



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

ELECTRONICS AND COMMUNICATIONS ENGINEERING DEPARTMENT

Slotted Optical Micro-Structures

A Thesis

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Electrical Engineering

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Doctor of Philosophy in Electrical Engineering (Electronics and Communications Engineering Department).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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CURRICULUM VITAE

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Muhammad Abdulraouf M. Othman

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SUMMARY

Faculty of Engineering – Ain Shams University
Electronics and Communications Engineering
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Thesis Title: “Slotted Optical Micro-Structures”

Submitted by: Muhammad Abdulraouf Muhammad Othman

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Micro-optical Fabry-Pérot filters are essential components for many applications in both the sensor and telecommunications domains. They can be built using the MEMS technology, which allows mass production, low cost and simple integration with many other components on a single chip. Such filters can be built using dielectric Bragg mirrors with relatively limited bandwidth, where the mirrors are required to be horizontal and the input light is vertical to the wafer, however, this does not allow for the mirror / filter integration with other components on the wafer. Vertical mirrors can be fabricated using either metallic coating or Si/air layered structures, however, metallic mirror does not allow for optical transmission and Si/air mirror could have a quite limited bandwidth. One of the solutions to build vertical mirrors with possibility of transmission is the structure of slotted metallic

mirror. Such structure allows for having the high mirror reflection coefficient and wide bandwidth of operation in addition to the ease of fabrication and compatibility with the MEMS technology. The objective of this work is the study of this slotted metallic vertical micro-mirror fabricated by the DRIE on a Si substrate. The thesis will develop modal technique for the prediction of the mirror performance under different polarization excitation. An analytical model is developed focusing on a limited number of generated modes in the slit. The model results are compared to the FDTD as well as the experimental results. A good agreement is obtained.

The mirror is then used to build a Fabry-Pérot resonator composed of a slotted micro mirror and a fiber coated with a multilayer coating to achieve high reflectivity to construct an optical filter. A theoretical model based on the Fourier optics analysis is used to predict the performance of this optical filter. The obtained results show also good agreement with the experimental results, when taking into account the uncertainties in the fabrication parameters.

The thesis is organized in six chapters as follows:

Chapter 1: gives a brief introduction to the motivation, objective, major contributions and organization of the thesis.

Chapter 2: presents the literature review on the different micromirror types used in the MEMS technology showing the advantages and disadvantages of these mirrors. This review is followed by a comparison between different types of mirrors. In addition, the theoretical background required for the understanding of the optical analysis used in the thesis is also introduced. This background includes a brief introduction to the Drude model for the metal losses, the Finite Difference Time Domain (FDTD) technique and the Fourier optics (FO) techniques for optical propagation in micro structures.

Chapter 3: provides an elaborate mathematical modeling for the slit transmittance. The solution provided in this chapter is based on solving the Eigen value problem (modal analysis) inside the inner boundaries of the slit for different excited modes (TE and TM). The mathematical expressions provided in this chapter using the modal analysis have closed forms and they are more accurate (when compared to FDTD results) than the scalar model that will be presented later in chapter 4, but it is more complicated.

Chapter 4: provides a study of the different parameters affecting transmittance of the newly presented optical slotted microstructure. Generally in literature, most of the focus is pointed towards metallic micromirrors with a vertical slit in subwavelength domain, but in our work we study the mirror beyond the subwavelength domain. A MEMS device with tunable slotted

micromirror is realized. The chapter ends with presenting the main technology used in fabrication of MEMS devices using deep reactive ion etching technology and a comparison between the FDTD results and practical measurement results.

Chapter 5: introduces one of the applications of the slotted micromirror in Fabry-Pérot filter construction. It starts with presenting the basic configuration of the Fabry-Pérot filter (resonator) and the idea of using such novel type of mirrors in the filter. Then a theoretical study based on Fourier optics (FO) is presented. The model surveys much of the simulation and physical properties of the filter. A comparison between the FO model results and the practical results is provided. The effect of varying the mirror slit width on resonator performance is demonstrated by fabricating and measuring micromirrors with different slit widths.

Chapter 6: gives a brief conclusion for the thesis and introduces several recommendations and suggestions for future work.

Keywords: Optical MEMS, Gaussian beam, Overlap integral, Parallel-plane waveguide, Micro-optical bench, Fourier Optics, Comb-drive actuator, SOI technology, Metallized mirrors, Tunable Finesse, Modal Analysis, Fabry-Pérot Cavity, and Tunable Finesse Resonator.

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