Ain Shams University
Faculty of Engineering
Electronics and Communications Department

Hybrid Semiconductor Fiber Ring Laser Gyroscope

A Thesis
Submitted in partial fulfillment of the requirements of a Master of Science degree in Electrical Engineering

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Faculty of Engineering – Ain Shams University

Electronics and Communications Engineering Department

Thesis Title: **"Hybrid Semiconductor Fiber Ring Laser Gyroscope"**

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Degree: **Master of Science in Electrical Engineering**

Examiners' Committee

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Statement

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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Curriculum Vitae

Name: Ahmed Saeed Shebl Salem

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Date of Degree: July 2011

Abstract

"Hybrid Semiconductor Fiber Ring Laser Gyroscope"

By

Ahmed Saeed Shebl Salem

The aim of this thesis is to present a hybrid semiconductor fiber ring laser gyroscope system constructed from standard single mode (SMF-28e) fibers and a semiconductor optical amplifier. We have constructed the optical setup with a novel technique for determining the direction of rotation. Moreover, we have used a long fiber cavity to enhance the gyro's sensitivity and temperature stability. We have proposed the use of an optical filter inside the laser cavity to enhance the gyro sensitivity. This filter will be used in combination with a novel technique for the SOA modulation to reduce the lock-in effect. A numerical model for the system was developed accounting for the multimode nature of the ring cavity as well as the modulation capability of the SOA. We have studied the thermal effects on the HRLG bias and validating this effect experimentally. We have optimized the system achieving the tactical gyro's grade. The final assembled system has been experimentally validated to achieve a bias instability of 2º/h and an ARW of 0.5º/√h.

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Thesis Summary

Conventional He-Ne Ring Laser Gyroscopes (RLG) require ultimate high quality laser cavities with super reflectivity mirrors which are precisely aligned. Moreover, The He-Ne gain medium is composed of a special mixture to achieve a bidirectional single longitudinal mode operation. These technological constraints result in high cost, heavy weight and large power consumption gyros. Recently the He- Ne RLG has become a mature technology, and the current development efforts involve cost reduction rather than efforts at performance gains. Therefore, this stable market cannot be penetrated by any means without a real technological bridge by innovative solutions. Recently, the matured, non-accessible He-Ne super mirrors technology has been superimposed by combining both semiconductor and fiber technologies to develop new gyros. Semiconductor and fiber technologies offer low cost, light weight and low power consumption. Moreover, a higher quality factor cavity can be realized with the low fiber losses.

The aim of this thesis is to present a hybrid semiconductor fiber ring laser gyroscope system constructed from standard single mode (SMF-28e) fibers and a semiconductor optical amplifier. We have constructed the optical setup with a novel technique for determining the direction of rotation. Moreover, we have used a long fiber cavity to enhance the gyro's sensitivity and temperature stability. We have proposed the use of an optical filter inside the laser cavity to enhance the gyro sensitivity. This filter will be used in combination with a novel technique for the SOA modulation to reduce the lock-in effect. A numerical model for the system was developed accounting for the multimode nature of the ring cavity as well as the modulation capability of the SOA. We have studied the thermal effects on the HRLG bias and validating this effect experimentally. We have optimized the system achieving the tactical gyro's grade. The final assembled system has been experimentally validated to achieve a bias instability of 2º/h and an ARW of 0.5º/√h.

The thesis is divided into seven chapters together with the lists of contents, tables and figures as well as the list of references. Chapter 1, this chapter presents the motivation beyond the thesis work, the thesis's objective and the thesis's major contributions. Chapter 2 presents a review on the gyroscopes specifically the optical ones. A literature survey on the H-RLG is presented, in which we are emphasizing on the HRLG main specification, limitations and challenges. Chapter 3 aims to present the analytical model of the HRLG. Chapter 4 presents an experimental setup for the HRLG. A novel technique is presented to determine the direction of the rotation of the RLG in the fiber based SOA ring laser gyros. In Chapter 5, a dynamic model for the HRLG was developed to support the dynamic current modulation with fully coupled differential equations. The model is used to study lock-in dynamics. We have showed

that the lock-in problem can be reduced by utilizing the long fiber cavity with a current modulation of the SOA. Chapter 6 presents the overall performance of the HRLG system. We will first study, the thermal effects on the system performance both experimentally and theoretically. The system performance is mainly evaluated using the Allan variance technique. The system is found to satisfy the tactical grade noise performance. Chapter 7 sums up the thesis conclusions while pointing out to the main suggestions for the future work.

PUBLICATIONS

[1] ***Ahmed Shebl,*** *Mohamed Y. Shalaby , Khaled Sharaf and Diaa Khalil "A method for determining the direction of rotation in ring laser gyroscope based on fiber ring cavity and semiconductor optical amplifier," Proc. SPIE, Fiber Lasers XII: Technology, Systems, and Applications, 2017*

[2] ***Ahmed Shebl****, Ahmed M. Othman, Ashraf Mahmoud, George Albert, Yasser M. Sabry, Khaled Sharaf, Diaa Khalil. " Ring Laser Gyroscope Based on Standard Single Mode Fiber and Semiconductor Optical Amplifier", Radio Science Conference (NRSC), 2016*

[3] ***Ahmed. Shebl****, K. Hassan; F. Al-Arifi; M. Al-Otaib; Y.M. Sabry; D. Khalil, "Thermal stability of multi-longitudinal mode laser beating frequencies in hybrid semiconductor-fiber ring lasers,". Proc. SPIE 9344, Fiber Lasers XII: Technology, Systems, and Applications, 93442L (2015).*

[4] George A. Adib, ***Ahmed Shebl,*** *Yasser M. Sabry, Diaa Khalil, "Beating Signal Power Level Improvement in Ring Lasers Based on Coupled Ring Resonators", Radio Science Conference (NRSC), 2016.*

[5] Kamal Khalil, Yasser M. Sabry, Khaled Hassan, ***Ahmed Shebl****, Mostafa Soliman, Yomna M. Eltagoury, and Diaa Khalil "In-Line Optical MEMS Phase Modulator and Application in Ring Laser Frequency Modulation", IEEE Journal of Quantum electronics, 2016.*

[6] Kamal Khalil, Khaled Hassan, ***Ahmed Shebl****, Mostafa Soliman, Fares Al-Arifi, Mohammed Al-Otaibi, Yomna M. Eltagoury, Yasser M. Sabry and Diaa Khalil, "MEMS-based frequency modulation of fiber ring laser," SPIE Photonics West – OPTO, San Francisco, February 2015.*

[7] Kamal Khalil, Khaled Hassan, ***Ahmed Shebl****, Mostafa Soliman, Yomna M. Eltagoury, Mohammed Al-Otaibi, Yasser M. Sabry, Diaa Khalil, "MEMS Corner-Cube Transmission-type Optical Phase Modulator in DRIE Technology," International Conference on Optical MEMS and Nanophotonics, Glasgow, Scotland, August 2014.*

[8] ***Ahmed Shebl****, Kamal Khalil, Angie El-Damak and Diaa Khalil "Modelling of Lock-in reduction in Semiconductor optical amplifier fiber based ring laser gyroscope" to be submitted to Journal of Quantum electronics.*

PATENTS

*[1] Diaa A. M. Khalil, Khaled Hassan , **Ahmed Shebl** , Mrwan Alayed, Fahad Aljekhedab, "MEMS based ring laser gyroscope with reduced lock-in", US Grant, US9574880B2, Grant date: 2017-02-21*

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