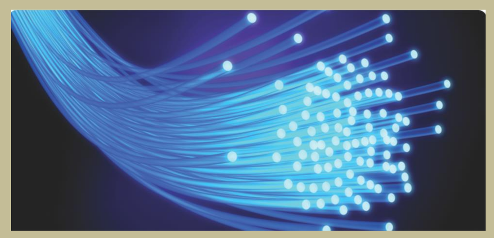
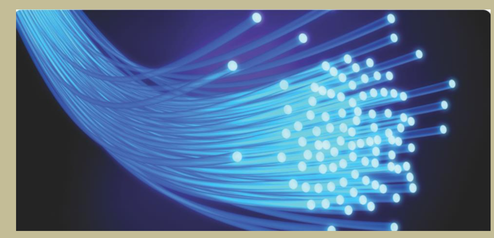
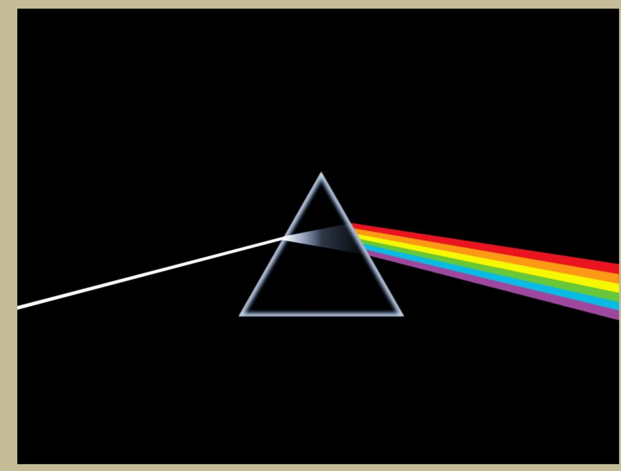
Measuring group delays and absorbance in Gaussian profile fibre Bragg gratings







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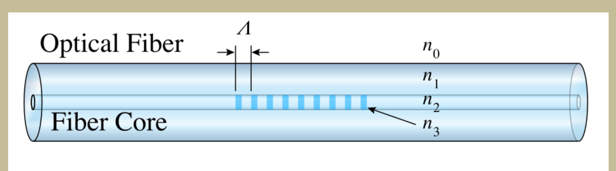
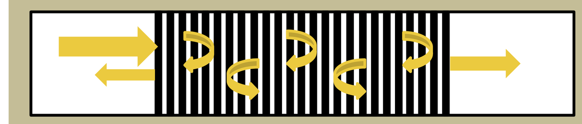
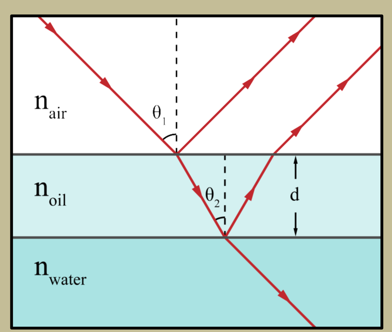
Introduction

Fibre Bragg gratings (FBGs) are produced by introducing periodic changes in the refractive index of the core of an optical fibre. This leads to a range of wavelengths being forbidden from propagating through the FBG which is called a photonic band gap (PBG). Gaussian profile FBGs have previously been shown to exhibit narrow bandwidth resonances by manipulating the PBG, leading to slowing light down by factors exceeding 100. The consequent build-up of localized fields in the resonator results in enhanced non-linear phenomena such as optical bistability due to the photothermal effect.





The principles behind how the FBG forms a PBG can be understood by considering the case of thin film interference. The colours on the bubble are the result of soap-air interface which is creating conditions for constructive and destructive interference for particular wavelengths of light. A periodic repetition of these thin films builds up the interference.



