

INTEGRATED OPTICS IN OPTICAL COMMUNICATION NETWORKS

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ABSTRACT

The field of integrated optics has changed considerably in the past 12 years. where The dimensions of photonic devices to be integrated have decreased by several orders of magnitude as belonging to the field of micro photonics, since they involved photons of light interacting with physical structures having dimensions mostly on the order of micrometers. a number of new areas in the general field of integrated optics have gained prominence. The telecommunication industry has continued the implementation of fiber-optic networks, not only for trunk lines but also to bring optical fiber waveguides to the office and home. This widespread use of optical fibers has created a demand for effective, but relatively inexpensive, optical amplifiers, couplers, and

switches. This demand has been met by erbium-doped fiber amplifiers (EDFAs) and by couplers and switches fabricated in glasses and in polymer materials. New systems have been developed that incorporate micro machined mechanical elements along with optical and electronic devices in an integrated structure.

KEYWORDS: Integrated optics Optical networks waveguide Restoration Network provisioning.

1. INTRODUCTION

The transmission and processing of signals carried by optical beams rather than by electrical currents or radio waves has been a topic of great interest ever since the early 1960s, when the development of the laser first provided a stable source of coherent light for such applications. Laser beams can be transmitted through the air, but atmospheric variations cause undesirable changes in the optical characteristics of the path from day to day, and even from instant to instant. Laser beams also can be manipulated for signal processing, but that requires optical

components such as prisms, lenses, mirrors, electro-optic modulators and detectors. All of these equipments would typically occupy a laboratory bench tens of feet on a side, which must be suspended on a vibration-proof mount. Such a system is tolerable for laboratory experiments but is not very useful in practical applications. Thus, in the late 1960s, the concept of “integrated optics” emerged, in which wires and radio links are replaced by light wave guiding optical fibers rather than by through-the-air optical paths, and conventional electrical integrated circuits are replaced by miniaturized optical integrated circuits (OIC's), also known as photonic integrated circuits (PIC's).

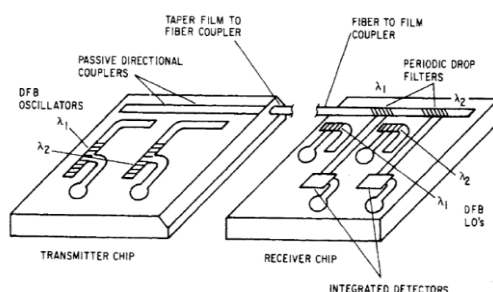
Several factors combined to bring integrated optics out of the laboratory and into the realm of practical application; these were the development of low loss optical fibers and connectors, the creation of reliable continuous wave laser diodes, and the realization of photolithographic micro fabrication techniques.

In the 1980s, optical fibers largely replaced metallic wires in telecommunications, and a number of manufacturers began production of optical integrated circuits for use in a variety of applications. Then the incorporation of optical fibers into telecommunications and data-transmission networks has been extended to the subscriber loop in many systems. This provides an enormous bandwidth for multichannel transmission of voice, video and data signals.

Research in integrated optics has two goals: One is to apply thin-film technology to the formation of optical devices and circuits. The other is the integration of a large number of optical devices on a small substrate, so forming an optical circuit reminiscent of the integrated circuit in microelectronics. Simple integrated optical circuits have also been constructed, and rapidly advancing semiconductor technology indicates that monolithic integrated optical circuits can readily be developed using GaAs-related compounds so the specific topics to be discussed are: the advantages of Integrated Optics, light-wave couplers and m-line spectroscopy, refraction and reflection of light in thin films, normal modes of the uniform, the graded and the metal-clad waveguides, optics in tapered films, theory of corrugated waveguides, and more importantly, physics of various thin-film optical devices and the method of the circuit formation.

