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Silicon Hollow Guides for Optical MEMS Applications

A Thesis submitted in partial fulfillment for the requirements of the degree of
Master of Science in Electrical Engineering

Submitted by

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2007

STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the degree of Master of Science in Electrical Engineering.

The work included in this thesis was carried out by the author in the department of electronics and communications engineering, Ain Shams University.

No part of this thesis has been submitted for a degree of a qualification at any other university or institute.

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موجهات الموجات المفرغة لتطبيقات النظم الكهروميكانيكية الميكرومترية الضوئية

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القاهرة 2007

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بتاريخ

اجيزت الرسالة
/ /2007م

موافقة مجلس الكلية
/ /2007م

موافقة مجلس الجامعة
/ /2007م

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الجامعة : جامعة عين شمس

سنة التخرج : 2003

سنة المنح : 2007

رسالة ماجيستير:

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عنوان الرسالة: موجهات الموجات المفرغة لتطبيقات النظم الكهروميكانيكية الميكرومترية الضوئية

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تاريخ البحث / / 2007

الدراسات العليا:

ختم الاجازة
بتاريخ

اجيزت الرسالة
/ /2007م

موافقة مجلس الكلية
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موافقة مجلس الجامعة
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تاريخ الحصول عليها : 2003

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Acknowledgment

My research and thesis would have not materialized if I did not have the support and encouragement of a number of people. I would like to express my deepest gratitude to Professor Diaa Khalil for his guidance and for many fruitful discussions we had over the time spent during completion of this thesis. Professor Diaa Khalil has been a mentor to me since I graduated and to him I owe the ability I gained to apply scientific thought to problems. His criticism helped polish my research and thinking.

I would like to thank Dr. Ahmed Hisham for his patience and efforts. Dr. Ahmed Hisham is mainly responsible for the choice I made to pursue research in optics. His extremely exciting lectures introduced me to the field and also drew the path I chose after graduation.

I would like to thank Professor Mahmoud Hanafy Ahmed for his encouragement and support. His vast knowledge in almost all scientific fields makes the experience of having discussions with him just wonderful and extremely informative.

I wish to express my deepest appreciation to Professor Alaa Kamel. Although his time is invaluable, he always managed to find time slots to discuss any matter with me whatsoever. He was a great source of inspiration to this work. Not only is he an expert on electromagnetic waves but a true genius and a wonderful person.

Silicon Hollow Guides for Optical MEMS Applications

By
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Abstract

New techniques for the calculation of the modal losses in hollow waveguides are developed. The techniques depend on the use of ray optics. Ray optical solutions in triangular cross section waveguides are used to calculate the losses of the fundamental mode in an equilateral hollow triangular waveguide. Due to the absence of total internal reflection at the interface, the losses arise from the partial reflections experienced by the rays at the interface. The partial reflections are used to derive an analytical formula for the losses of the fundamental mode. A perturbation technique is then employed to obtain an analytical formula for the fundamental mode losses in the specific case of a silicon hollow waveguide having a V groove cross section. The results of the analytical formulae are verified by comparison to the Beam Propagation Method (BPM). This method is specific for such a cross section only and does not yield information on the polarization dependent loss. The ray optical technique is then generalized for the case of arbitrary cross section hollow waveguides having an axis of symmetry. This yields a semi-analytical formula that uses the field of the corresponding closed waveguide. For cross sections with known analytical solutions, the semi-analytical formula yields analytical results that are exactly the same as those arrived

at by different techniques under the same approximations. The technique also yields information on both wavelength dependent loss (WDL) and polarization dependent loss (PDL). Applying this technique to the silicon V groove waveguide, we find that the previously obtained results are almost identical to the new results.

We mention the optimum parameters required for the fabrication of the silicon V groove and accompany them by scanning electron microscope (SEM) images of some of the fabricated samples. We then discuss the characterization technique, the obtained results and how to improve on them.

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Introduction

Recently, hollow waveguides have attracted increasing attention in sensing applications. In these applications, light is made to interact with a material, usually a fluid. The fluid is usually flowing in a duct and therefore in order for light to interact with the material, it should be guided by the duct. However, the material of the duct almost always has a refractive index greater than the fluid which is supposed to be the core material. This excludes the use of total internal reflection to guide the light along the duct, and the guide becomes leaky. Such a configuration can be used to guide light, but it must be carefully designed in order to reduce leakage to acceptable levels.

Hollow waveguides have also found applications in Optical MEMS. They can be fabricated easily using techniques already available and provide a solution for optical interconnects in optical switches. Light in Optical MEMS devices travels to some extent in free space where it may suffer from diffraction and coupling losses to other devices. However, the use of hollow waveguides reduces the coupling losses by eliminating reflection since the core material is air. The structure of the hollow waveguide can be varied to produce a multitude of devices such as polarizers and filters. Structures fabricated and available in the literature usually have a rectangular cross section and are fabricated mainly by deep reactive ion etching or using sacrificial layers that are etched away at the end of the process.

Difficulties in hollow waveguides having a single substrate exist both in analysis and fabrication. Numerical techniques available to calculate the losses of the modes of these waveguides are either inadequate or take a very long time. Fabrication techniques are complicated and expensive. In this work, we propose the use of Silicon V grooves as hollow waveguides. After the groove is fabricated, it is covered with another Silicon wafer thus giving a triangular cross section.

The fabrication process of the silicon V groove is very simple. Also, the side walls are crystalline planes leading to lower scattering losses. The depth of the V groove can be controlled through the mask width and therefore, it is possible for example to have a 3D tapered waveguide with a process that uses a 2D mask.

We develop an analytical model based on ray optics to calculate the losses of the fundamental mode in the silicon V groove waveguide. We compare the results of this model to simulation and find that good agreement is obtained. Next we generalize the method to arbitrary cross sections and arbitrary modes. The technique is semi-analytical and uses the field of a waveguide of the same cross section but assumed to be closed. The results of this method are compared against previous analytical models for specific geometries and the same results are obtained. Then the method is used to derive results for new waveguide geometries.

Fabrication of the waveguide is described and the optimum fabrication parameters are mentioned. The fabrication process was refined and polished through viewing fabricated samples using the scanning electron microscope (SEM). Characterization of the waveguide is also described and problems that need to be overcome in the practical work are mentioned.