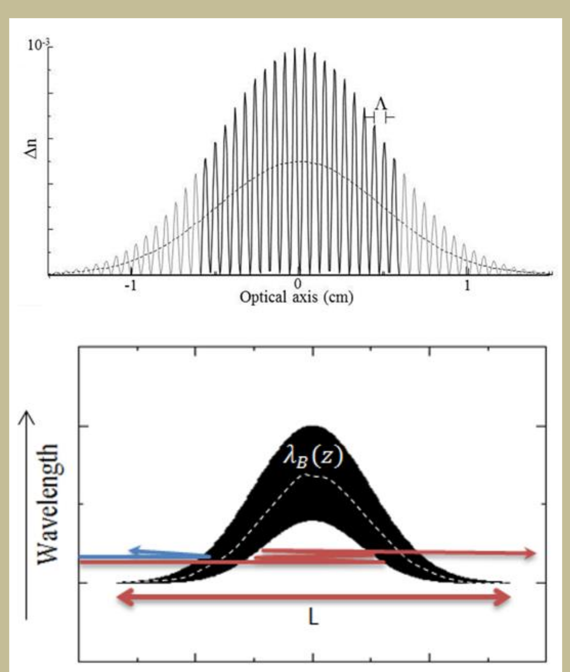
Motivation

The purpose of this research was to measure and compare the group delay and absorbance of light in three different FBG designs with increasing magnitudes of Δn. Although a higher Δn does produce a better resonator it also introduces greater loss which decreases group delay. Hence, the expectation was that there exists an optimal amount of Δn which produces the greatest τ_g.

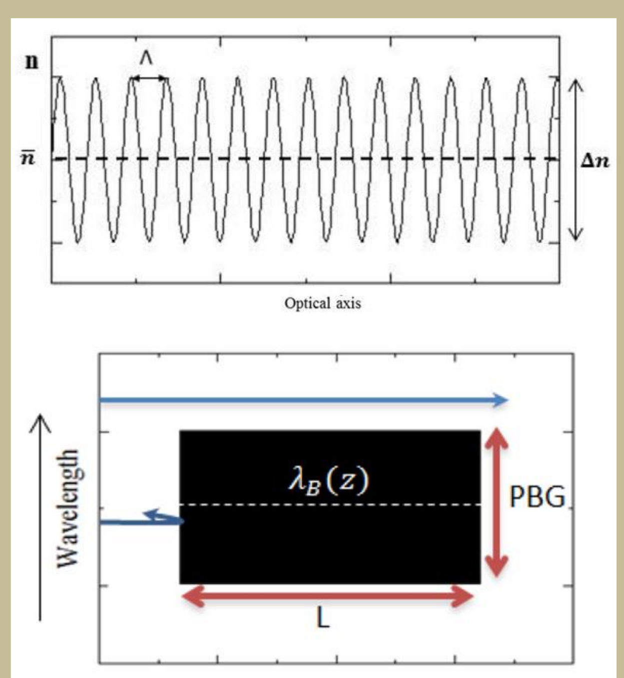
Theory

In a uniform FBG the periodic change in refractive index (Δn) is constant so the PBG along the length of the FBG is rectangular in shape. Although the condition for perfect reflection only exist for the Bragg wavelength, λ_B, the PBG represents the wavelengths close enough to the λ_B to be effectively forbidden from being transmitted.

Gaussian Profile FBG[1]



