ZING FIBER MEASUREMENTS

A PREPRINT

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ABSTRACT

Fibercore's polarizing fibers allow a single polarization state of light to be transmitted through the fiber [1]. As the light enters the fiber, the light aligned with the fast axis will be attenuated while the light aligned with the slow axis proceeds through the fiber. We investigate the effect of fiber-coil radius on the relative power of polarization states for a 1064nm laser as well as the profile of the laser beam.

We claim that Zing-fiber does effectively work as a polarization fiber, allowing the S-polarized light to pass and attenuating the P-polarized light. This effect for a given 4m fiber, 1064nm light source, does not vary significantly between winding radii in the range of 30mm to 150mm. The output beam profile is non-Gaussian and appears more affected by small winding radii as compared to large radii.

1 Background

1.1 Polarization in Light

Electromagnetic waves are electric and magnetic fields that propagate though space where the E and B components are always perpendicular. The direction of propagation, $\overrightarrow{S}$, is given by $\overrightarrow{S} = \overrightarrow{E} \times \overrightarrow{B}$. Therefore the propagation is always perpendicular to both $\overrightarrow{E}$ and $\overrightarrow{B}$. Even though we can have multiple sources of light travelling in the same direction, it does not necessarily mean that the $\overrightarrow{E}$ and $\overrightarrow{B}$ fields of these two sources are aligned. This is where the notion of polarization becomes useful [2].

By convention, the polarization of light refers to the oscillation plane of the electric field. Since light is wave-like in nature, we can consider the light ray as a superposition of light in two orthogonal polarization states, S and P. If the electric fields of all the individual photons, or light particles, are all oscillating exclusively in the same plane, that light is considered polarized. If that plane is fixed in time, the light is linearly polarized. If that plane is moving in a circle in time, the light is circularly polarized [2].

Unpolarized light is more difficult to visualize. We can consider the unpolarized light as having half of the E-field oscillations occurring in the S direction, and half in the P-direction [2].

1.2 Creating Polarization: Birefringence

Birefringence is the property of a material having a refractive index that depends on the polarization and propagation direction of light. Therefore when light is incident on the birefringent material, the polarization states of the beam are refracted differently, see Fig. 1 [2]. This property can be manipulated in optic fibers so as to attenuate P-polarized light while allowing S-polarized light through.

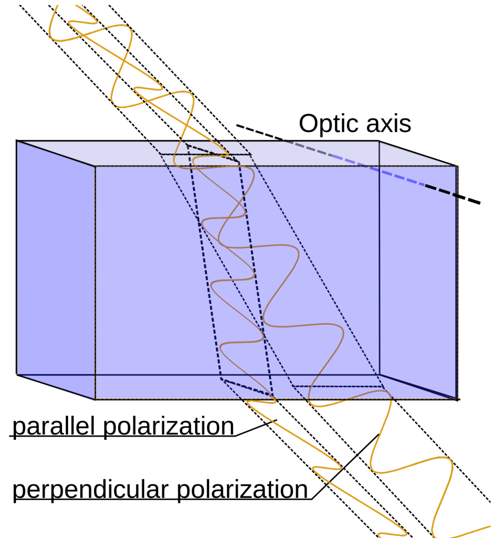

Figure 1: Diagram displaying the propagation of light through a birefringent material [3]

1.3 Polarizing Fibers

Fibercore's Polarizing (PZ), or Zing^{TM} fibers are optic fibers in which only one polarization state is allowed to propagate. The goal of the design is to output highly linearly polarized light. For the HiBi Zing fiber, radial high birefringence is applied across the cross section which creates two orthogonal modes with different effective indices of refraction as well as propagation constants. The 'slow' axis corresponds to a high effective index and a low propagation constant. This high index confines the light in this mode to the core region, allowing the light to propagate effectively. The light aligned with the fast axis is attenuated [4]. In our experiment, the slow axis is aligned with the S-polarization of the beam.

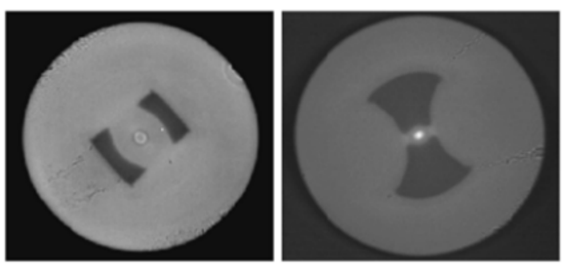

Figure 2: Cross section of PZ fibers showing the bowtie shape. HB800C 'Bow-Tie' PM fiber (left) and HB830Z 'Bow-Tie' PZ fiber (right) [4]

The radial birefringence is created by "Stress applying Parts" or SAPs along one axis in the fiber. The stress is created by the different thermal expansion coefficients in the SAP's materials. When the fiber cools after construction, the SAP and surrounding silica cool at different rates, creating a stress gradient across the cross section. This stress changes the refractive index of the fiber, creating the necessary birefringence mentioned above. Due to shape of the SAP, the stress-induced birefringence is referred to as 'Bow-Tie' geometry as in Fig. 2 [4].

1.3.1 Guidance

When the fiber is bent, the stress gradient produced by the SAPs combines with the stress from the bending or winding radius creating local variations in the refractive index which alter the guiding properties of the fiber. This bending creates a higher effective refractive index towards the center of the bend and a lower index towards the outside of the bend. The light will be lost to cladding modes and dissipated by coating. This is expected to modify the beam profile, making the beam non-Gaussian [4].

Table 1: Equipment used in experiment

Equipment
DBR Fiber-Pigtailed Laser with built in isolator, 1063.9nm
RIGOL M300 Data Acquisition / Switch System
Fibercore, ZingTM Polarizing Fiber,
WinCamD-LCM – USB 3.0, 1" CMOS Beam Profiler System
Polarizing Beam Splitter
2 Mirrors
2 Photodiodes
Collimators, Mounts
Power supply

2 Experiment

2.1 Setup

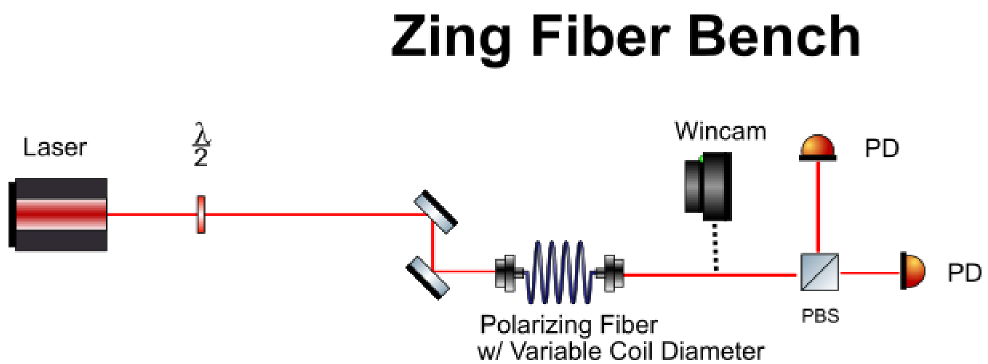

Figure 3: Sketch of the optical setup used in the experiment. The S-polarized laser travels through a half-waveplate, $\frac{\lambda}{2}$, to rotate its polarization axis. The light then reflects off two mirrors and travels through the Zing fiber. The zing fiber at either end is held up by collimators. After exiting the fiber, the light is split according to polarization's states by a Polarizing Beam Splitter, PBS. The two power outputs are then read by two Photo Detectors, PD. Between the collimators and the PBS there is a movable WinCam which was inserted in the path for beam profile measurements between successive polarization measurements.

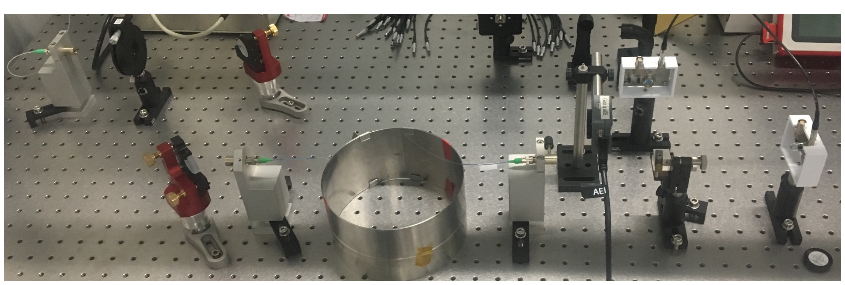

Figure 4: Photograph of the optical setup sketched in Fig 3

In order to measure the power of the polarization states after travelling through the zing fiber we setup an optical bench as in Fig. 3. The laser emits s-polarized light which propagates through a half-waveplate in order to rotate its polarization axis. Initially the rotation is 0 degrees, not changing the initial polarization state. The light then reflects off two mirrors and travels through the Zing fiber. The zing fiber at either end is held up by collimators. After, the light is split according to polarization's states by a polarizing beam splitter. The two power outputs are then read by two photo detectors. We then convert the voltage measurements from the photo detector to power measurements to measure the power of the different polarization states.

Figure 5: Photo of the different radii mounts used in the experiment. The first to the left is a variable radius cake ring that can be extended to 150mm radius. The smallest to the right is a collapsible cup with a 30mm radius. We took data for approximately 10mm increments in radius.

Allowed diameter for lifetime	Residual strain to proof test ratio	Lifetime [years]	Lifetime [s]
Coil Diameter [mm]	S_a / S_p	t_a [years]	t_a [s]
9.5	0.884	3.17E-08	1.0E+00
10.5	0.799	3.17E-07	1.0E+01
11.6	0.722	3.17E-06	1.0E+02
12.9	0.652	3.17E-05	1.0E+03
14.2	0.589	3.17E-04	1.0E+04
15.8	0.533	3.17E-03	1.0E+05
17.4	0.481	3.17E-02	1.0E+06
19.3	0.435	3.17E-01	1.0E+07
21.4	0.393	3.17E+00	1.0E+08
23.6	0.355	3.17E+01	1.0E+09
26.2	0.321	3.17E+02	1.0E+10
50.0	0.168	7.62E+08	2.4E+16

Figure 6: Lifetime of zing fibers with different winding diameters [5]

We needed to obtain a mount with a variable radius r to test the effects of the radius on the polarization output for a single laser frequency. We used a variable diameter cake mold for radii in the range: $100mm < r <= 160mm$. For smaller radii we were unable to obtain a similar contraption. We instead found a collection of metals with radii in the range: 30mm < r <= 100mm. For r = 30mm we used a small, collapsible cup. We did not use radii smaller than 30mm as the lifetime of the fiber decreases appreciably below 30mm, see Fig. 6.

When winding the fiber around the mounts it is important to take care so as to not damage the fibers. Also, since the fiber is mounted to a collimator, each time the radius is changed this has to be undone. This constant re-positioning of the fiber end to the collimator could conceivably shift the alignment of the beam.

2.2 Method

After assembling the materials as in Fig. 3 and Fig. 4 and aligning the beam we were prepared to take data. To measure the relative power output in the two polarization levels we used a data acquisition unit to take 100 measurements of the voltage across the photodiode. We take 100 measurements so that we can use an average power because the laser beam power is not entirely constant. Then, we turned off the laser, moved the WinCam into the beam path, turned the laser back on, and took a measurement of the beam profile. We repeated these steps for radii in increments of 10mm between 30mm and 150mm.

In order to understand the effectiveness of the polarizing fiber, for r = 30mm, 60mm and 90mm we gathered additional polarization data. We rotated the half-waveplate between $0°$ and $90°$, taking voltage measurements with the photodiodes at each $5°$ interval.

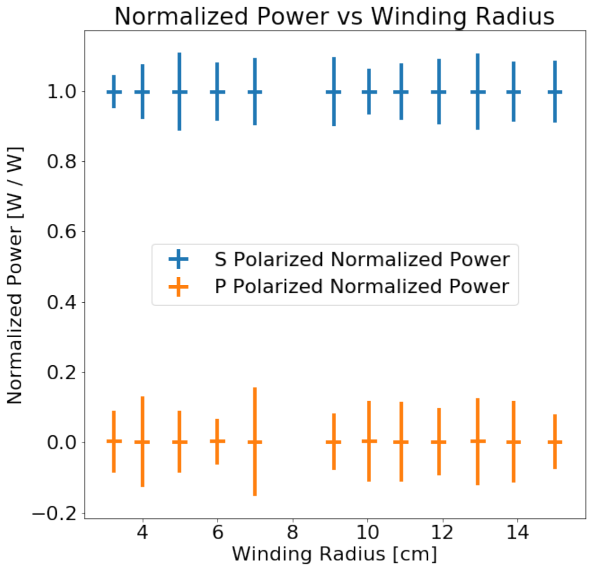

Figure 7: Normalized power from both S and P polarized light.

