A NOVEL IDEA OF USING SOLITON IN FIBER BRAGG GRATING

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A NOVEL IDEA OF USING SOLITON IN FIBER BRAGG GRATING

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To all the beloved person in life especially
Mom, Dad and My Lovely Siblings

No Love
can cross the path of our destiny without leaving some
mark on it forever.......

To my dearest friends:
There are no limits to our possibilities.
At any moment, we have more possibilities that we can act upon.
When we imagine the possibilities, our vision expands,
We capture our friends and our life is meaningful.
We can reach out and touch the limits of our being.

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ABSTRACT

With the rapid development in sensing and optical telecommunication, fiber optic plays an important role in transmission systems as a low-loss and wide-bandwidth medium. In this study, three fiber Bragg gratings (FBGs) are fabricated using conventional method known as the phase mask technique. Bragg's wavelength of 1551.09 nm, 1551.29 nm and 1551.66 nm and reflectivities values of 30.18%, 78.12% and 44.73% respectively are obtained. For soliton writing, the equations based on the coupled mode theory have been derived. A Matlab coding has been developed in order to solve some of these equations. The simulation of potential energy distribution throughout the grating is examined by varying the value of nonlinear parameters of α, β, γ, and a new element known as θ is added in the equations. The results show that the nonlinear parameters affect the motion of photon in the FBG and under certain condition, it is possible to trap the photon and hence obtain the optical soliton. The fabrication results show that the FBG with reflectivity of 78.12% can be classified as good FBG compared to the other two FBGs. The simulation studies show that amongst those nonlinear parameters, α significantly affects the potential well due to its ability of this parameter in order of photon trapping. This study thus shows that is plausible to use soliton for FBG writing and the properties of soliton for such purpose can be controlled by manipulating α, β, γ and θ.

ABSTRAK

Sejajar dengan perkembangan pesat dalam bidang penderia dan teknologi komunikasi, gentian optik memainkan peranan penting dalam sistem pancaran sebagai medium yang mempunyai daya kehilangan yang rendah dan jalur lebar yang luas. Dalam kajian ini, tiga gentian parutan Bragg (FBG) telah berjaya difabrikasi menggunakan teknik topeng fasa dengan panjang gelombang masing-masing ialah 1551.09 nm, 1551.29 nm dan 1551.66 nm bersama darjah pantulan masing-masing sebanyak 30.18%, 78.12% dan 44.73%. Teknik penghasilan parutan Bragg menggunakan soliton telah diterbitkan dalam beberapa persamaan yang diperolehi daripada Teori Mod Pengganding. Kod Matlab juga telah dihasilkan dalam menyelesaikan persamaan-persamaan yang telah diterbitkan. Simulasi taburan tenaga keupayaan sepanjang parutan telah dibuat dengan mengubah nilai-nilai parameter tak linear iaitu nilai-nilai α, β dan γ. Selain itu, satu parameter yang baru telah ditambah dalam persamaan tenaga keupayaan untuk mengkaji kesannya terhadap taburan tenaga keupayaan. Hasil keputusan kajian fabrikasi menunjukkan FBG dengan darjah pantulan 78.12% adalah yang terbaik berbanding FBG yang lain dan dari simulasi pula jelas menunjukkan α memberi impak yang paling besar terhadap pola pergerakan foton dalam telaga keupayaan berbanding parameter-paramater tak linear yang lain. Ini menyumbang terhadap penangkapan foton sekaligus kewujudan elemen yang dikenali sebagai soliton optik. Ini menunjukkan bahawa adalah mungkin penggunaan soliton untuk fabrikasi FBG dan ciri-ciri soliton untuk tujuan berkenaan boleh dikawal dengan memanipulasi α, β, γ dan θ.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

λ_B	-	Bragg wavelength
Λ	-	Spatial period (or pitch) of the periodic variation
N_{eff}	-	Effective index for light propagating in a single mode fiber
$A(z)$	-	Forward propagating modes
$B(z)$	-	Backward propagating modes
$\psi(x,y)$	-	Transverse modal field distribution
ω	-	Frequency
β	-	Propagation constant of the mode
$n_g^2(x,y,z)$	-	Refractive index variation along the fiber
K	-	Spatial frequency of the grating
Δn^2	-	Index modulation of the grating
Γ	-	Coupling coefficient
r	-	Radius of the core of FBG
a	-	Radius of the cladding of FBG
l	-	Length of the grating
R	-	Reflectivity of the grating
n_2	-	Kerr coefficient
$\delta n_g(z)$	-	Periodic index variation inside the grating
$n_2 I$	-	Nonlinear index change
$\overline{n}$	-	Average refractive index of the medium
$\varepsilon(z)$	-	Perturbed permittivity
$E_{f,b}(z,t)$	-	Forward and backward propagating waves

