Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

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MSc (Aachen University of Applied Science, 2013)
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“Design and Analysis of Fiber-optic Mach-Zehnder Interferometers for Highly Sensitive Refractive Index Measurement”

Department of Mechanical Engineering

Friday, April 17, 2020
1:30 P.M.
Remote Defence

Supervisory Committee:
Dr. Colin Bradley, Department of Mechanical Engineering, University of Victoria (Supervisor)
Dr. Martin Jun, Department of Mechanical Engineering, UVic (Member)
Dr. Peter Wild, Department of Mechanical Engineering, UVic (Member)
Dr. Tao Lu, Department of Electrical and Computer Engineering, UVic (Outside Member)

External Examiner:
Dr. ChaBum Lee, Department of Mechanical and Engineering, Texas A & M University

Chair of Oral Examination:
Dr. Jens Bornemann, Department of Electrical Engineering, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract
The development of reliable, affordable, and efficient sensors is a key step forward in providing tools for efficient monitoring of critical environmental parameters. Fiber-optic sensors are already widely used in various industrial sensing fields. They have proven themselves reliable in harsh environments and can measure different physical quantities, such as temperature, pressure, strain, refractive index (RI), and humidity. Fiber-optic Mach-Zehnder Interferometer (MZI) is a well-studied optical fiber interferometer that has proven capacity for sensing ambient refractive index.

In this dissertation, we present Fiber Bragg grating (FBG) embedded in a microfiber Mach-Zehnder Interferometer designed for sensing temperature and refractive index. The MZI is constructed by splicing a short length of 40-μm-diameter microfiber between standard single mode fibers. A one-millimeter-long FBG is then written in the microfiber using a direct, point-by-point, ultrafast laser inscription method. The microfiber MZI shows only moderate sensitivity to ambient refractive index and temperature changes. In contrast, the microfiber FBG is insensitive to ambient refractive index change, while it exhibits typical sensitivity to temperature variation. These distinct characteristics of the FBG and MZI sensors enable the simultaneous measurement of refractive index and temperature as well as temperature compensation in ambient refractive index measurement.

Further, we report the use of a fiber-optic Mach-Zehnder Interferometer to measure core refractive index changes written by femtosecond laser irradiation. The core-offset interferometer was constructed by splicing a lightly misaligned stub of standard single-mode fiber between the device’s lead-in and lead-out optical fibers. When the core refractive index of an in-fiber interferometer is altered, that process changes the phase of the core light. Since the phase of light propagating in the cladding (reference arm) remains unchanged, the transmission fringe pattern of the interferometer undergoes a spectral shift. In the present research, that spectral shift was used to quantify the effective core refractive index change in a standard single-mode fiber.
In addition, we designed and developed a custom flame-based tapering machine that is used to fabricate miniaturized Mach–Zehnder interferometers (MZIs) using sharply tapered photonic crystal fiber (PCF). This technique produces sensors capable of highly sensitive ambient refractive index (RI) measurements. The sensor is fabricated by fusion splicing a small stub of PCF between standard single-mode fibers with fully collapsed air holes of the PCF in a splicing region. Tiny flame geometry enables the sharp tapering of the PCF, resulting in a short fiber length and high RI sensitivity. It appears that sharp tapering has a great impact on RI sensitivity enhancement, when compared with methods that decrease taper waist diameter. The tapering technique is further used to construct the Mach-Zehnder Interferometer-based fiber-optic refractive index (RI) sensor by uniformly tapering standard single mode fibers (SMF) for RI measurement. The fabricated MZI device does not require any splicing of fibers and shows excellent RI sensitivity.