Uniform FBG

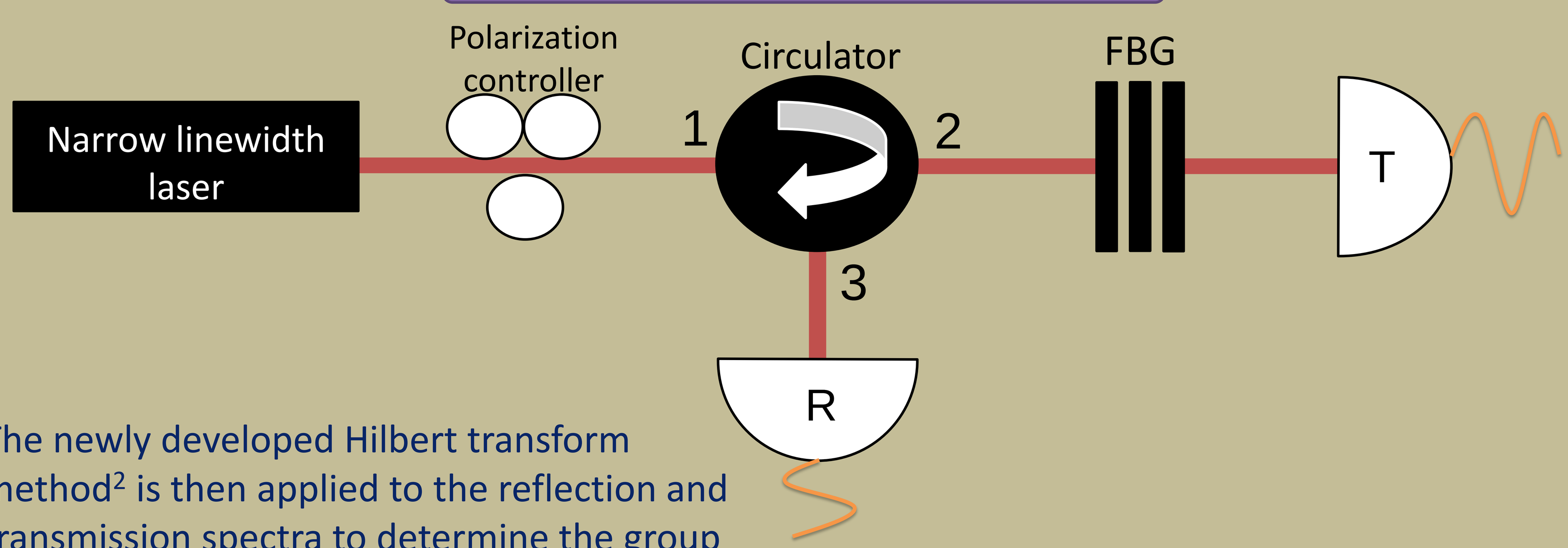


If the FBG's envelope of Δn , follows a Gaussian curve, the increase in λ_B, stretches the PBG into its characteristic form of the Gaussian profile FBG which allows for light to be trapped in resonant modes before being transmitted onwards with some group delay (τg). The larger the Δn, the stronger the resonant mode, however, a large Δn could have proportional absorbance that would introduce loss.

Methodology

A tunable, narrow linewidth fibre laser is used in the experimental set-up below to measure the transmission and reflection spectra of different Gaussian profile FBGs.

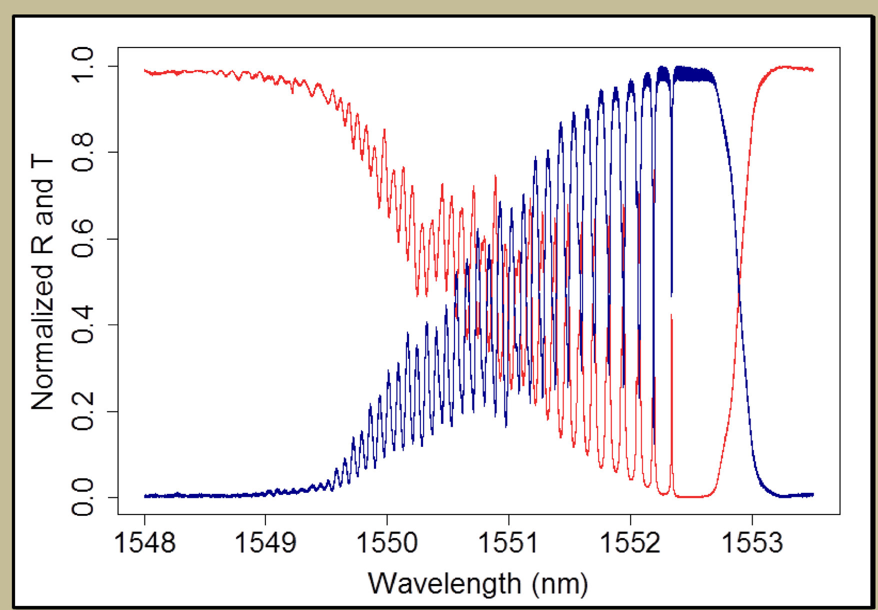
Schematic of experimental set-up

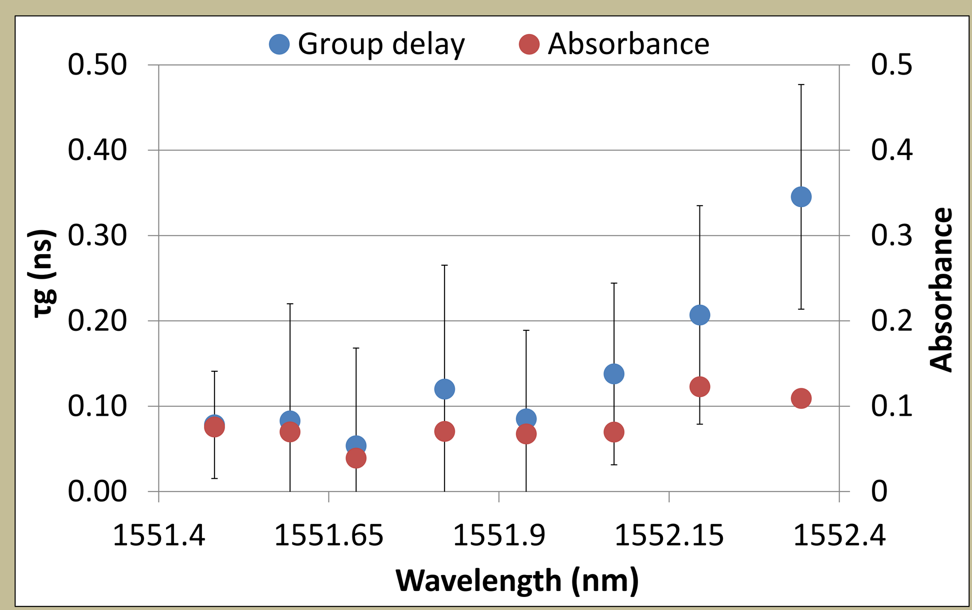


The newly developed Hilbert transform method[2] is then applied to the reflection and transmission spectra to determine the group delay for peaks in transmission caused by resonant mode in the FBG. The fraction of light absorbed is what remains after accounting for the normalizing transmission and reflection.