κ	-	Coupling between the forward and backward propagating waves in the FBG
k_i	-	Incident wavevector
K	-	Grating wavevector
k_f	-	Wavevector of the scattered radiation
n_{eff}	-	Effective refractive index of the fiber core at free space center wavelength
Δn	-	Amplitude of the induced refractive index perturbation formed in the core of the fiber
z	-	Distance along the fiber in longitudinal axis
$R(l,\lambda)$	-	Reflectivity
λ	-	Wavelength
Ω	-	Coupling coefficient
Δk	-	Detuning wavevector
K	-	Propagation constant
M_p	-	Fraction of the fiber mode power contained by the fiber core
V	-	Normalized frequency of the fiber
n_{co}	-	Core radius
n_{cl}	-	Cladding radius
λ_w	-	Irradiation wavelength
φ	-	Intersecting beams
Λ_g	-	Period of the grating
Λ_{pm}	-	Period of the phase mask
Λ_g	-	Period of fringes
λ_{uv}	-	UV wavelength
N	-	Number of grating
$\overline{P}_{unperturbed}$	-	Unperturbed polarization
$\overline{P}_{grating}$	-	Perturbed polarization
μ	-	Transverse mode number
$\hat{e}_z$	-	Unit vector along the propagation direction z
$\delta_{\mu\upsilon}$	-	Kronecker's delta

$\vec{E}$	-	Electric field vectors
$\vec{H}$	-	Magnetic field vectors
$\vec{D}$	-	Displacement vectors
$\vec{B}$	-	Flux density
c	-	Speed of light
$\vec{E}(z,t)$	-	Electric field
ω_0	-	Central frequency
k_0	-	Wavenumber
P_0	-	Total power inside the grating
e_f	-	Forward propagating modes
e_b	-	Backward propagating modes
Γ_s	-	Self Phase Modulation
Γ_x	-	Cross-phase modulation effects
C	-	Constant of integration
$\hat{\delta}$	-	Detuning parameter
$V(A_0)$	-	Potential energy distribution in a FBG structures while the light propagating through the grating structures

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

A Fiber Bragg Grating (FBG) is a periodic variation of the refractive index of the core in the fiber optic along the length of the fiber as shown in Figure 1.1. The principal property of FBGs is that they reflect light in a narrow bandwidth that is centered abour the Bragg wavelength, λ_B which is given as (A. Orthonos and K. Kalli, 1999)

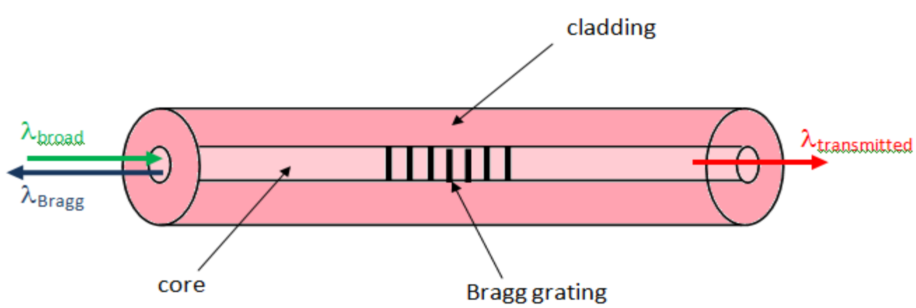

Figure 1.1: Illustration of Fiber Bragg Grating (R. Kashyap, 1999)

$$\lambda_B = 2N_{eff}\Lambda \tag{1.1.}$$

where Λ is the spatial period (or pitch) of the periodic variation and N_{eff} is the effective index for light propagating in a single mode fiber.