1.1 Advantages of Integrated Optics

To consider the advantages of a fiber-optic OIC system as compared to its electrical counterpart, as shown Fig. (1.1) illustrates many special advantages of the integrated optic . In this system, the transmitter and receiver are each contained on an OIC chip, and the two are interconnected by means of an optical fiber waveguide. the light sources are integrated laser diodes of the distributed feedback type, emitting at different wavelengths λ_1 , and λ_2 . Only two diodes are shown for simplicity, but perhaps hundreds would be used in a practical system. Since the light emitted by each laser is at a different wavelength it travels vi independent optical “carrier” waveguide, so that many signals can be transmitted simultaneously, or “multiplexed”, by the optical fiber. In the receiver, these signals can be separated by wavelength selective filters and routed to different detectors .additional laser diodes may be used in the receiver as local oscillators (LO) for detection of the optical signals.



Fig(1.1)

And concerning the standard means of interconnecting the advantages can be listed as follow

- ☐ Immunity from electromagnetic interference (EMI)
- ☐ Freedom from electrical short circuits or ground loops
- ☐ Safety in combustible environment
- ☐ Security from monitoring
- ☐ Low-loss transmission
- ☐ Large bandwidth (i.e., multiplexing capability)
- ☐ Small size, light weight
- ☐ Inexpensive, composed of plentiful materials

1.2 Electro–optic effect

The integrated optics as the name suggests is the technology which deals with various components used in the optical communication system especially (WDM systems) and concerns about the devices which is fabricated on a wafer to create a light guide environment

on some substrate ,so the circuit look like an electrical integrated circuit and that's where the name come from. After creating sudden waveguide structure on the substrate .the signal which comes through the optical fiber is connected (fed to) this device and the property of the light are changed then fed back to the optical fiber. At the heart of these integrated optical device there is a phenomenon which is called the (electro- optic effect), which states that the. refractive index of the material changes with the application of electrical field Change in the refractive index/

$$\Delta n = n_o^3 r \frac{E}{2}$$

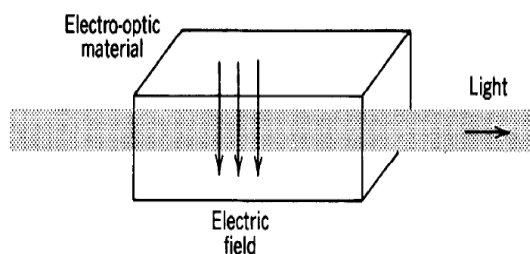
Where (r) is the electro optic coefficient, and (E) is the electrical field,

Certain materials change their optical properties when subjected to an electric field ,This is caused by forces that distort the positions, orientations, or shapes of the molecules constituting the material. The electro-optic effect is the change in the refractive index resulting from the application of a dc or low-frequency electric field.

In (Fig1.2). A field applied to an anisotropic electro-optic material modifies its refractive indices and thereby its effect on polarized light .The dependence of the refractive index on the applied electric field takes one of two forms:

- The refractive index changes in proportion to the applied electric field, in which case the effect is known as the linear electro-optic effect or the Pockels effect.

The refractive index changes in proportion to the square of the applied electric field, in which case the effect is known as the quadratic electro-optic effect or the Kerr effect.



Figure(1.2) A steady electric field applied to an electro-optic material

The change in the refractive index is typically very small. Nevertheless,

Materials whose refractive index can be modified by means of an applied electric field are useful for producing electrically controllable optical devices, as indicated by the following examples:

- A lens made of a material whose refractive index can be varied is a lens of controllable focal length.
- A prism whose beam bending ability is controllable can be used as an optical scanning device.
- Light transmitted through a transparent plate of controllable refractive index undergoes a controllable phase shift. The plate can be used as an optical phase modulator.
- An anisotropic crystal whose refractive indices can be varied serves as a wave retarder of controllable retardation; it may be used to change the polarization properties of light.
- A wave retarder placed between two crossed polarizers gives rise to transmitted light whose intensity is dependent on the phase retardation
- The transmittance of the device is therefore electrically controllable, so that it can be used as an optical intensity modulator or an optical switch.

