

Ministry of Higher Education and Scientific Research

Ferhat Abbas University - Setif 1

Institute: Optics and Precision Mechanics

Department: Optics and precision mechanics

Field: Science and Technology

Sector: Optics and Precision Mechanics

Master's thesis

Fiber Laser Tree Models

Presented by: Ms.Ghezali Chaima

Ms.Chitibi Rym

Supervised by: Pr. Belloui B

Devant le jury:

Dr. Guechi

(Président)

Dr. Guessoum Am

(Examineur)

Defended on: 04/07/2023

TABLE OF CONTENTS

GENERAL INTRODUCTION	1
CHAPTER I: DEVELOPMENT AND THEORIES OF FIBER LASERS	3
I.1 Introduction	3
I.2 Development of fiber laser	3
I.3 Erbium doped fiber laser	7
I.4 Theoretical Models for Fiber Lasers	9
I.4.1 The rate equation model	9
I.4.1.1 Simple rate equation model	10
I.4.1.2 Two-level rate equation model	10
I.4.1.3 Four-level rate equation model	11
I.4.2 The mode field diameter equation	12
I.4.2.1 Gaussian approximation	12
I.4.2.2 LP mode approximation	12
I.4.2.3 V-number approximation	12
I.4.3 The beam quality factor equation	13
I.4.4 The threshold pump power equation	14
I.4.5 The gain equation	15
I.4.6 Theory of Intensity Noise	16
I.4.7 The pulse duration equation	18
I.4.7.1 Gaussian pulse duration formula	19
I.4.7.2 Sech pulse duration formula	19
I.4.7.3 Soliton pulse duration formula	20
I.4.8 The saturation intensity equation	20
I.4.8.1 Homogeneous broadening formula	21
I.4.8.2 Inhomogeneous broadening formula	21
I.4.8.3 Two-level system formula	21
I.4.9 Cladding-pumped fiber lasers	21
I.4.9.1 Gain formula	22
I.4.9.2 Pump absorption formula	22
I.4.9.3 Threshold formula	22

SUMMARY

I.4.9.4 Output power formula	22
I.4.10 Nonlinear effects in fiber lasers	23
I.4.10.1 Self-phase modulation (SPM)	23
I.4.10.2 Cross-phase modulation (XPM)	24
I.5 Fiber Laser Tree models	25
I.6 Conclusion	25
CHAPTER II: DEMONSTRATION AND SIMULATION OF FIBER LASER THEORIES ..	27
II.1 Introduction	27
II.2 Demonstration and Simulation of Fiber Laser Theories by MATLAB	27
II.2.1 Simulating and Solving a Dynamical System: Numerical Integration and Plotting of Differential Equations using MATLAB's ode45 Function	28
II.2.2 MATLAB Code for Mode Field Diameter (MFD) Calculation and Gaussian Beam Intensity Profile Visualization	29
II.2.3 MATLAB Code for Calculating M^2 Value and Generating 3D Beam Intensity Distribution Plot	30
II.2.4 Threshold Power vs. Fiber Length: MATLAB Code for Calculating and Plotting	31
II.2.5 Analyzing the Relationship Between Gain and Pump Power Density: A MATLAB Code Demonstration	33
II.3 Demonstration and Simulation of Fiber Laser Theories by Python	34
II.3.1 Calculating Intensity Noise in a Laser Amplifier System using Python: Analysis and Plotting	34
II.3.2 Analyzing Time Delay due to Dispersion (Δt_D) in Relation to Angular Frequency Difference ($\Delta\omega$) in Python	35
II.3.3 Graphical Representation of Saturation Intensity (I_{sat}) as a Function of Non-Radiative Lifetime (τ_n) in Python	36
II.3.4 Analysis and Visualization of Fiber Laser Output Power vs. Wavelength	37
II.3.5 Analyzing Power Spectrum Variation with Wavelength in Fiber Lasers: Spectral Broadening and Self-Phase Modulation Effects	37
II.4 Demonstration Mathematics of the Theories of Fiber Laser Models	39
II.4.1 The rate equation models	39
II.4.2 Self-phase modulation (SPM)	41
II.4.3 XPM-induced asymmetric spectral broadening	42
II.5.1 Modeling	44
II.5.2 Population, Spontaneous Emission and Lifespans	44

SUMMARY

II.5.3 Definitions of absorption.....	45
II.5.4 Definition of stimulated emission.....	46
II.5.5 Cross Section	46
II.5.6 Amplification Coefficient and Susceptibility.....	47
II.6 Conclusion	48
CHAPTER III: SIMULATION OF FIBER LASER USING OPTISYSTEM.....	49
III.1 Introduction.....	49
III.2 Configurations of EDFL	49
III.2.1 Experimental EDFA	50
III.3 Experimental and simulation of fiber laser.....	51
III.3.1 Experimental configuration	51
III.4 Ring Laser Simulation.....	52
III.5 Erbium doped fiber ring laser	54
III.6 Conclusion	56
GENERAL CONCLUTION	57
BIBLIOGRAPHY	58

GENERAL INTRODUCTION

Over the past few years, industries have had to come up with innovative technological solutions and materials tailored to environmental and economic requirements. Among these materials is a laser, which stands for “light amplification by stimulated emission of radiation,” is a device that produces a coherent, focused beam of light through a process of stimulated emission. The basic principle behind lasers involves the interaction of atoms or molecules within an active medium. An active medium, which can be a solid, liquid or gas, contains atoms or molecules in an excited state. Among the types of lasers, there are fiber lasers operate based on the principle of stimulated emission, where light amplification occurs through the stimulated emission of photons. The gain medium in fiber lasers is an optical fiber doped with rare-earth elements such as erbium, ytterbium, or neodymium. When pumped with an external light source, these dopants absorb energy and become excited. Subsequently, the excited dopants emit photons that are confined within the fiber by total internal reflection, leading to the amplification of light. This process creates a population inversion, where more atoms are in the excited state than in the ground state, resulting in a powerful laser output.

Fiber lasers consist of several key components that work together to generate and amplify laser light. The core component is the active fiber, which acts as the gain medium and is doped with rare-earth elements. A pump source, typically laser diodes or fiber-coupled laser diodes, excites the dopants in the active fiber. The optical cavity, formed by two mirrors (one highly reflective and one partially reflective), provides the feedback loop necessary for light amplification. Wavelength selective elements, such as fiber Bragg gratings, may be incorporated to achieve spectral filtering. These components, combined with the inherent advantages of fiber lasers, contribute to their high efficiency, excellent beam quality, compact size, and reliability.

Fiber lasers have several advantages over traditional lasers, including higher efficiency, better beam quality, and greater flexibility in terms of design and operation. They are also more compact and lightweight, making them ideal for use in industrial and scientific applications including cutting, welding, marking, and engraving of various materials such as metals, plastics, and ceramics. They are also used in medical and scientific research, telecommunications, and defense systems [1-2].

The main objective of this research is to understand the function mechanism of fiber lasers and use simulations to explain the phenomenon of fiber lasers.

This thesis makes the following contributions: