tsung-Yu, 2009). For water, this gives a minimum diameter of approximately 1.9 mm, much larger than the fibers.

However, more recent research suggests that the lower limit is not as important as initially believed. Tests involving pipes of 1 mm diameter show that below the limit the pipes still function properly as heat transfer devices. The smaller diameter heat pipes have higher thermal resistances, but also have much higher dry-out heat fluxes (Yang, Khandekar, & Groll, 2008). Theoretical methods for modeling PHPs exists, using finite-difference methods (Dobson, 2004). However, they are beyond the scale of this paper.

Neutron Detector

The primary purpose of the theoretical work for the neutron detector is the determination of a suitable way to create a neutron detection substance inside the fibers. Since ZnS is insoluble in water, the immediately obvious method is to create a mixture of two soluble substances out of which ZnS would precipitate when passed through the fibers.

Zinc acetate dehydrate and thioacetamide are chemicals that were on hand and contained the proper ions. The zinc ion is provided by the fact that zinc acetate dehydrate dissociates as follows:

$$Zn(O_2CCH_3)_2(H_2O)_2 \Rightarrow Zn^{2+} + 2\ (O_2CCH_3)^{1+} + 2\ H_2O$$

The thioacetamide dissociates thusly:

$$C_2H_5NS \Rightarrow C_2H_5N^{2+} + S^{2-}$$

This puts Zn^{2+} and S^{2-} in a position where they may react and form ZnS. As ZnS is insoluble in water, it should precipitate out, allowing the other ions to be washed away with the solvent. Finally, *o*-carborane ($C_2B_{10}H_{12}$) is included to provide the boron atoms for alpha particles.

Chapter 3

Experimental Results

This section will develop experimental techniques to verify and extend the findings of the theoretical calculations. However, due to constraints on time and resources, not all experiments were conducted; the recommended experiments will be given, and the use of the data will be explained.

Miniature Thruster

Due to resource restraints, this test was not able to be performed. However, following is the proposed test setup.

First, a microstructured optical fiber has a layer of platinum deposited along one end of its length, using chemical vapor deposition techniques. Selective deposition along the length of the fiber is possible by heating only the portion of the fiber where the coating is desired (Krumdieck, 2009).

Because the forces generated are very small compared to what most laboratory accelerometers are able to detect, a suspended test setup is recommended. A basin for the H_2O_2 is suspended from two arms attached to angle transducers. The uncoated end of the fiber is placed in the basin, and the coated end is pointed away from the basin, in the direction such that any force produced turns the arms attached to the transducers. See Figure 3.1.

