

# **Polarization Maintaining Photonic Crystal Fibers and Their Application as Sensors for Environmental Monitoring**

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under the supervision of Professor Y. Jay Guo

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## Declaration

I, Tianyu Yang, declare that this thesis, is submitted in fulfilment of the requirements for the award of PhD, in the Faculty of Engineering and IT at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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# Abstract

Photonic crystal fibers (PCFs) have attracted enormous attention since they were first reported in the 1990s. The pioneering theoretical and experimental studies on this kind of structured fiber showed that they have unique properties and could overcome many limitations of conventional optical fibers. This thesis focuses on the development of polarization maintaining (PM) PCFs using a variety of innovative methods and their applications as environmental sensors.

This thesis firstly starts with a short review of conventional optical fiber and available guiding mechanism of solid-core and hollow-core PCFs. Then, main characteristics of solid-core PCF, i.e., guided mode number, loss performance, birefringence, and chromatic dispersion, are presented.

Then, this thesis reports two different approaches to introduce high birefringence in PCFs and demonstrates how they lead to the ability to selectively emphasize one of the two propagation constants associated with the two degenerate fundamental propagation modes to attain the desired PM behavior. Two highly birefringent PCFs are proposed for the THz regime. One is based on a novel asymmetric structure, the other one is based on the asymmetric material distribution. It is also noted that the scaling ability allow one to get similar birefringence and loss properties at another frequency by scaling up or down the dimensions of the whole configuration.

Another success of this thesis was the development of a high-performance PM PCF based on the effective elimination of one of the major polarization modes and all higher order modes. While such single-polarization single-mode (SPSM) PCFs are available in the optical regime, very few have been reported in the THz regime. A novel approach that utilizes the effective material absorption loss to realize SPSM PCFs in the THz

regime is presented. Two SPSM PCFs are presented that can yield wide SPSM working bandwidth in THz and reasonable loss difference.

Finally, it will be demonstrated that the ENZ-augmented SPSM PCF design is very suitable in the long wavelength infrared (LWIR) range, from 10 to 11  $\mu\text{m}$ , as a sensitive sensor for environmental monitoring. An unexpected, significant resonant absorption behavior associated with the presence of the ENZ rings was discovered. It was also found that the resonance wavelength is very sensitive to the refractive index of the medium filling the air holes. Subsequently, it was determined that a short-length sensor can be realized with the LWIR SPSM PCF design and that it can be used to detect the concentration of salt in water.

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# Acronyms

CL	Confinement loss
EML	Effective material absorption loss
ENG	Epsilon-negative
ENZ	Epsilon-near-zero
Hi-Bi	High birefringence
HO	Higher order
HRS	Highly resistive silicon
IR	Infrared
LD	Loss difference
LWIR	Long-wave infrared
MLD	Minimum loss difference
NZI	Near-zero-index
PCF	Photonic crystal fiber
PM	Polarization maintaining
PML	Perfectly matching layer
SiC	Silicon carbide
SPSM	Single-polarization single-mode
TCO	Transparent conductive oxide
THz	Terahertz
TL	Total loss
XP	X-polarized
YP	Y-polarized
3D	three dimensional

