Optical Properties of Gain incorporating Photonic Resonators

by

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CIIT/FA15-BPH-019/ISB

BS Thesis

In

Physics

COMSATS University Islamabad

Islamabad - Pakistan

January, 2019

COMSATS University Islamabad

Optical Properties of Gain incorporating Photonic Resonators

A Thesis Presented to

COMSATS University Islamabad

In partial fulfillment

of the requirement for the degree of

Bachelor of Science in Physics

by

Ahmad Bilal
CUI/FA15-BPH-019/ISB

Spring, 2019

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A Under Graduate Thesis submitted to the Department of Physics as partial fulfillment of the requirement for the award of Degree of BS (Physics).

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Optical Properties of Gain incorporating Photonic Resonators

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Has been approved

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Declaration

I **Ahmad Bilal** (CIIT/FA15-BPH-019/ISB) hereby declare that this project neither as a whole nor as a part there of has been copied out from any source. It is further declared that I have developed this thesis and the accompanied report entirely on the basis of my personal efforts made under the sincere guidance of my supervisors. No portion of the work presented in this report has been submitted in support of any other degree of qualification of this or any other University or Institute of learning, if found I shall stand responsible.

Date:

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Certificate

It is certified that Ahmad Bilal (Registration No. CIIT/FA156-BPH-019/ISB) has carried out all the work related to this thesis under my supervision at the Department of Physics, COMSATS University Islamabad and the work fulfills the requirement for award of BS degree.

Date: Jan, 2019

Supervisor:

Dr. Ahmer Naweed
Associate Professor, Department of Physics

Head of Department:

Dr. Sajid Qamar
Department of Physics

Dedication

This thesis is dedicated to my mother who brought me up all by herself, motivated me to always persue my dreams and made me the gentleman I am today.

Abstract

Since long, electronic integrated circuits have dominated our modern technology. Now with the dawn of photonics, which is basically using integrated circuits made up using optics, its not far that our modern technology takes a new toll and slide into a new generation of digital devices. Basically, Photonics is the technology of generating and harnessing light, and other form of radiant energy whose quantum unit is a photon. These can be used in multiple applications , to explore the vastness of the Universe, cure serious and unknown diseases and even help in forensics to solve difficult crime cases.

In this project, we extended the research on optical ring resonators for such mediums in which there is gain. First we studied normally the optical properties of passive resonators and measured the effects of EIT and EIA in them (details later discussed). Then we moved over focus on active resonators varrying different parameters to acheive EIT and EIA in gain incorporating photonic resonators which have extensive amount of applications. The main focus for this project was to model the characteristics and properties of active resonators and compare it with the results of passive resonators. Due to the gain property of active resonators, similar effects can be seen here as in passive resonators but without losses involved. The main idea was to establish a photonic device that could work efficiently as passive resonators and also have more output.

Light is a beautiful thing, it makes us see things, but what if it also starts to help us organize our data, compute our equations, play our music, record our documents and basically do everything what a modern digital device, built on electronics, is capable of doing? I guess we'll find out!

Indeed, in the creation of the heavens,
and the earth and the alternation of
the night and the day, are signs for
those of understanding.

The Nobel Quran [3:190]

Ackowledgement

In the name of Allah, who is the most beneficient and merciful. I would start off this extensive documentation with a quote from Carl Sagan, one of the greatest science educator, who created enough enthusiasm and curiosity in me to persue my career in Physics. He said, *"Somewhere, something incredible is waiting to be known".* This is one of the reason I chose to be a student of physics, it inspires me to search for the unknown clues that are hidden in the very fabric of reality. Physics gave mankind the power to dominate their world and use the best of nature for their benefit.

Since childhood, I had always been fascinated by computers and gadgets. Having the background of engineers in my family, I almost ended up joining the computer engineering in High School. But the curiosity inside me had made me a star gazer. So I had questions about how they get where they are, and what are they made of? These questions were those which made me switch my field to Physics which is a science of never-ending curiosity. In this process, a lot of people are included some directly and some indirectly, most of which are my family because of their never-ending support had made me persue my dreams.

I would personally like to thank my supervisor in BS project, Dr. A. Naweed. Who helped me through thick and thin to complete this project and who kept me motivated enough to continue my research in field of photonics. I would like to thank my batch counselor Dr. A. H. Mujtaba, who's support and teachings made us all work harder and harder for the progression of science. Also there is a big role of Ms. Zarqa in my motivation for this project. She not only recomended me to Dr.

Naweed, but she is also my mental health counselor when I am in dire need of help. I would like to thank my peers in this, because the support and love I get from them is unmeasureable. Then again I would like to thank my family and especially my mother, who never asked me about my GPA and anything and always said, ”if you love what you are studying, only then you can get true learning.”

In the end, it is important to know that Knowledge is a never ending process, and Physics is such a beautiful field that every time I learn a new concept about the universe, it feels like I have been born again.

Ahmad B. Yousafzai

Islamabad, Jan 2019

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Chapter 1

Introduction

1.1 Resonators

A resonator is a device that exhibits resonant behavior naturally (or artificially) on some resonant frequencies, that is, it oscillates at those frequencies with higher amplitudes than others. These frequencies are called its resonant frequencies. These oscillations can either be electromagnetic waves or mechanical waves as well. There are different uses of resonators, they can be used to filter some specific frequencies or can also be used to generate a specific frequency of the wave. A resonator in which the waves exists in hallow space is called a cavity resonator, which is used in electronics and radio signal processing, known as microwave cavities, to generate, transmit and receive electromagnetic signals. Acoustic cavity resonators, in which sound is produced by air vibrating in a cavity with one opening, are known as Helmholtz resonators.