FBGs are simple intrinsic devices that are made in the fibre core by imaging an interference pattern through the side of the fibre (Meltz *et. al*, 1989). FBGs have all the advantages of an optical fibre, such as electrically passive operation, lightweight, high sensitivity with also unique features for self-referencing and multiplexing capabilities. This gives them a distinct edge over conventional devices (Nahar Singh *et. al*, 2006). Therefore, FBGs in optical fibers have a wide range of applications, such as for sensors, dispersion compensators, optical fibre filters, and all-optical switching and routing (T. Sun *et. al*,2002). An UV laser source is used to form FBG's in fiber optics either through internal writing (Hill *et. al*, 1978) or external writing technique (A. Orthonos and K. Kalli, 1999). In this study, the novel idea of using soliton is introduced for FBG.

Solitons are particle-like waves that propagate in dispersive or absorptive media without changing their pulse shapes and can survive after collisions. Various types of optical soliton phenomenon have been studied extensively in the area of nonlinear optical physics. These includes the nonlinear Schr edinger solitons in dispersive optical fibers, spatial and vortex solitons in photorefractive material, waveguides and cavity solitons in resonators (*Y. S. Kivshar and G. P. Agrawal*, 2003).

The first step in this study is to fabricate FBGs using conventional method. Then the novel method of writing the gratings on FBG using soliton is introduced. This will be studied numerically. Mathematical modelling is developed through the first principle of derivation. Simulated result obtain will be able to characterize the soliton waves and FBG's. Further details about FBG and soliton history, development, theory, fabrication, simulation, testing and evaluation are expounded in this thesis.

1.2 Background of the Study

Over the last decade fiber Bragg gratings(FBG) have become the key components for optical communications systems and sensor applications. They are used as flexible and low cost in-line components to manipulate any part of the optical transmission and reflection spectrum. FBG is formed by the periodic variations of the refractive index in the fiber core. Several techniques have been established to inscribe them with UV-lasers (*R. Kashyap*, 1999). However, these technologies are limited to photosensitive fiber core material, which are unsuitable for high power applications. Only recently modifications have been demonstrated in a non photosensitive fiber but at the expense of longer exposure times (*K. W. Chow et. al, 2008*).

1.3 Problem Statement

The main motivation of this research is to pursue the novel idea of using optical soliton writing in Fiber Bragg Gratings. First, the FBGs are fabricated using the Excimer UV Laser conventional method. For the soliton writing, distribution of potential energy equations has been derived based on coupled-mode theory. Simulation has shown the trend of photon movement along the grating in order to obtained optical soliton. Current method of using UV laser source could be enhanced by introducing soliton since we know that lasers are expensive and bulky in size. Usage of solitons gives less external interference since it only consists of minimal amount of losses along the propagation regarding the properties of soliton itself. Based on this study, the optimized parameters will be identified for inscribing grating to fiber optics using optical soliton.

1.4 Aims and Objectives

This research aims to introduce new soliton writing in FBG. The principal objective of this study is to investigate the novel idea of using soliton in FBG. A mathematical model on soliton FBG writing will be developed. The equations will be derived based on the coupled mode theory. A MatLab coding will be developed to solve these equations.

1.5 Scope of the Study

This research starts with a literature review of FBG's. Next the FBG's principle of operation, and fabrication techniques are discussed. The theory involved in the modelling of soliton will be developed. It is based on the coupled-mode theory including the Kerr nonlinearity, group velocity dispersion (GVD) and self phase modulation (SPM) and simulation on soliton writing of FBG will be performed. The conventional method of FBG fabrication process will be conducted using the phase mask technique using Excimer UV laser source at a wavelength of 248 nm. Results obtained from experiments, modelling and simulation will be analysed in terms of Bragg wavelength, reflectivity and the bandwidth.

1.6 Research Methodology

This study covers two main areas, namely, experimental setup of FBG fabrication, evaluation, modelling and simulation on the existence of optical soliton in grating structure in FBG. Phase mask technique is utilized to fabricate the FBGs in this research. The motion of a particle moving in FBG represents the pulse propagation in the grating structure of fiber optics exhibiting the existence of optical fiber. In order to describe the photon motion, the function of potential energy is depicted via modelling and the simulation. Figure 1.2 shows the flow and steps undertaken to conduct this research.

