SIMULATION OF DUAL FIBRE BRAGG GRATINGS AS A FABRY-PEROT TUNABLE FILTER

SITI NAFISAH BINTI MD RASHID

UNIVERSITI TEKNOLOGI MALAYSIA

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This thesis is dedicated to my wonderful parents,
Md Rashid Md Said and Hanizah Abd Jalil.

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ABSTRACT

A Fabry-Perot Bragg Gratings (FP-BG) is developed by using two uniform fibre Bragg gratings (FBG) system. The objective of this research is to simulate single, dual FBGs and fabricate single FBG by using phase mask writing with a UV KrF excimer laser. Three single FBGs with Bragg wavelength of 1551.09 nm, 1551.29 nm and 1551.66 nm have been fabricated with reflectivity values of 30.2%, 78.1% and 44.7% respectively. FBG's with reflectivity value of 78.1% are categorized as good and strong FBG, since its reflectivity value is more than 50%. Some simulation works were also executed in this research to generate the transmission spectrum of single and dual FBGs. For single FBG, the transmission spectra for different values of grating lengths and reflectivities have been studied. Results showed that the transmission spectra of single FBG becomes wider if the grating produced is short, and longer when the reflectivity value is increased. For dual FBGs, simulations were performed by varying the separation distance between the two FBGs. The separation distance was varied from 0.5 cm to 5.5 cm, with an increment of 0.5 cm. The result showed that any increase of the separation distance led to an increase in the number of maximum transmission peaks of dual FBGs, due to the absorption phenomenon. Only selected wavelengths with certain frequencies were allowed to transmit at the fibre's end and the dual FBGs performed acted as a Fabry-Perot filter. This new configuration of FP filter exhibited similar behaviours as the conventional FP etalon, in which the parameters of free spectral range (FSR), full-width-half-maximum (FWHM) and finesse can be obtained from the transmission profiles.

ABSTRAK

Satu Fabry-Perot telah dibina menggunakan dua parutan Bragg (FP-BG). Objektif penyelidikan ini adalah untuk memfabrikasi satu dan dua parutan Bragg di dalam teras gentian optik menggunakan kaedah topeng fasa, dan laser KrF sebagai sumber tenaga UV. Tiga parutan Bragg dihasilkan, dengan panjang gelombang Bragg 1551.09 nm, 1551.29 nm dan 1551.66 nm, bersama nilai pantulan masing-masing 30.2%, 78.1% dan 44.7%. Parutan Bragg dengan nilai pantulan 78.1% dikategorikan sebagai parutan Bragg yang kuat dan berkualiti kerana mempunyai nilai pantulan melebihi 50%. Kerja-kerja simulasi turut dilakukan dalam kajian ini bagi menghasilkan spektrum lepasan untuk satu dan dua parutan Bragg. Untuk satu parutan Bragg, kerja simulasi melibatkan perubahan pada panjang parutan Bragg dan juga nilai pantulan. Hasil yang diperoleh menunjukkan spektrum lepasan parutan Bragg menjadi semakin lebar apabila panjang parutan adalah pendek, dan kelihatan panjang, sekiranya nilai pantulan ditambah. Untuk dua parutan Bragg, kerja simulasi melibatkan perubahan pada jarak pemisahan antara dua parutan, yang mana ia diubah dari nilai 0.5 cm hingga 5.5 cm, dengan pertambahan sebanyak 0.5 cm. Hasil simulasi menunjukkan apabila jarak pemisahan ditambah, bilangan spektrum lepasan maksima akan bertambah, disebabkan oleh fenomena serapan. Hanya panjang gelombang dengan frekuensi tertentu sahaja dibenarkan untuk melepasi suatu gentian optik, menjadikannya berfungsi sebagai suatu penapis Fabry-Perot. Sebagai satu konfigurasi Fabry-Perot, dua parutan Bragg ini turut menghasilkan profil lepasan seperti FP etalon, di mana parameter-parameter seperti *free spectral range* (FSR), *full-width-half-maximum* (FWHM) dan *finesse* dapat dilihat pada spektrum lepasan yang terhasil.

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LIST OF SYMBOLS

$a_i^{(+)}$	-	Amplitude of -*i*th mode traveling in +*z* directions
$a_i^{(-)}$	-	Amplitude of -*i*th mode traveling in -*z* directions
A	-	Absorption
D	-	Dip power
d	-	Separation distance between two fibre Bragg gratings
dz	-	Length of the *k*th uniform section
$\vec{E}(z)$	-	Electric field
E_{uv}	-	UV pulse energy
$\vec{e}_i$	-	Modal field of the –*i*th mode
FBG	-	Fibre Bragg grating
FP	-	Fabry-Perot
FSR	-	Free spectral range
FWHM		Full-width-half-maximum
k	-	Wave vector
K	-	Magnitude of the grating plane
L	-	Grating length
n_{eff}	-	Effective refractive index
$\overline{n}(x, y, z)$	-	Periodic refractive index perturbation of the grating
$n_0^{\ 2}(x, y, z)$	-	Index profile of waveguide
$n(x, y, z)$	-	Grating index profile
OSA	-	Optical spectrum analyzer

P	-	Phase shift matrix
R	-	Reflectivity
T_k	-	Transfer matrix of fibre Bragg grating
T	-	Transmission
TLS	-	Tunable laser source
t_{uv}	-	UV exposure time
β_i	-	Propagation constant of the –*i*th mode
κ	-	Local coupling coefficient
Ω	-	"dc" self coefficient
δ	-	Detuning
δn	-	Index perturbation
ς	-	"ac" coupling coefficient
υ	-	Fringe visibility
λ	-	Wavelength
λ_{bragg}	-	Bragg wavelength
λ_{uv}	-	UV wavelength
Λ	-	Grating period
Λ_{pm}	-	Phase mask period
Λ_g	-	Period of the fringes
$\Delta\lambda$	-	Bandwidth
ω	-	Angular frequency of propagation

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fabry-Perot filter is an optical resonator that confines and stores light energy at selected frequencies (K.Madingoane, 2009). In an optical transmission system which incorporates a feedback mechanism, light is repeatedly reflected within the system and thus circulates without escaping from the system. A simple Fabry-Perot (FP) filter comprises of two parallel planar mirrors spaced at a fixed distance apart as shown in Figure 1.1.

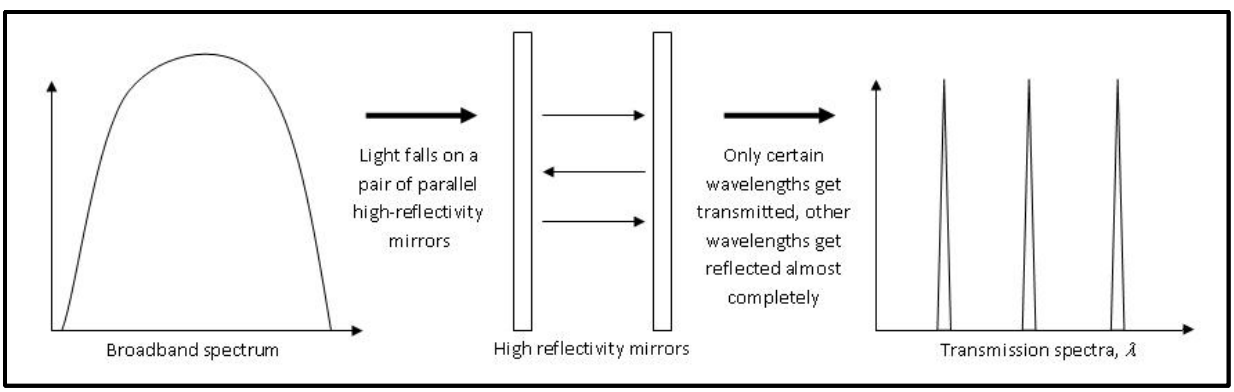

Figure 1.1 : Fabry-Perot interferometer system (K.Thyagarajan and A.Ghatak, 2007)

The rays travelling between the mirrors are kept perpendicular to the plane of the mirrors via a two-lens system. The lenses are placed outside the mirrors in order to establish parallel rays inside the resonance cavity between the mirrors, and to focus the output light onto the detector following the Fabry-Perot filter.

A Fabry-Perot device can be used for measuring wavelengths with high precision, for studying the fine structure of spectrum lines and as a high quality optical resonator for a laser construction. Placing two identical Bragg gratings in series on a single-mode fibre, results in a FP etalon within the fibre core. This is a novel way of introducing a tunable filter. This filter allows specific wavelength to pass while rejecting all other wavelengths.

This new configuration will offer different perspectives compared to the conventional one. Thus, it can be applied to be used in both fibre laser and fibre sensing field.

1.2 Problem Statement

The main motivation in this research is to fabricate two fibre Bragg gratings in a single length of optical fibre. Towards this end, the research addresses a set of interrelated questions such as which technique is suitable to use for fabricating the dual FBG's, what are the effects of grating length and reflectivity parameters to the FBG transmission spectrum, how does the FBG transmission spectrum changes if the value of separation length between two FBGs are varied?

1.3 Objectives of Study

The objective of this research is to fabricate a single and dual fibre Bragg gratings in the core of an optical fibre by using the phase mask technique. The characteristics of FBG will be studied and compared with the simulated result. A model based on coupled mode theory is developed. The modelling part includes the investigation of the transmission and reflection spectrum of single FBG for different values of reflectivity and grating length. For dual FBGs, this study will investigate the transmission spectrum produced by dual FBGs, when the separation distance between two FBGs is varied.

1.4 Scope of Study

This research begins with the historical perspective of FBG, principles operation, and its fabrication techniques. Secondly, we will identify the equipments, parameters and requirement involve in the yielding of single and dual FBG. Thirdly, the fabrication process of FBG will be conducted by using a phase mask technique using an excimer laser. Finally, the performance of fabricated FBG will be assessed in different experimental setups.

1.5 Research Methodology

Research methodology plays an important role in any type of research. The first step in any research methodology is conducting a literature survey. The related topics had been reviewed which consists of the historical aspects of FBG, the theory and concepts been used, the parameters and characteristics of FBG, and also their applications. Using the coupled mode theory (CMT) and transfer matrix method (TMM) equations are first derived to describe the single and dual FBG's. A model is then developed to describe the transmission and reflection spectra of single and dual FBG's based on the variations of reflectivities, grating lengths and separation distance between two FBG's. The derived equations are solved using computational codes developed based on the Matlab software.

For the experimental investigations, the single FBG's are fabricated using a phase mask technique. A KrF UV excimer laser is used to write the gratings inside the core of the optical fibre. The transmission or reflection spectrum is monitored using the OSA. A TLS is used to provide the broadband spectrum. The results achieved from both works have been compared and discussed.

1.6 Significance of Study

This research will provide an understanding of single and dual FBG's, its fabrication process, its reliability and as a Fabry-Perot tunable filter using the novel idea of two gratings inside the fibre core.

1.7 Organization of the Study

The thesis consists of six chapters. Chapter 1 provides the background of study, problem statement, objectives, scope of study, research methodology, and also the significance of study. The literature review is described in Chapter 2 including the theory, principles, characteristics and properties, fabrication methods, and the review on applications of dual FBGs. Chapter 3 provides the mathematical approach that has been used in modelling work, which consists of the Coupled Mode Theory and Transfer Matrix Method.

Chapter 4 discusses the experimental set-up, equipments needed, fabrication process of single FBG using a phase mask technique, and the simulation of single and dual FBGs respectively, using the Matlab software. The results from the experimental work and simulation work are discussed and analyzed in Chapter 5. Finally, the conclusion with some recommendations are made in Chapter 6.