Ain Shams University
Faculty of Engineering
Electronics and Communications Department

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

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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

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ABSTRACT

This thesis aims at improving our understanding of one of the main topologies of optical gyroscopes, the fiber based ring laser gyroscope. This type of fiber rotation sensors is considered one of the recent configurations in the past decade that expected to present a good alternative to the other available optical gyros such as He-Ne RLG and FOG in the industrial and commercial market due to its low cost, its integration capability and ease for fabrication and maintenance. Since this configuration still has some performance limitations such as limited dynamic range and noise performance, due to multiple longitudinal modes' MLM operation, and increased lock-in effect which limits the system's sensitivity at low rotation rates, we intend to provide a theoretical and experimental study of lock-in phenomena in F-RLG system and propose a practical solution for it based on optical MEMS technology and as well, introducing a practical solution of the MLM operation.

To this end, A MEMS based optical phase modulator based on corner cube micro-mirror is presented and proposed as a solution for the lock-in removal in F-RLG instead of the conventional mechanical dithering techniques, since the MEMS Phase modulator PM is less expensive, has lower weight and is more compatible with fiber systems. The designed device is fabricated using the deep Reactive Ion Etching DRIE technology, aligned to and integrated with optical fibers in a single package. The Phase modulation as well as frequency modulation of the ring laser using the fabricated device is demonstrated experimentally in the lab. A Numerical model is also developed for the accurate simulation of the ring laser demonstrating the lock-in phenomena in F-RLG. The model is based on the solution of the rate laser equations for both the field amplitudes and phase. It allows the study of the elimination of the lock-

in using the MEMS PM. The F-RLG system was experimentally characterized with giving more focus on the lock-in effect. However, the experimental of lock-in elimination using the developed MEMS PM was not completed due to unavailability of lensed fibers with the designed specs to achieve the required performance. A new scheme for single longitudinal mode operation of FRL in bi-directional sense was also demonstrated experimentally as a step in developing SLM F-RLG to avoid the problems of MLM operation of F-RLG.

Keywords: Ring laser gyroscope, MEMS phase modulator, lock-in reduction, SOA based fiber-RLG, frequency modulation, fiber ring laser, bi-directional SLM fiber ring laser.

SUMMARY

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F-RLG has two main performance limitations which are its multiple longitudinal mode operation which limits its noise performance and dynamic range and lock-in effect which limits its sensitivity and ability to measure low rotation rates. In this work, we focused on studying these two problems with giving more attention to the lock-in effect. The main objective is to study and present a solution of the lock-in problem using MEMS technology. MEMS based optical phase modulator PM is proposed as a solution of the lock-in problem instead of conventional mechanical dithering since MEMS based optical components are low cost components, compatible with fiber systems and more suitable for commercial applications. This MEMS PM was optically designed, fabricated and characterized along with verification of its usage as an optical phase modulator in fiber based ring laser systems and the frequency modulation of FRL was also verified practically and theoretically using this modulator. While the practical verification of reducing or removing the lock-in effect using this MEMS PM was not achieved due to limitation in getting AR coated lensed fibers with the required specs because of lack of suppliers and time, a theoretical study and numerical model of the lock-in phenomena based on rate equations approach was pro-

vided with including the proposed solution showing the feasibility and theoretical verification of the proposed technique.

A solution of the other main challenge in F-RLG system, the MLM operation, is proposed. We present a configuration for single longitudinal mode bi-directional ring laser. This configuration needs no special or expensive components such as special filters or fiber Bragg gratings as proposed in different techniques of SLM ring lasers. A conventional FRL system along with relaxed specs mechanically tunable filter were used. The SLM operation is achieved through the combined effects of gain starving by tuning the filter to blue edge of the gain curve and gain nonlinear saturation process. A practical verification of the SLM operation is provided and tuning of this SLM bi-directional laser was achieved over a range of 40 nm of wavelength.

Accordingly, the thesis is organized in five chapters as follows:

Chapter 1: gives a brief introduction of the motivation, objective, major contributions and organization of the thesis.

Chapter 2: is a review of the F-RLG system. A review of the main concept of the optical rotation sensing is summarized. The main challenges which are reported in literature are discussed with focusing on two main problems, the MLM operation and the lock-in effect. The lock–in effect concepts are also reviewed followed with review of the reported techniques of optical phase modulation. MM rate equation model of FRL system was presented to extract its spectral characteristics. Techniques used to generate SLM laser were also reviewed and summarized. The chapter ends with reviewing one of the main technologies used in fabrication of MEMS devices which is deep reactive ion etching technology.

Chapter 3: introduces the analysis of F-RLG system starting with presenting the basic configuration of the system and the idea of using such system in rotation sensing. After that, a theoretical study of the lock-in phenomenon in F-RLG is introduced arriving at a theoretical model based on rate equations approach to describe such phenomenon. The model is solved using numerical techniques and the results are provided along with their discussion which shows good agreement with the expectations and experimental measurements. Also, the effect of including phase modulators in F-RLG to reduce lock-in effect is represented using analytical expressions and verified using the same numerical model. We follow the system modeling with characterization of the system usage as a rotation sensor and lock-in effect characterization in F-RLG system. A novel technique for SLM operation of FRL in bi-directional sense is also presented with its experimental characterization and verification.

Chapter 4: summarizes the work done for realization of MEMS based optical phase modulator and its application in FRL system. Starting by introducing the principle of its operation followed by its optical design and brief discussion of its mechanical design. The device fabrication results, packaging and electrical and optical characterization are discussed. Application of this MEMS PM in frequency modulation of FRL is presented at the end of the chapter which is considered as a validation of the concepts presented to use the electrically actuated corner cube micro-mirrors as phase modulators and the compatibility of these modulators with fiber based systems especially the F-RLG or FRL systems.

Chapter 5: gives the conclusion of this thesis and introduces several recommendations and suggestions for the future work.