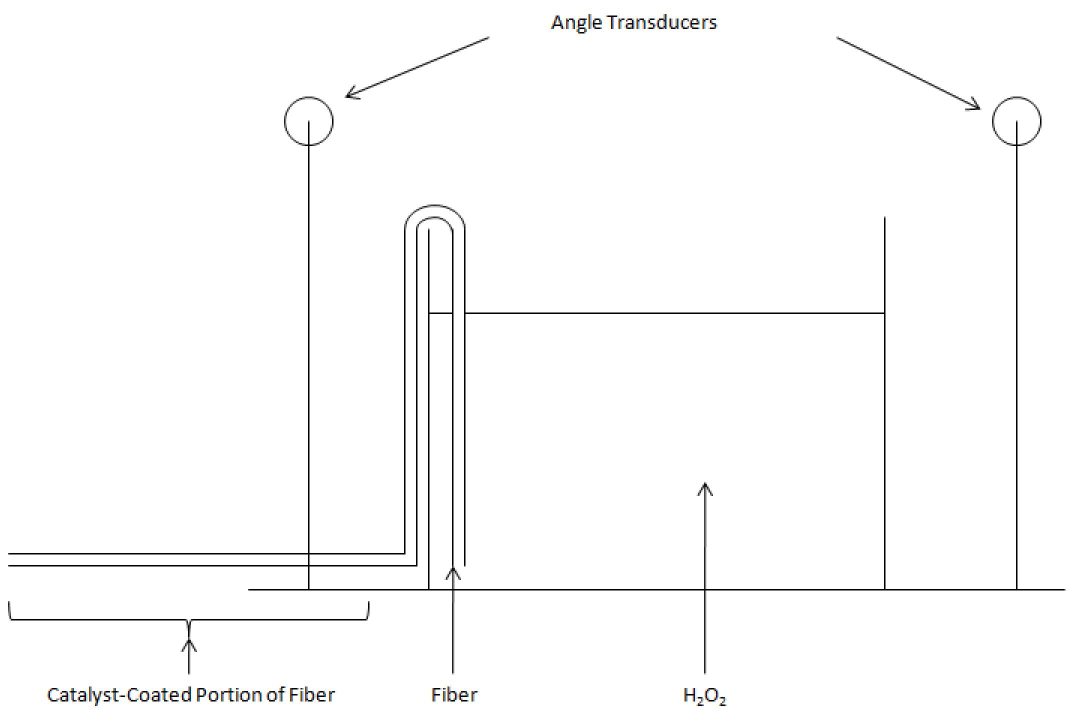

Figure 3.1 – Thruster Experiment Setup

A simple force balance will show that $F_t = m\ g \tan\theta$, where F_t is the force produced by the thrust, m is the mass of the system, g is the gravitational acceleration, and θ is the angle of the arm measured with respect to the horizontal.

Capacitor

Theoretical calculations show that devising cylindrical capacitors out of the optical fibers is not worthwhile; however, more complex geometries may be useful. For example, the figure below would allow for the positive and negative channels to be much closer together, allowing for a higher capacitance and energy storage capability.

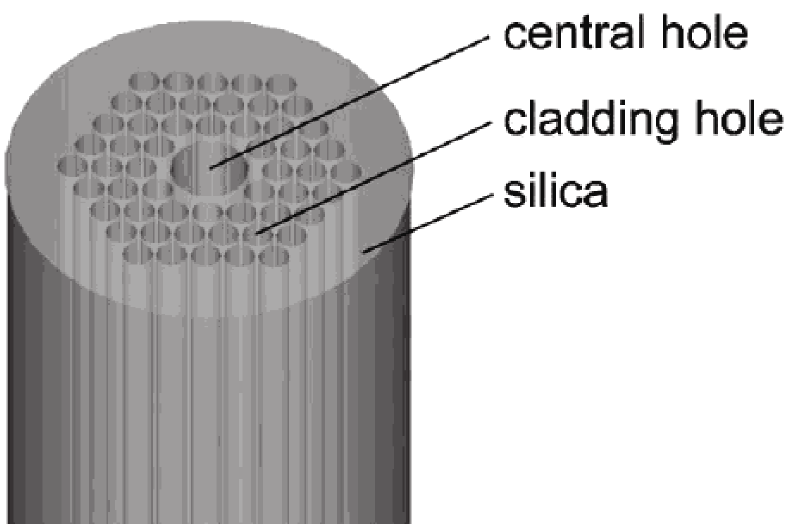

Figure 3.2 – Complex honeycomb geometry fiber. Courtesy (Huang, Xu, & Amnon, 2004)

The primary obstacle with this geometry is filling the holes selectively, so that short circuits do not occur, and the conductive filling in the holes do not touch. The solution, devised by Huang, Xu, and Amnon, is shown below.

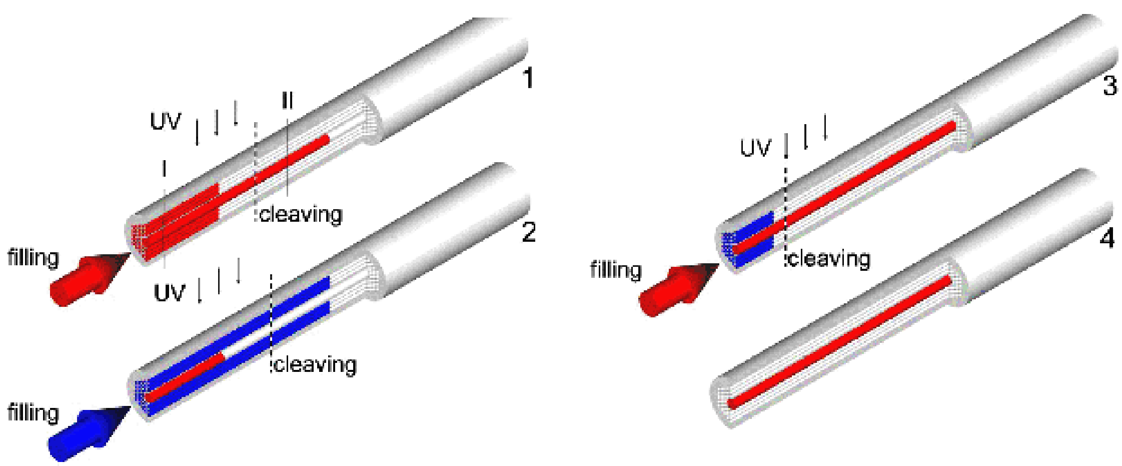

Figure 3.3 – Selective Filling Process. Courtesy (Huang, Xu, & Amnon, 2004)

Since the center hole has a larger diameter, a glue forced into the channels will flow faster in the largerchannel, and therefore fill faster. This glue is then set using a UV source, shown in 1 of Figure 3.3. The fiber is then cut, such that the plug in the center channel remains, and another glue can be forced into the smaller channels, and since the middle channel is blocked, this glue can be forced deeper than the plug in the center channel, as in 2. This can then be cut, such that the smaller channels remain plugged, and the center channel can be filled to whatever depth is desired, as in 3. The plug for the smaller channels can then be cut off, leaving only the center channel filled, as in 4, allowing the smaller channels to then be filled, creating a capacitor.

Heat Transfer

Simple flow through pipe

To test the use of the fibers as a heat transfer device with simple internal flow, the following setup was used.

Figure 3.4 – Simple Internal Flow Setup

A syringe pump is on the left, to control the flow rate of water through the fiber. The syringe is attached to a rubber tube, to which the fiber is attached. On the other side of the fiber, another tube carries the heated water into the basin on the right. A simple hot plate acts as the heat source, with the metal block in the center raising the rubber tubing from the heated surface so that the fiber is heated, but the rubber tubes are not heated and melted. In the foreground is the thermal imaging camera used to gather the thermal data while the test is running.

Following is an image from the data collected. This run used two 75 µm ID/205 µm OD fibers, with a volumetric flow rate of 1 mL/min.