1.2.1 Electro-Optic Modulators

Phase Modulators

As shown in fig (1-3) when a beam of light traverses a (LiNbO₃) cell of length L to which an electric field E is applied, it undergoes a phase shift $\varphi = n(E)kL = 2\pi n(E)L/\lambda_0$, where λ_0 is the free-space.

$$\varphi - \varphi_0 = \frac{2\pi n^3 E L}{\lambda_0}$$

wavelength. Let (equ.1) be as follow:

Where

If the electric field is obtained by applying a voltage V across two faces of the cell separated by distance d, then $E = V/d$, and (equ.1) gives.

$$\varphi = \varphi_0 - \pi \frac{V}{V_\pi},$$

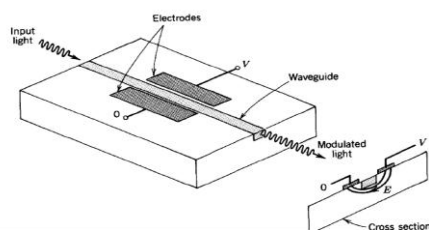


Fig (1-3)

why we used Lithium Niobate (LiNbO_3)? as there is certain materials whose dielectric constant can be change by application of electric field called the electro optic material(EOM), there are a common(EOM) materials like Lithium Niobate and Gallium Arsenide. The Lithium Niobate has wide wavelength range of transparency and gives relatively large change in dielectric constant or refractive index; that is the reason behind large numbers of electro optic devices Are based on the Lithium Niobate material. Other materials like Gallium Arsenide requires relatively high electric fields to realize the same change in the dielectric constant. But it also has the low what is called electro optic coefficient. So essentially talking about the devices which are based on Lithium Niobate material, this material is an N isotropic material, with different refractive index or dielectric constant reactions and when the electric field is applied, the dielectric constant change depends upon which direction the electric field is applied with respect to the axis of the crystal.

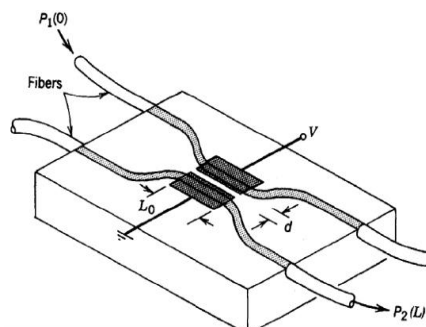
1.2.2 DIRECTIONAL COUPLERS

An important application of the electro-optic effect is in controlling the coupling between two parallel waveguides in an integrated-optical device. This can be used to transfer the light from one waveguide to the other, so that the device serves as an Electrically controlled directional coupler.

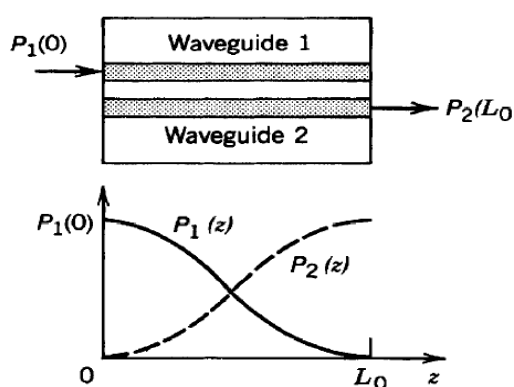
The coupling of light between two parallel single-mode planar waveguides is shown in the fig(1-4)a and b where the optical powers carried by the two waveguides, $P_1(z)$ and $P_2(z)$, are exchanged periodically along the direction of propagation z two parameters govern the strength of this coupling process: the coupling coefficient e (which depends on the dimensions, wavelength, and refractive indices), and the mismatch of the propagation constants,

$$\Delta\beta = \beta_1 - \beta_2 = 2\pi \Delta n / \lambda_o$$

where Δn is the difference between the refractive indices of the waveguides. If the waveguides are identical, with $\Delta B = 0$ and $P_1(0) = 0$, then at a distance $z = L_c = \pi/2\beta$, called the transfer distance or coupling length, the power is transferred completely.



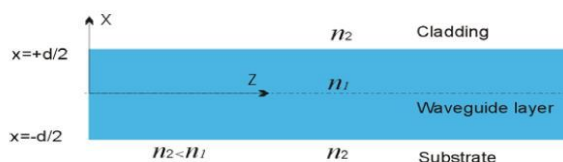
Fig(1-4)A



Fig(1-4)b

1.2.3 WAVEGUIDES

A wave guide is a dielectric structure where the dielectric constant at the center of configuration is larger than that at the edges. using this kind of structure the optical beam can propagate within the waveguide while maintaining the mode size. The waveguides have different forms: planar waveguides, see Figure. (1-5), standard optical fibers, channel waveguides,



Fig(1-5) A symmetric dielectric waveguide structure. The wave is propagating along the +z direction.

To understand the guided modes in a waveguide it is helpful to consider the simple case of a symmetric step index waveguide. A light wave which consists of electric and magnetic fields

can propagate along the z-direction of the waveguide in various ways. Transverse-magnetic (TM) modes and transverse-electric (TE) modes are provide two orthogonal mode conditions. In TM modes, the magnetic field vector is normal to the z-direction of the light propagation. In TE modes, the electric field vector is normal to the z-direction of light wave propagation.

Channel Waveguide Structure and Effective Index Method

Planar or slab dielectric waveguides demonstrate most of the important characteristics of guided optical wave radiation, but the planar or slab structure waveguide is not a very useful geometry for practical applications because of the infinite spatial extent of the wave in one direction. In most practical applications more complicated waveguides structures are used including graded index waveguides and channel waveguides

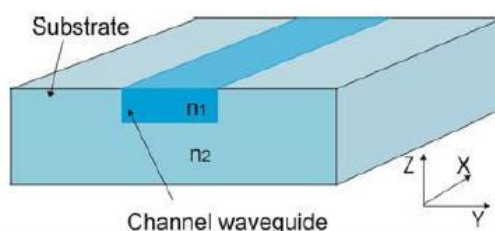


Figure 5-2. The channel waveguide structure, refractive index . $n_1 > n_2$

A channel waveguide is a guide which offers confinement in two dimensions as opposed to the one dimensional confinement offered by planar or slab waveguides. Many waveguide fabrication techniques, such as zinc in diffused channel waveguides in lithium niobate, lead to a smoothly varying refractive index in contrast to the step index treated in the analysis in the preceding sections for the planar waveguide. Maxwell's equations cannot be solved for the cladding, core and substrate regions together with the boundaries conditions to obtain the allowed modes without an accurate mathematical model for the refractive index profile of the core. In addition, the development of a field solution for this kind of structure is more complicated than for a step index structure.

WAVEGUIDE MODAL TESTING

Waveguides only support specific electric field distributions called normal modes. The idea of a normal mode can be illustrated most easily in one dimension. If a one dimensional cavity is created with two metal plates, the solutions for any wave between those plates must be zero at the plates. This solution takes the general form.

$$\vec{E} = \hat{k} \sin\left(\frac{m n \pi}{d}\right)$$

Where $\vec{E}$ is the electric field vector, $\hat{k}$ is the direction of the field, m is the mode number, n is the index of refraction of the material, and d is the separation of the plates. Moving to two dimensions, there are two mode numbers, and the mode structure becomes more interesting. The number of modes and their separation in frequency is an indication of the waveguide. Properties. Waveguides with different dimensions, index of refraction, and shape will have different modal behavior. Therefore, it is possible to utilize the modal structure of a waveguide to determine its properties.

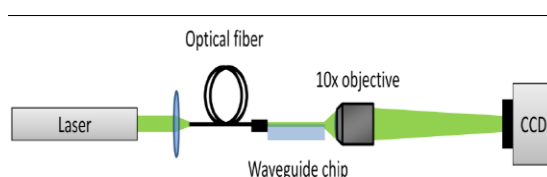
There are many methods to determine the modal behavior of a waveguide. By prism coupling light out of the waveguide, it is possible to determine the number and distribution of modes in the waveguide.

However, in a diffused waveguide the modes are very closely spaced due to the small difference in refractive index. That close spacing makes it difficult to reliably measure the modes. Therefore another method was used.

