AIN-SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering Department

The Optical Spectrometer and Its Engineering Applications

A Dissertation Submitted by

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In Partial Fulfillment for the Degree of Doctor of Philosophy in Electronics and Communications Engineering

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ABSTRACT

Faculty of Engineering

Ain Shams University

Name of the Researcher: Tarek Abdel-Mottalib Al-Saeed

Title of the Dissertation: The Optical Spectrometer and Its Engineering Applications.

In Partial Fulfillment for the Degree of Doctor of Philosophy

This research presents a general analysis for the wedge interferometer used in the Fourier Transform Spectrometer. The wedge interferometer is superior over conventional Michelson interferometer in immunity against mechanical vibration of the moving mirror. It also reduces sampling errors. This is done by using two wedges one stationary and one moving. The optical path difference results from the lateral motion of the moving wedge. In this work we study the effect of miniaturizing both interferometers and discuss the advantages and disadvantages of the wedge spectrometer when compared to conventional Michelson Spectrometer. Diffraction effects in both spectrometers are studied by considering a Gaussian beam and calculating the visibility degradation against different parameters of the interferometer. We found that the wedge interferometer performs better than the Michelson interferometer. Further, the dispersion effects in the wedge due to variation of the refractive index of the wedge material studied. We study the dispersion effect using approximate equation. Then, we propose a rigorous algorithm to cancel the dispersion the dispersion effect. Finally, the degradation of signal-to-noise ratio due to different source is considered. We presented the effect of error sampling due to error in moving arm. We discuss the error in linear motion of the mirror in Michelson and the linear lateral motion of the wedge. We also discuss the error of misalignment of the wedge due to rotation of the moving wedge about the center of the base of this wedge. Finally, the temperature effects on the refractive index of the material of the wedge and the theram expansion of the wedge are analyzed. We found that the wedge is superior for error in linear motion. For small motion error the Michelson interferometer is superior due to temperature effects. The rotation specifically of order milliradian, the wedge gives bad results and bad signal-to-noise-ratio.

Keywords: Michelson interferometer, wedge interferometer, Fourier transform spectrometer, dispersion, diffraction, SNR.

SUMMARY

Faculty of Engineering

Ain Shams University

Name of the Researcher: Tarek Abdel-Mottalib Al-Saeed

Title of the Dissertation: The Optical Spectrometer and Its Engineering Applications.

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The dissertation work is intended mainly for the study and analysis of the wedge interferometer when used as a Fourier Transform Spectrometer. The work is motivated by the great interest on miniaturized interferometers, especially for hand held applications. On the course of the analysis we study the diffraction effects in both Michelson and wedge interferometers and compare between them. Further we discuss the dispersion effects in the wedge due to variation of refractive index of the material of the wedge. Finally, we discuss the signal-to-noise-ratio in both interferometers and compare them.

The dissertation consists of six chapters. The first chapter explains the concept of optical spectrometer. Then we discuss the working concepts of the dispersion spectrometer and the Fourier transform spectrometer showing the main advantages of the Fourier transform spectrometer. Finally we introduce the wedge interferometer as a new configuration of the FT spectrometer more immune to mechanical vibrations

In the second chapter we present optical modeling of the wedge. This is done by studying the Gaussian beam transformation as it passes through a glass prism. We consider oblique incidence of the Gaussian beam on the interface between two dielectric media and derive an equation for spot size transformation in two perpendicular planes. The resultant beam

will generally be an elliptic Gaussian beam. The theoretical results from such Gaussian optics model are compared to the results obtained experimentally.

In the third Chapter, we consider the diffraction effects in both Michelson and wedge interferometers. A Gaussian optical model is used to predict the optical behavior of the interferometers and estimate its visibility. The visibility variations with optical path difference, detector size, initial spot size of the beam, wavelength and wide band spectrum are studied. We compared visibility in both interferometers for monochromatic beams. For quantitative performance evaluation, we defined two parameters describing the error in the spectrum and its overlap with the source spectrum.

In the fourth chapter we consider the dispersion in the wedge interferometer due to variation of the refractive index with wavelength. We first analyze the problem of dispersion approximately, then we develop a model for rigorously compensate the dispersion induced by the wedge. We used the parameters: error and overlap, defined in the Chapter 3 to evaluate the spectra obtained by the proposed rigorous model.

In the fifth chapter, we consider the signal to noise ratio, SNR, in FT spectrometer. First, we consider the noise resulting from error in sampling and linear vibration in the moving mirror in the conventional Michelson and in the moving wedge interferometers. Then, we discuss both the effect of temperature variation and sampling error on the resultant SNR. The temperature fluctuations effect on the SNR is also considered. Finally, we consider wedge misalignment, caused by rotation of the moving wedge about the center of its base and its effect on the SNR.

Finally, chapter six present the conclusion and future work

List of Symbols

n	Refractive index
λ	Wavelength
σ	Wavenumber
I	Interferogram
B, S	Source and recovered spectra
f	Factor when multiplied by motion of the wedge we obtain optical path difference
Φ, φ	Phase
L	Lateral Motion of the wedge
q	Factor for transformation of the Gaussian beam spot size
s	Rayleigh distance
z_0	Position of beam waist
V	Visibility
W_0	Initial beam radius
θ	Beam divergence angle
$\delta\nu$	Spectral width
k	Propagation constant

List of Abbreviations

OPD	Optical path difference
SNR	Signal to noise ratio
FTS	Fourier transform spectrometer
FTIR	Infrared Fourier transform spectrometer
MEMS	Micro electromechanical systems
AOTF	Acousto-Optic Tunable Filter
NIR	Near Infra Red
CCD	Charge Coupled Device
PMT	Photomultiplier Tube
FFTS	Fast Fourier Transform Spectrometer
SOI	Silicon Over Insulator
ILS	Instrument Line Shape
FPGA	Field-Programmable Gate array

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List of Publications

1- Tarek A. Al-Saeed and Diaa A. Khalil, " Dispersion compensation in moving-optical-wedge Fourier transform spectrometer" Applied Optics, 10 Jul. 2009, vol.48, no.20, pp.3979-3987.

2- Tarek A. Al-Saeed and Diaa A. Khalil,"Diffraction effects in optical microelectromechanical system Michelson interferometers" Applied Optics, 10 Jul. 2010, vol.49,no.20, pp.3960-3966.

3- Tarek A. Al-Saeed and Diaa A. Khalil,"Spot size effects in miniaturized moving-optical-wedge interferometer", Applied Optics, 10 Jun. 2011, vol.50, no.17, pp.2671-2678.

4- Tarek A. Al-Saeed and Diaa A. Khalil," Signal to Noise Ratio Calculation in a moving-optical-wedge Spectrometer", Applied Optics. 2012, 20 October, vol.51, no.30, pp.7206-7213.

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