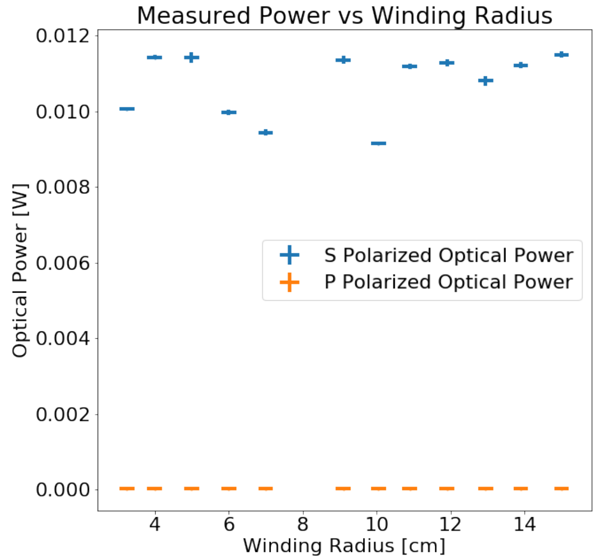

Figure 8: Power output for both S and P polarized light

3 Data Analysis

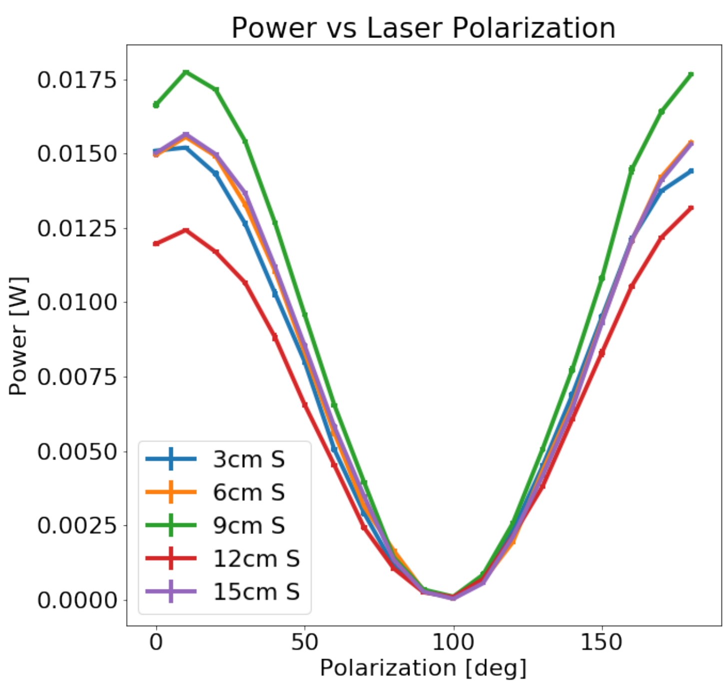

Figure 9: Power output vs polarization angle for different winding radii. There does not seem to be an explicit dependence on winding radius with respect to the power emanating from the fiber. The various magnitudes most likely have to do with error in the collimator alignment.

3.1 Polarization

First, we had to convert the voltage across the photodiode to a power measurement using:

$$V = \alpha R P \tag{1}$$

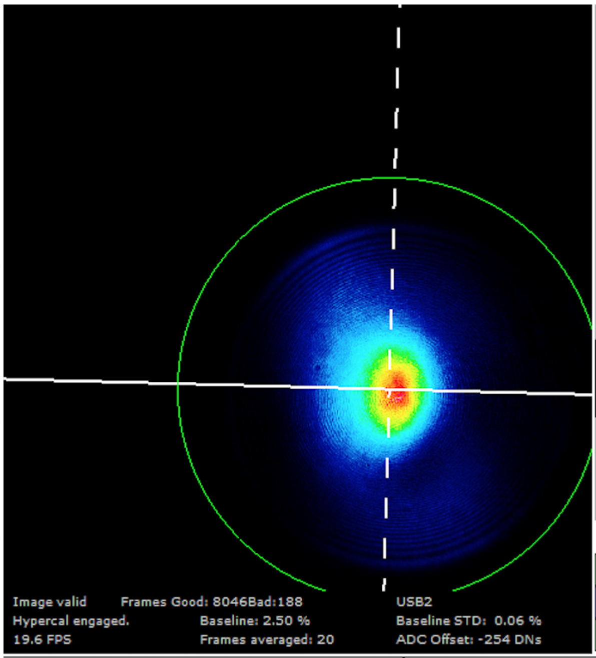

Figure 10: Beam profile at 30mm radius

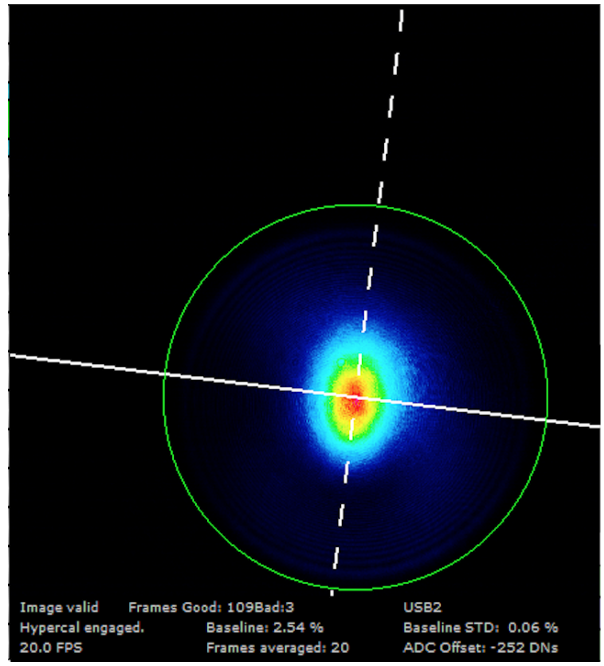

Figure 11: Beam profile at 150mm radius

Where $\alpha = 0.3A/W$ is the responsivity determined by the photodiodes, R is the resistance of the feedback resistor in the trans impedance amplifier, and P is the optical power.

In Fig. 7 we plot the normalized power against the winding radius of the coil and find that at a given radius between 30mm and 160mm, the relative optical power for each polarization does not shift significantly between radii. In fact, it is clear in Fig. 8 that the polarization for S-polarized light is either unaffected by the turning radius or else dominated by noise as the values do not shift throughout the measurement. The power provided by the P-polarized light however does seem to change with radius. It is important to note that the fiber had to be screwed and unscrewed to the collimator every time the fiber was switched, the variance is most a product of the sensitive optic equipment as opposed to an intrinsic property of the fiber.

We also evaluated the effects of changing the angle on the half-waveplate on the measured power in Fig 9. The half-waveplate changes the polarization of the incoming wave. When the waveplate is set to $0°$ or $90°$, the incoming S-polarized light leaves as S-polarized light. When the half-waveplate is set to $45°$, the light leaves the half-waveplate as P-polarized light. When only P-polarized light is selected at $45°$, the PZ fiber attenuates almost all of the light. Therefore we see the sinusoidal pattern as in Fig. 9.

Because the P-polarized light is highly attenuated we claim that the Zing-fiber does effectively work as a polarization fiber, allowing the S-polarized light to pass and attenuating the P-polarized light. Further, this effect for a given 4m fiber, 1064nm light source, does not vary significantly between winding radii in the range of 30mm to 150mm.

3.2 Beam Profile

We also investigated the effects of winding radius on the beam profile. In Fig 10 and 11 we see the beam profiles for a winding radius of 150mm and 30mm respectively. These profiles are similarly non-Gaussian. This is most likely due to the stress gradient produced by the bow-tie geometry combining with the stress from the bending or winding radius. This creates local variations in the refractive index which alter the guiding properties of the fiber. This modifies the beam profile, making the beam non-Gaussian [4]. As we decreased the winding radius, we did not see a significant change in the beam profile itself.

4 Conclusion

We claim that Zing-fiber does effectively work as a polarization fiber, allowing the S-polarized light to pass and attenuating the P-polarized light. This effect for a given 4m fiber, 1064nm light source, does not vary significantly between winding radii in the range of 30mm to 150mm. The output beam profile is non-Gaussian due to the effects of the winding. This effect does not seem to vary with a changing radius.

A further study would include a comparison to a baseline ’no winding’ radius, a straight cable. This was impossible in this experiment as the distance between the two collimators where the fiber was placed was too short to allow for a straight fiber. We would also block the ambient light from the room on the photodiodes. This ambient light mixed with the laser beam, especially when the incident power was low, adding an external source of error. A more reliable way to wind the fiber around the radius could also be devised. We could also explore the impacts of length of the fiber on the desired output, and changing the laser frequency. We would also be interested in exploring the back scatter rates of the different winding radii.

References

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[2] Hugh D. Young and Roger A. Freedman. University physics with modern physics. chapter 10, pages 1093–1100. Addison-Wesley, New York, 2012.

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