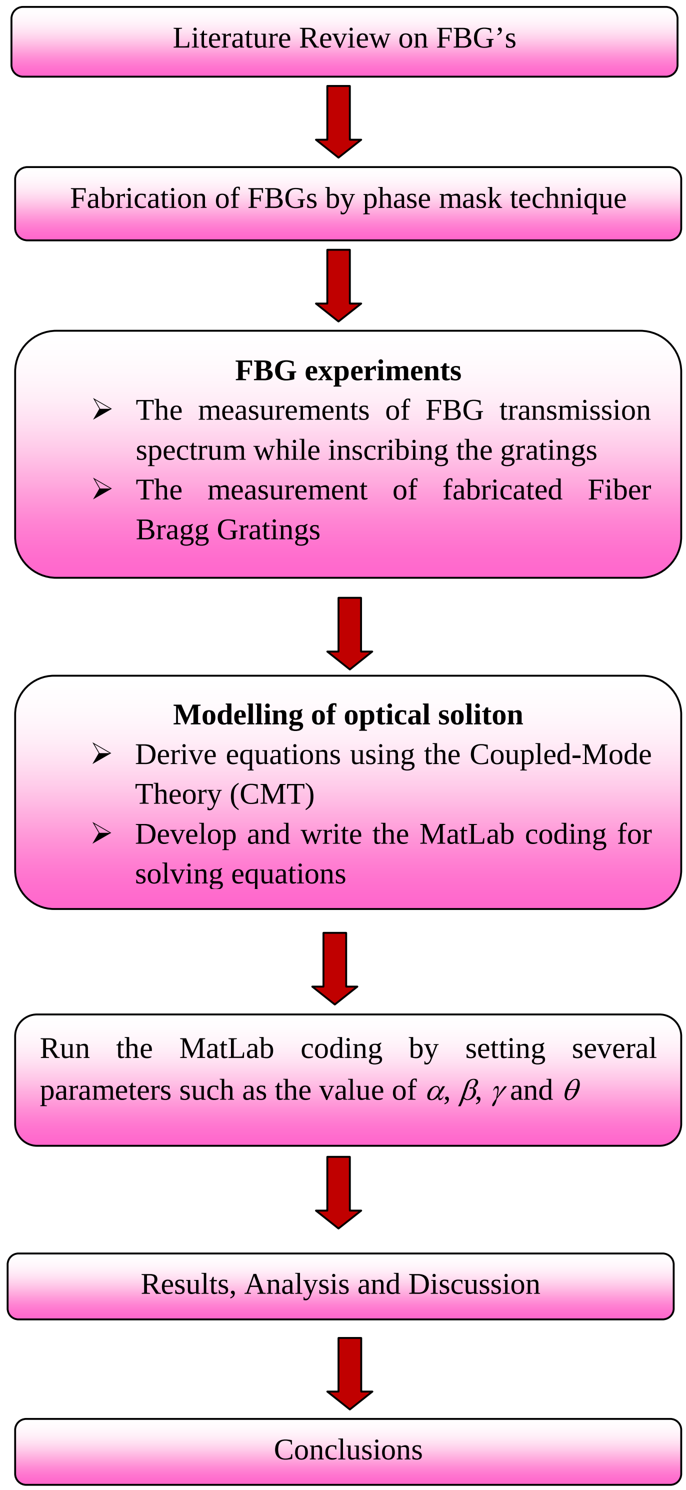

Figure 1.2: The flow chart for the research methodology on using optical soliton writing in FBG.

1.7 Significance of the Study

This research will contribute towards the research areas of nanophotonics and optical solitons especially in FBG writing. These lasers are complicated devices, and additionally their use restricts significantly the possibilities to adjust pulse parameters like its duration and shape. Furthermore it may overcome the disadvantages of the bulky lasers and high power requirements. The novel idea of using soliton writing in Fiber Bragg Grating will be plausible.

1.8 Organization of the Study

Chapter 1 provides a brief introduction on the overall review of the research background, work undertaken including the problem statement, objectives, scope,significance of the study and the research outline. The literature review is introduced in Chapter 2. Chapter 3 describes the simulations related to the modelling of FBG according to the certain properties and characteristics. In Chapter 4, the mathematical modelling of soliton will be shown numerically. Chapter 5 describes the fabrication technique used and the results of the FBG experiments. Chapter 6 presents the results and discusses the parameters obtained from the fabricated FBG through experiment and simulation. Finally, the thesis is summed up as Chapter 6 and recommendations for future work are suggested.