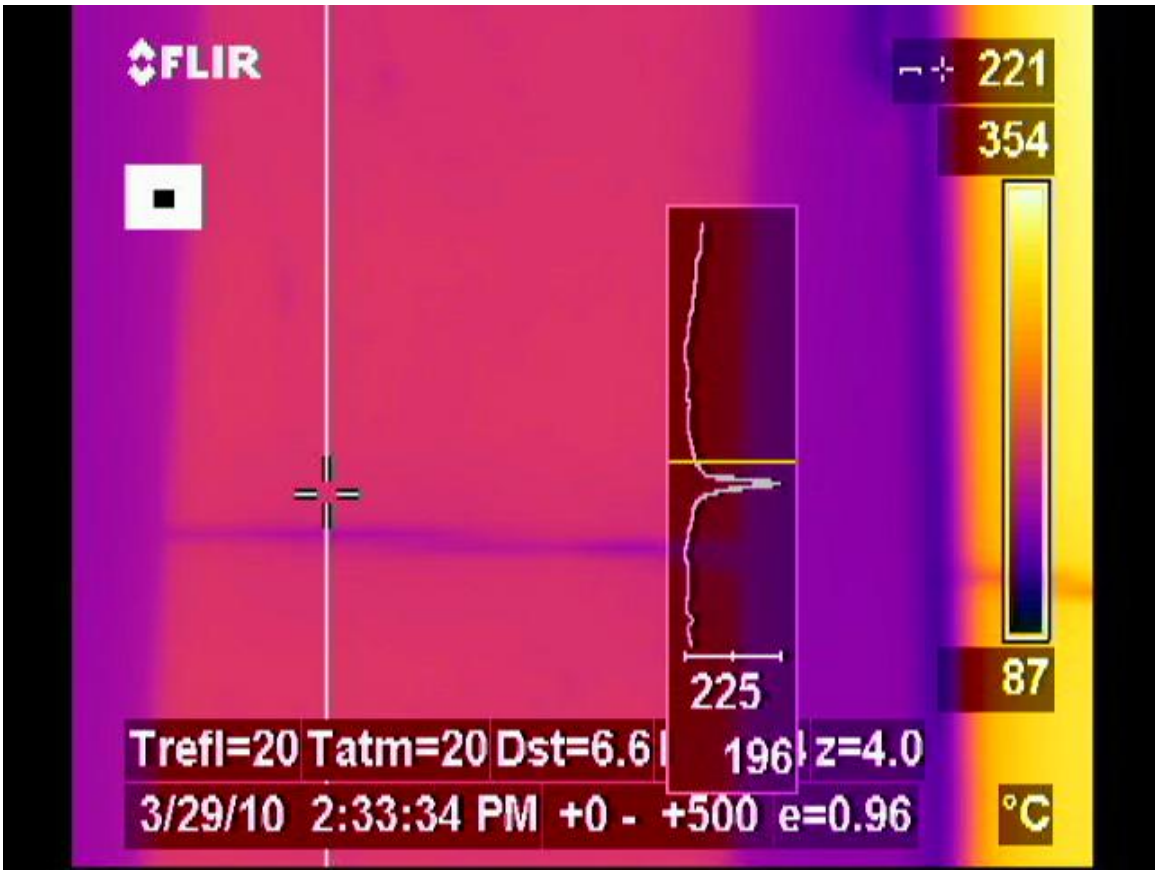

Figure 3.5 – Thermal Data for 2 Fibers at 1 mL/min

This data shows that at mass flow rates as low as 1.67 $*10^{-5}$ kg/s, a 30^{0} C surface temperature difference can be achieved. This is a very good result; however, to find the exact amount of heat being removed, and the efficiency of the heat exchanger made with these fibers, thermocouples capable of measuring the fluid temperature would be needed.

Pulsating Heat Pipe

The PHP is simple to build; a tube is filled with the operating fluid, the ends are either connected or submerged in a basin, and the ends are placed on their respective heat sources and sinks. To test the theory, a simple PHP was built with larger-diameter tubing, to more easily observe the behavior.

Figure 3.6 – Large Pulsating Heat Pipe setup

This simple test allowed the pulsing liquid plugs to be observed. However, when this setup was repeated with the microstructured optical fibers, the fibers proved too small to easily see the liquid/gas interface. However, with properly heat-resistant microscopes and sufficiently small thermocouples, the efficacy of this size PHP can easily be determined.

Neutron Detector

The first test that needed performed for the neutron detector was a verification that the precipitate forming was indeed ZnS, as there was concern that the *o*-carborane, magnesium, and any other contaminants, were causing ZnO, a similarly insoluble white powder, to precipitate instead. To test the material, an X-Ray Diffraction was performed in the Materials Research Lab on February 16, 2010 with the assistance of Nichole Wonderling. The results of the diffraction are below:

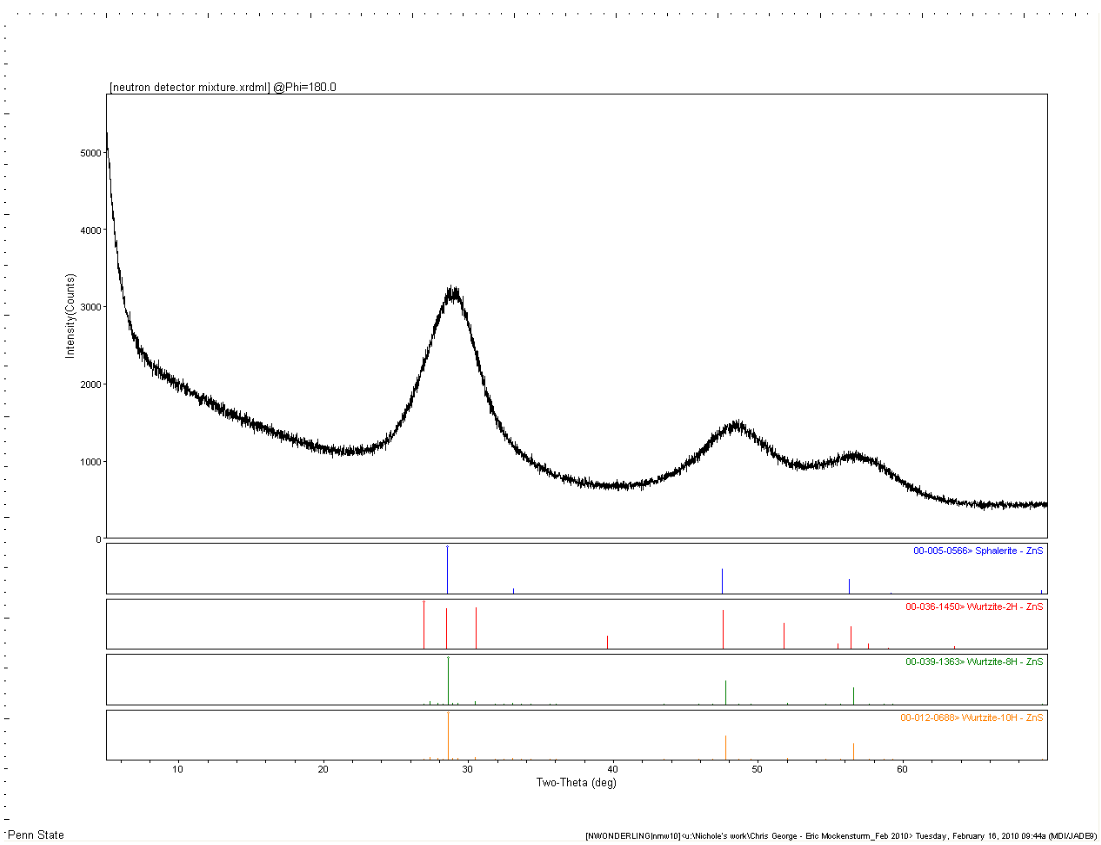

Figure 3.7 – X-Ray Diffraction results

The black graph is the results of the test, while the smaller colored plots below are the theoretical results for various ZnS structures. The extremely wide peaks show that the ZnS is nanoparticle form, rather than a large, discreet structure. However, since the wide peaks of the test correspond to the sharp peaks of all the various macro ZnS structures, the sample is definitely ZnS, and not ZnO. Additionally, the *o*-carborane and magnesium activator are in low enough concentrations that they do not appear in this test (Wonderling, 2010).

With the neutron detection mixture verified, the effect of the optical fibers should next be tested. Setup is given below:

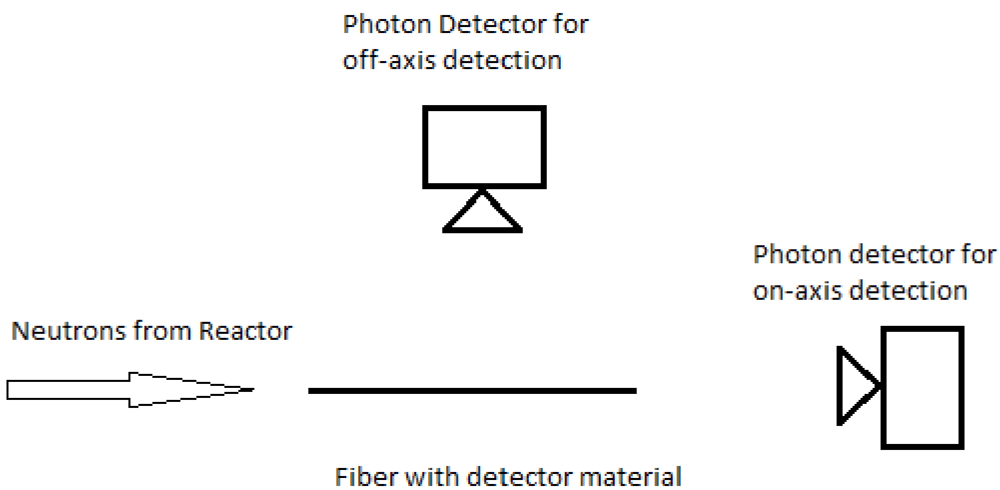

Figure 3.8 – Neutron Detector Test Setup

The fiber is placed axially along the neutron path, so that the fiber is most likely to guide the resulting photon to the photon detector directly in line with the neutron. The off-axis photon detector will then be able to detect the relative number of photons that are being scattered in the detector, rather than following the shape and path of the fiber.

An additional recommended test would be the same as above, but replacing the fiber with a container of the ZnS mixture of equivalent volume to that contained in the fiber. This would then give a benchmark for the number of photons that stay on the same direction of travel, and the number that end up deflecting off the path.

Chapter 4

Conclusions and Potential Applications

The following is an overview of results for each area of interest. All areas have shown potential for applications. However, these potential applications all require additional development and testing, and so the suggested course of action is given.

Miniature Thruster

As the miniature thruster concept was not tested, it is not possible to give a definite answer to the suitability of the fibers for this application. However, the research and theoretical calculations suggest that it is feasible, and may prove cheaper and easier to manufacture than nanoscale thrusters. Further testing is recommended.

Capacitor

The capacitor use of microstructured optical fibers is also untested, but the theoretical calculations suggest that a simple cylindrical capacitor does not have any outstanding properties to make it worth the cost in effort and materials to manufacture one.

However, more complex geometries could potentially be worth further investigation. They allow for higher energy densities, and can be custom-shaped to the application, to optimize their electrical properties. Further calculations and testing is recommended.