Results

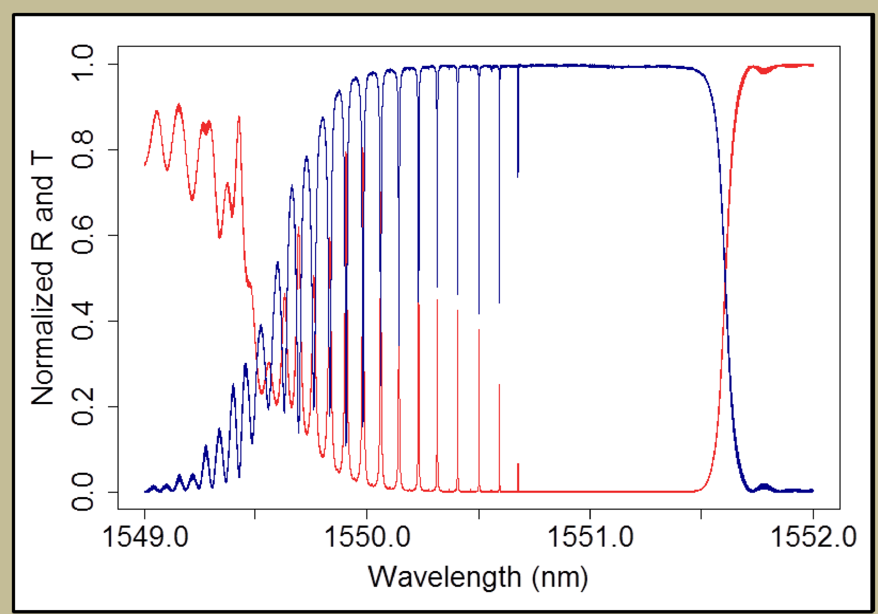
FBG with the smallest Δn

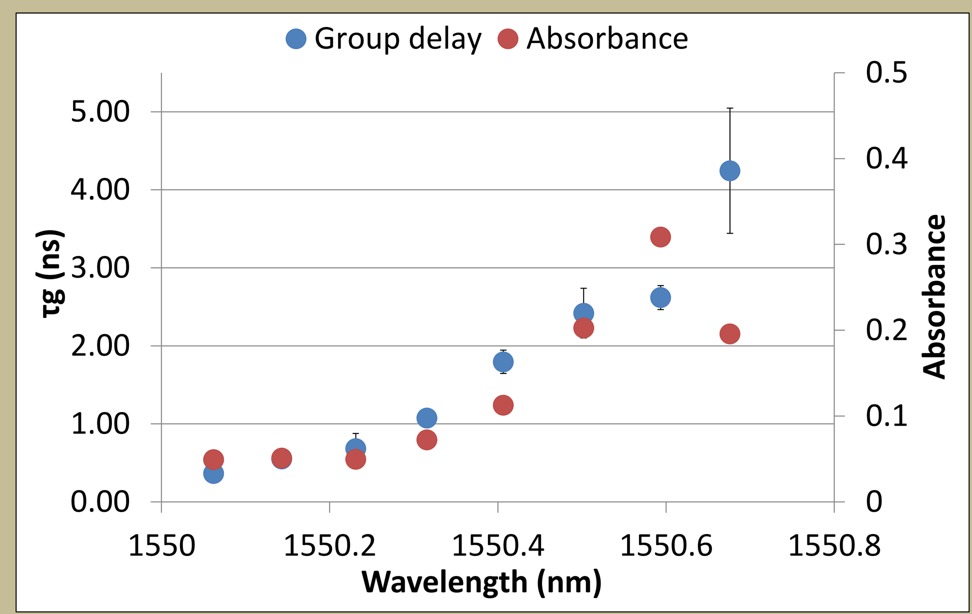




FBG with medium Δn

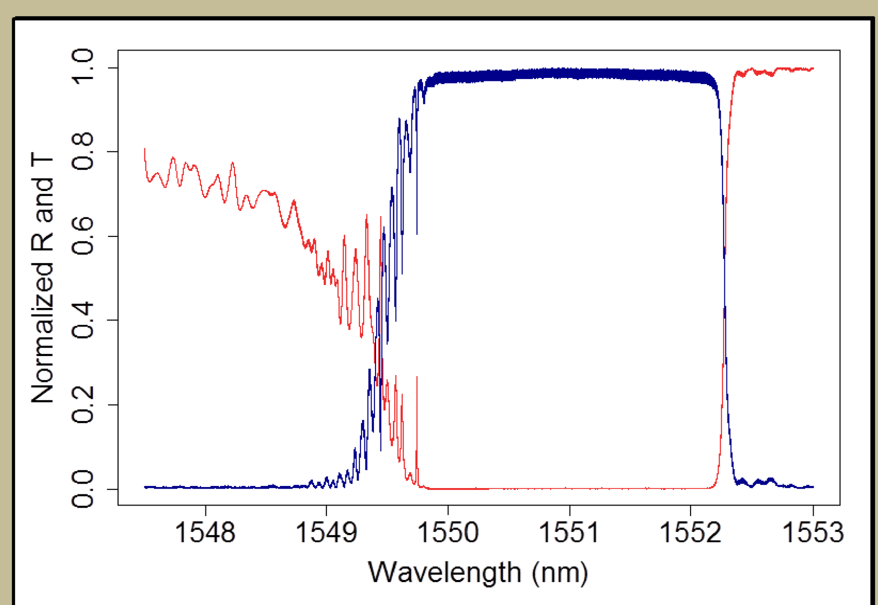
It appears that the fraction of light in the resonant modes consumed by absorption increases with larger Δn.