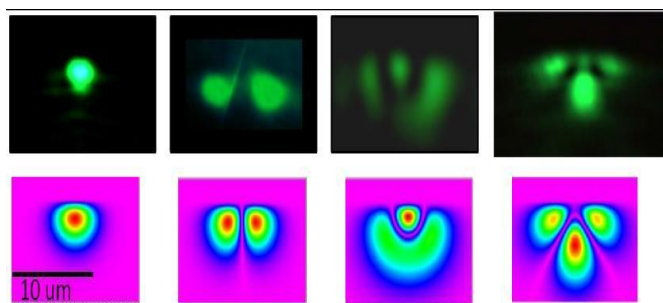
Preferential excitation and end facet imaging

In order to determine the modes in the waveguide, light of different wavelengths was introduced into the waveguide. This excitation source was moved with respect to the waveguide. For a given position of the source, different supported modes will be excited. Therefore, by moving the source to positions that isolate a single mode, and repeating this process for each mode that is observed and for each wavelength of interest, it is possible to determine the modes that are supported by that waveguide.

Figure(5-3)is a diagram of the experimental setup used and Figure (5-4) shows images obtained from the experiment and simulation, demonstrating the different modes that exist in the waveguide



Fig(5-3) Diagram of experimental apparatus for endfire coupling and output facet imaging.



Fig(5-4) Measured (top) and simulated (bottom) modes for K diffused waveguide at 532nm.

Reducing Light Scattering

While integrating the waveguides reduced scattering from many sources, there were still sources of scattered light that needed to be addressed. The two large sources that were addressed were: the micro fluidic channel, and the connection point between the incoming optical fiber and the waveguide.

Scattering from the micro fluidic channel

The most straightforward design of the system in this thesis would have a microfluidic device etched into the thick substrate wafer. This is the same wafer that contains the waveguides. Therefore, at the interrogation region, where the waveguide and the microfluidic channel cross, the channel would actually be etched into the waveguide. This is quite obviously a situation that would produce scattering.

Looking at the modes of the waveguides shown in the previous section, a large change in the index of refraction in the top 200nm of the waveguide would be near some of the most intense fields in the waveguide mode. This change in index of refraction would cause scattering. Furthermore, the scattering is located immediately adjacent to the detection area, the region where scattering is most detrimental. This behavior is actually beneficial in some applications. Work in integrated concentration detection devices utilize this exact design to provide integrated illumination for a region of fluid. The light that propagates through the fluid is then sent to a spectrometer, providing a measure of the concentration of the sample of interest in the fig (5-5)a&b. But, this behavior is not beneficial. The next solution would be then to move the microfluidic channel up out of the waveguide and into the cover slip (the top glass). However, this causes scattering for a similar reason as the channel in the waveguide. The reason why is explained below.

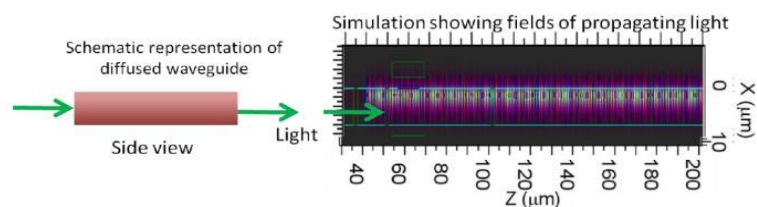


Fig (5-5) a Schematic and simulation showing light propagating diffused waveguide in the absence of a microfluidic channel.

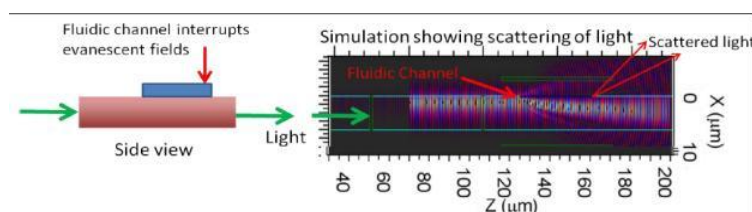


Figure (5-5) b: Schematic and simulation showing light propagating diffused waveguide and being scattered by a microfluidic channel. The value plotted in the simulation is field strength.