Heat Transfer

Simple flow through pipe

Testing has shown that the fibers are excellent in this use. Their small size means a high surface area for heat transfer. This means not only a quick response time to temperature fluctuations, but also that relatively small flow rates are required to transport useful amounts of heat. Additionally, the small form factor means that is easily incorporated into small devices and situations where space is limited and focused heat control is needed. The one recommendation for further development is a couple to allow the fibers to be more easily attached to other tubes or syringes.

Pulsating Heat Pipe

The pulsating heat pipe design was unable to be tested in a useful manner, due to the constraints of the optical and thermal measuring equipment available. However, due to the fibers' success in a simple flow situation, they show promise in this application as well. Further testing is recommended.

Neutron Detector

The neutron detector experiments were not able to be performed, but since the neutron detector material mixture seems to have been created properly, testing in the nuclear reactor is recommended.

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Appendix A

Optimization of Capacitor Geometry

A few efforts were made to optimize the geometry of the fibers for capacitor energy density. First, considering only a cylindrical capacitor, the ratio of radii z = a/b, can be maximized for energy density. The result is that the optimum ratio is $z = \frac{1}{\sqrt{e}}$.. However, this optimum geometry does not give a significant increase over the fibers used.

The next effort made was using finite element methods. In COMSOL, the optimization package was used, and a moving mesh/parameterized geometry was attempted. However, in the limited time of the project, the errors were never fully worked out, and results were never achieved.

Finally, a topological optimization was attempted. This method, implemented in COMSOL, is outlined in (Sigmund, 2001). This method is based on a distribution of two materials, and the method is used to optimize the distribution of materials throughout the area of interest. Unfortunately, in a capacitor, the geometric element of interest is the shape and position of boundaries between materials, which is not as well defined. However, with some application of finite element concepts, it may be possible to adjust this method to look at boundaries and their relative positions, greatly increasing the applicability of the method to alternate problems.

VITA

Christopher M. George

Education:

Pennsylvania State University *Graduating May 2010*
Bachelor of Science in Mechanical Engineering
Honors in Mechanical Engineering
Minor in Engineering Mechanics

Work Experience:

Teaching Assistant – PSU Center for Engineering Design and Entrepreneurship *Aug 2009 to Present*
I am currently working as the teaching assistant to the course Engineering Design 496C: CATIA V5 Fundamentals and Applications. I answer any questions from the students, assist them with project planning, and do a few small presentations on the uses and downfalls of computer-based engineering techniques.

Lifecycle Engineering Intern – Medrad Inc *June to Aug 2009*
My work with this medical equipment company dealt with troubleshooting in-the-field failures for the company's radiological injectors. While I performed a few cost-reduction efforts, most of my summer was spent working on a stop-shipment issue with Medrad's flagship product. This project included working among multiple departments, extensive communication with component suppliers, and FDA-regulated documentation.

Laboratory Assistant—PSU Materials Research Laboratory *June to Dec 2008*
As a member of the Materials Research Institute support staff, I worked regularly with engineers engaged in materials research, where I regularly ran, maintained, and fixed research equipment.

Laborer —Precision Excavating, Inc. *May to Aug 2007*
As a laborer and basic equipment operator for an excavation company, I gained experience in the interaction between engineers and laborers, and discovered my personal aptitude with mechanical systems in the operation, repair, and maintenance of heavy excavating equipment.

Accomplishments:

Officer – Penn State Swing Dancing Club *April 2007 to April 2009*
Serving as secretary of the club for one academic year, I was responsible for communications for the club, as well as organizing recruiting efforts. The second year, I served as vice-president, and organized twice-weekly lessons for groups often exceeding 100 dancers. Additionally, I helped prepare and defend proposals to the allocation committee to fund weekend workshops with professional instructors and to hire professional bands for dances.

Best Design Communication Winner—Freshman Design Competition *May 2007*
Sponsored by Armstrong World Industries, this group competition required the design of a new concept for panel ceilings, and a presentation of this design to members of the School of Engineering and to representatives from Armstrong.

Member—Project PAWS *Aug to Dec 2006*
I coordinated a program with Penn State's Center for Sustainability, the Schreyer Honors College, and the Architectural Engineering department to raise awareness of environmentally friendly building methods, as well as showing students their impact on the environment.

Eagle Scout *Aug 2003*
As an active Boy Scout, I participated in leadership development programs on a local, state, and national level, and earned Scouting's highest honor, the rank of Eagle Scout.

Software Experience:

MATLAB
Mathematica
ANSYS
COMSOL
CATIA
SolidWorks
Data Physics SignalCalc
STAR Modal
Linux-based OS