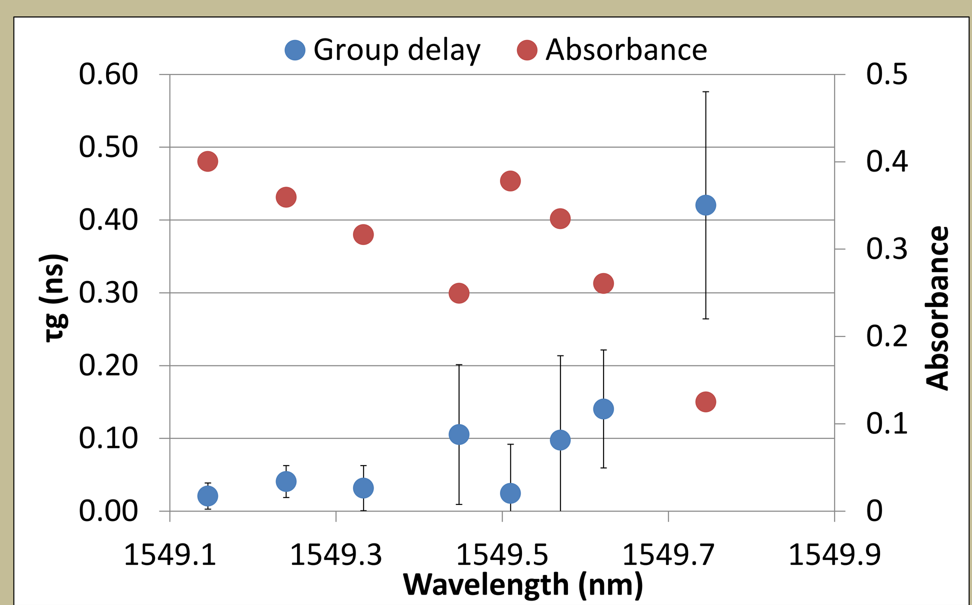




Consequently there must be an optimum Δn where the improvement of the resonant mode is not overwhelmed by absorption. The absorption is an unavoidable consequence of writing the FBG into the optical fibre. The reforming of chemical bonds in the glass that leads Δn also results in absorption.

FBG with the largest Δn

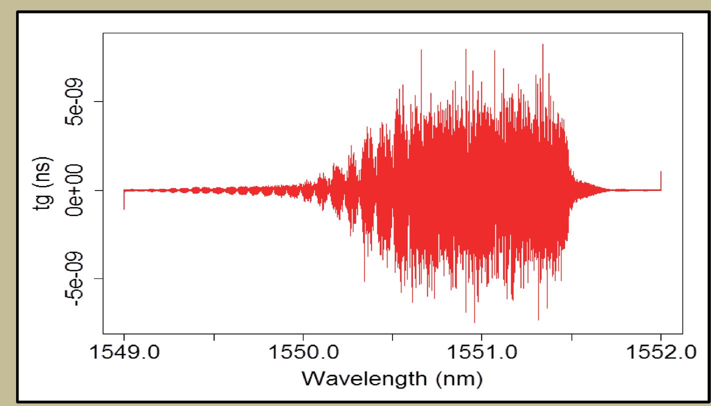




Conclusion

For Gaussian-profile FBGs to show larger group delays and consequently greater field intensity enhancement, they much account for the impact of absorption. This could be achieved at the design level by minimizing light's exposure to the areas with high Δn while still maintaining the resonant mode.

τ_g for medium Δn FBG



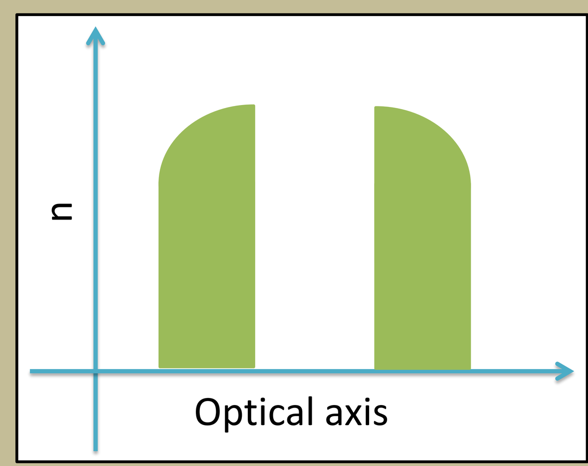
The main source of error in the experiment is the difficulty in assessing τ_g which is highly sensitive to noise. Even the τ_g for the FBG with medium Δn which was the clearest had significant noise.