Index-matched layer

As described in the previous sections, scattering is caused by a discontinuity in the index of refraction seen by an electromagnetic field. Therefore, an ideal architecture would provide a uniform index of refraction along the length of propagation of the waveguide. What this necessitates is that the microfluidic channel be embedded in a layer of material that has an index of refraction equal to that of the material in the microfluidic channel (in this case, water, with $n=1.33$). A crosssectional diagram of this index-matched layer compared to different positions of the channel in a standard glass-to-glass bonded system is shown in Figure (5-6). In the case of the index-matched layer, there is no index change as a wavefront propagates through the microfluidic channel, resulting in no scattered light

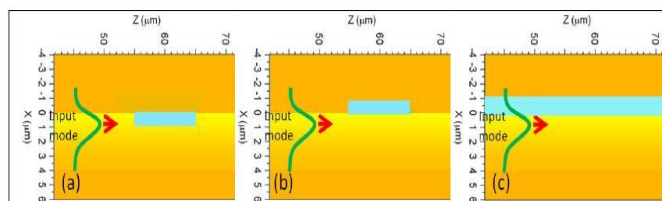
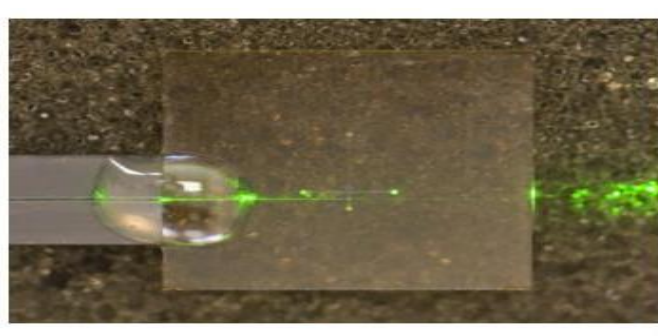


Figure (5-6): Architectures to reduce light scattering from waveguide. (a) Channel etched into the waveguide, (b) channel in the coverglass, (c) channel in an index-matched layer.

Scattered light from fiber optic connection

Another source of scattered light was the connection point between the incoming fiber optic and the device. While diffused waveguides provide a good index match for optical fibers, their shape is not the same, and therefore the match is not perfect. There is some scattered light at the connection that does not get collected by the waveguide. In the simplest design of the system proposed in this thesis, the waveguide is straight. This design has the shortcoming that any light scattered at the interface with the optical fiber is then propagating directly to the detection area, shown in the image of Figure (5-7)a and the diagram of Figure (5-7)b



(5-7)a ,Laser light guided in completed chip with straight waveguide. Light scattered from connection point is visible.

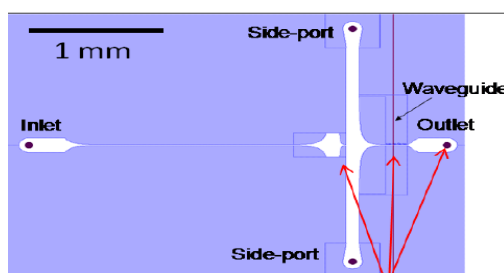


Figure (5-7)b: Diagram of straight waveguide design. Light scattered from fiber-waveguide connection scatters in to detection zone.

Fabrication process overview

The fabrication process that is presented is the result of many process design choices. Many alternative fabrication procedures are possible, but this procedure provided the optimal tradeoffs in terms of design considerations. Specifically, the desired characteristics were: optical clarity and scattering minimization, low temperature, high bond strength, and process robustness. The procedure utilizes a polymer called Cytop both as a bonding layer and to define the microfluidic channels. The procedure is presented in Figure (5-8), below.

The microfluidic chips are fabricated on 100 mm wafers of Schott BK-7 glass using mostly processes that are available in a standard MEMS fabrication facility. BK-7 glass was chosen as the substrate due to its high optical purity and strength, and availability of processes to diffuse high quality optical waveguides.

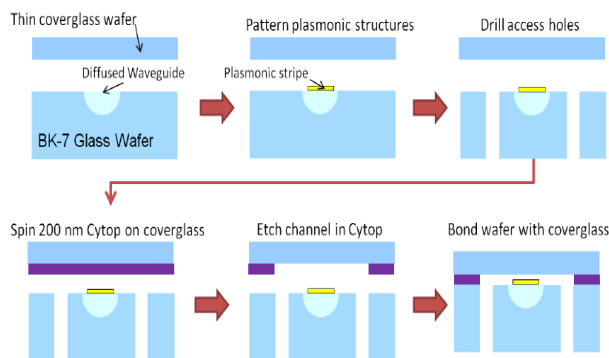


Fig (5-8) Overview of fabrication procedure

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