AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics Engineering and Electrical Communications

Cavity Enhanced Spectroscopy

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

by

Mahmoud Abbas Mohamed Abdelrahman Selim

Bachelor of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

Faculty of Engineering, Ain Shams University, 2016

Supervised By

Prof. Diaa Abdel Maguid Khalil

Dr. Yasser Mohammed Sabry

Cairo - (2019)

AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications

Cavity Enhanced Spectroscopy

by

Mahmoud Abbas Mohamed Abdelrahman Selim

Bachelor of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

Faculty of Engineering, Ain Shams University, 2016

Examiners' Committee

Name and Affiliation	**Signature**
Prof. Walid Tawfik Younis National institute of laser sciences Cairo University, Egypt	…….
Prof. Amr Ezzat Safwat Electronics Engineering and Electrical Communications Faculty of Engineering, Ain Shams University	…….
Prof. Diaa Abdel-Maguid Khalil Electronics Engineering and Electrical Communications Faculty of Engineering, Ain Shams University	…….

Statement

This thesis is submitted as a partial fulfillment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Student name: Mahmoud Abbas Mohamed Abdelrahman Selim

Signature

……...…….

Researcher Data

Name : Mahmoud abbas Mohamed Abdelrahman Selim

Date of birth : 1/6/1993

Place of birth : Cairo, Egypt

Last academic degree : B.Sc. in Electrical Engineering

Field of specialization: Electronics Engineering and Electrical Communications

University issued the degree : Ain Shams University

Date of issued degree : June 2016

Current job: Teaching assistant at Faculty of Engineering, Ain Shams University.

Acknowledgment

All praise is to Allah for bestowing upon me the chance, strength, and ability to complete this work as every good and perfect gift is from Him and according to His will and grace.

My sincere gratitude goes to my parents and my brother. This work would not have been possible without their continuous encouragement, patience, support, and assistance.

My words can't express my gratitude to my advisor Prof. Diaa Khalil, who introduced me to optics science and guided me through my research and career to the best. His example is an inspiration for me in my career and life. I'd like also to thank my co-advisor Dr. Yasser Sabry for his continuous help, discussions, and flexibility to accept my ideas and refine them to reach better results. His encouragement and support led me through tough moments. Both treated me not just as their student but also as their friend and son. I wouldn't be able to finish this work without their support, guidance, encouragement, and confidence in me.

Special thanks to Prof. Amr Safwat and Prof. Walid Tawfik for their time and effort in reviewing my work

Special thanks go to Prof. Mahmoud Hanafi who accepted me as member of the research team at Optical Communications and Lasers Lab (LLOC), Ain Shams University.

I would like to thank all my colleagues especially George Albert, Ahmed Othman, Ahmed Amr, and John Onsy for their cooperation and help in this work.

Mahmoud Abbas

Cairo, Egypt

Thesis Summary

This thesis aims to develop novel alignment-free miniaturized cavity-enhanced spectroscopy techniques on the scale of optical fibers and on the microsystem technologies. To this end, a novel alignment-free active intra-cavity single and dual coupler fiber-based cavity-enhanced has been proposed. The former configurations have been studied analytically and numerically. Then, the configurations have been validated experimentally. A simulation model for the enhancement factor in the effective length has been elaborated. The model results have been compared with the experimental results. An enhancement factor of 942 has been reached-which is the highest enhancement factor achieved in the fiber-based cavity-enhanced techniques.

In addition to, another alignment-free novel technique based on multi-longitudinal mode laser intensity spectroscopy-enabling to couple higher power to the optical cavity-has been proposed. The effect of the gain saturation on the effective length has been studied analytically and numerically. Besides, a novel RF-frequency based cavity-enhanced spectroscopy technique has been proposed. The technique is based on the detection of high frequency spectroscopic signal to eliminate the flicker noise.

Moreover, microfluidics cavity-enhanced spectroscopy based on MEMS technology has been proposed. The different excitation sources (single mode fiber and multimode fiber) have been simulated by using Fourier optics. In the case of single mode fiber, the cavity's response has been studied at the different beam waist. While in the case of multimode fiber, the cavity's response has been studied at a different numerical aperture. Then, the cavity's response of the standard single mode and multimode fiber has been compared. Then, the fabrication process procedures have been discussed and demonstrated. The effect of surface roughness has been elucidated. Then, the design of

the microfluidics cavities has been elaborated. Finally, the fabricated microcavities chips have been measured and utilized in enhancing the sensitivity of different fluids.

The thesis is divided into six chapters as listed below:

Chapter 1:

This chapter gives a concise introduction, the motivation, the objectives, the major contributions and overview of the organization of the thesis.

Chapter 2:

This chapter presents a literature review of the concepts and state-of-the-art related to cavity-enhanced spectroscopy. This review includes ring resonator theory, the theory of the different state-of-the-art cavity-enhanced techniques, an elaborate comparison between these techniques, and sensing mechanisms incorporated with cavity-enhanced spectroscopy.

Chapter 3:

This chapter investigates cavity-enhanced spectroscopy technique on fiber cavities. A novel dual and single coupler intra-cavity technique have been proposed. The techniques have been studied in a passive and active configuration. The analysis of the main factors affecting the effective length for each configuration such as fiber coupler coupling coefficient, spectrum analyzer resolution, large extinction coefficient, wavelength dependent round-trip net gain, and noise sources have been elucidated analytically and numerically. Finally, the experimental results of the different configuration have been discussed and compared.

Chapter 4:

This chapter proposes a novel frequency and intensity-based cavity-enhanced techniques using a multi-longitudinal mode laser. Firstly, we present an analytical model for novel techniques. Secondly, the key parameters of each technique have been

studied. Thirdly, the proposed configurations have been studied numerically. Finally, the experimental results have been discussed.

Chapter 5:

This chapter investigates extending the cavity-enhanced spectroscopy technique to microfluidics technology scale. Firstly, An simulation model elaborates the effect of the source excitation coherence on cavity response. Secondly, the proposed designs have been studied using the presented model investigating the effect of the different design parameters. Finally, the experimental results have been discussed.

Chapter 6:

This chapter gives the thesis's conclusions and introduces several recommendations and suggestions for future work.

Keywords:

Gas sensor, Cavity-enhanced spectroscopy, Finesse enhancement, Semiconductor optical amplifier, Microwave photonic filter, Multi-mode laser, Optical modes beating, Ring sensors, Coupled resonators, Fiber optics sensors.

CONTENTS