1.1.1 Explaination

The term resonator is most often used for a homogeneous object in which vibrations travel as waves, at an approximately constant velocity, bouncing back and forth between the sides of the resonator. The material of the resonator, through which the waves flow, can be viewed as being made of millions of coupled moving parts (such as atoms). Therefore, they can have millions of resonant frequencies, although only a few may be used in practical resonators. The oppositely moving waves interfere with each other, and at its resonant frequencies reinforce each other to create a pattern of standing waves in the resonator. If the distance between the sides is d, the length of a round trip is $2d$. To cause resonance, the phase of a sinusoidal wave after a round trip must be equal to the initial phase so the waves self-reinforce. The condition for resonance in a resonator is that the round trip distance, $2d$, is equal to an integer number of wavelengths λ of the wave:

$$2d = N\lambda, \qquad N \in \{1, 2, 3, \dots\}$$

If the velocity of a wave is c, the frequency is $f = c/\lambda$ so the resonant frequencies are:

$$f = \frac{Nc}{2d} \qquad N \in \{1, 2, 3, \dots\}$$

So the resonant frequencies of resonators, called normal modes, are equally spaced multiples (harmonics) of a lowest frequency called the fundamental frequency. The above analysis assumes the medium inside the resonator is homogeneous, so the waves travel at a constant speed, and that the shape of the resonator is rectilinear. If the resonator is inhomogeneous or has a nonrectilinear shape, like a circular drumhead or a cylindrical microwave cavity, the resonant frequencies may not occur at equally spaced multiples of the fundamental frequency. They are then called overtones instead of harmonics. There may be several such series of resonant frequencies in a single resonator, corresponding to different modes of vibration.

1.2 Optical Resonators

To perform more advanced calculations, it is important to have some understanding of how mpmath works internally and what the possible sources of error are. This section gives an overview of arbitrary-precision binary floating-point arithmetic and some concepts from numerical analysis.Most of the time, using mpmath

1.2.1 Different Geometeries

is simply a matter of setting the desired precision and entering a formula. For verification purposes, a quite (but not always!) reliable technique is to calculate the same thing a second time at a higher precision and verifying that the results agree.

1.3 Fabry-Perot Resonators

To perform more advanced calculations, it is important to have some understanding of how mpmath works internally and what the possible sources of error are. This section gives an overview of arbitrary-precision binary floating-point arithmetic and some concepts from numerical analysis.

1.3.1 Explaination

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1.4 Ring Resonators

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1.4.1 All-Pass

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1.4.2 Add drop

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1.4.3 Coupled Ring

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Chapter 2

Area of Study

2.1 The Fabry-Perot Interferometer

Most of the time, using mpmath is simply a matter of setting the desired precision and entering a formula. For verification purposes, a quite (but not always!) reliable technique is to calculate the same thing a second time at a higher precision and verifying that the results agree.

2.1.1 Theory of Fabry-Perot interferometer

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2.1.2 Finese, Q-factor

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2.2 Gain incorporation in Resonators

To perform more advanced calculations, it is important to have some understanding of how mpmath works internally and what the possible sources of error are. This section gives an overview of arbitrary-precision

2.2.1 Beer's Law

binary floating-point arithmetic and some concepts from numerical analysis.Most of the time, using mpmath is simply a matter of setting the desired precision and entering a formula. For verification purposes, a quite (but not always!) reliable technique is to calculate the same thing a second time at a higher precision and verifying that the results agree.

2.2.2 Beer's law study as gain

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2.3 Gain medium

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Chapter 3

Coupled Resonators with Gain

3.1 Coupled resontaor with Gain medium

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3.1.1 Gain element

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3.2 Calculation/Equations

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3.3 Coupling Regimes

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Chapter 4

Electromagnetically Induced Transparecy

4.1 EIT in Atoms

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4.1.1 Two level Atoms

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4.2 EIT in ring resonators

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4.3 EIT in Coupled resonators(CRIT)

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4.4 CRIT with gain

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4.5 Results

To perform more advanced calculations, it is important to have some understanding of how mpmath works internally and what the possible sources of error are. This section gives an overview of arbitrary-precision binary floating-point arithmetic and some concepts from numerical analysis.Most of the time, using mpmath is simply a matter of setting the desired precision and entering a formula. For verification purposes, a quite (but not always!) reliable technique is to calculate the same thing a second time at a higher precision and verifying that the results agree.

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Chapter 5

Electromagnetically Induced Absorbption

5.1 EIA concepts

To perform more advanced calculations, it is important to have some understanding of how mpmath works internally and what the possible sources of error are. This section gives an overview of arbitrary-precision binary floating-point arithmetic and some concepts from numerical analysis.To perform more advanced calculations, it is important to have some

5.1.1 EIA in atoms

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5.1.2 EIA Quantum phenomena

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5.2 EIA in resonators

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Chapter 6

Conclusion

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Appendix A

Abrevations

EIT Electromagnetically Induced Transparency

EIA Electromagnetically Induced Absorption

CRIT Coupled Resonator Induced Transparency

CRIA Coupled Resonator Induced Absorption

FSR Free Spectral Range

MRR Micro Ring Resonator

MZI Mach Zehnder Interferometer

FWHM Full width at half maximum

CMT Coupled Mode Theory