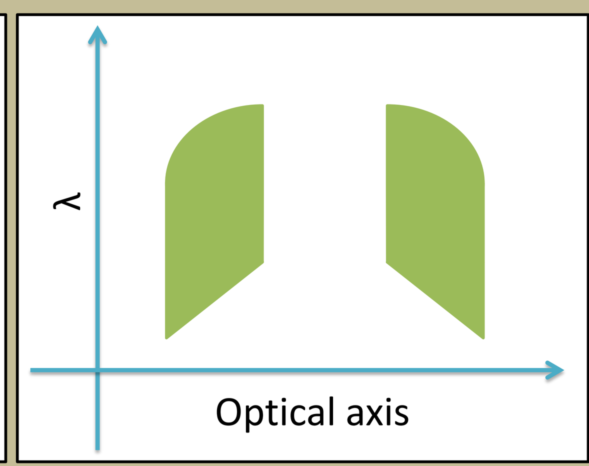
Future research

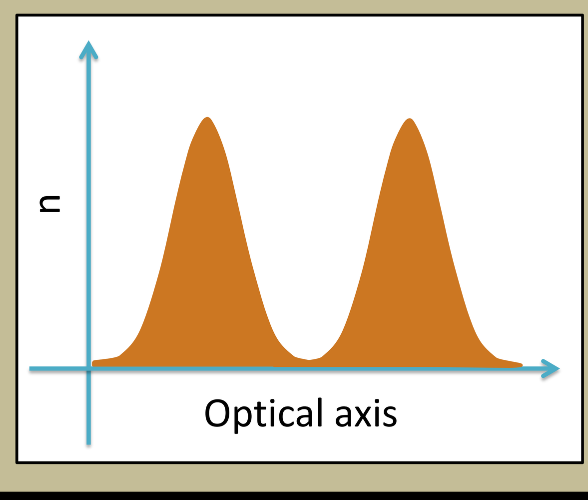
Focus of future research:

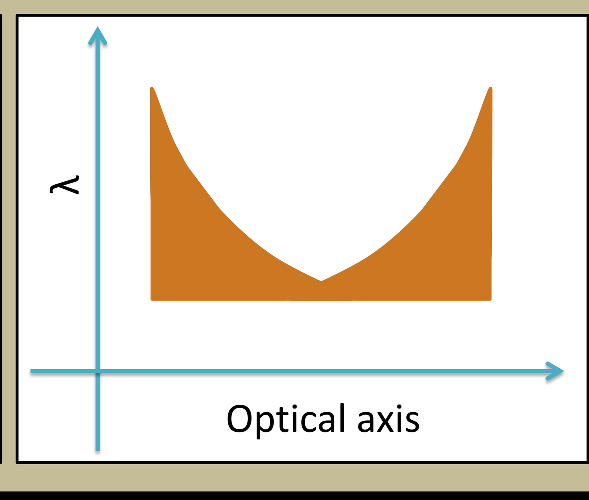
- Creating FBG designs with minimized amounts of altered material to reduce loss and increase τ_g
- Creating FBGs with greater tolerance for noise
- FBGs with greater tolerance for noise

New designs









Acknowledgments

This project was possible due to the support and mentorship of Dr. Jeremy Upham. It is also important to recognize the assistance of Priptal Kanhaiya for the assistance in data analysis and UROP for the funding of the research.

References

1. J. Upham, I. De Leon, D. Grobnic, E. Ma, M. C. Dicaire, S. Schulz, S. Murugkar, R. W. Boyd. "Enhancing optical field intensities in Gaussian-profile fibre Bragg gratings." Optical Letters. **39**, 4 (2014).

2. M.C. Dicaire, J. Upham, I. De Leon, S. A. Schulz, R. W. Boyd. "Group delay measurement of fibre Bragg grating resonances: Fourier and transform interferometry versus Hilbert transform." Journal of the Optical Society of America. [In press]