2D Single Mode Channel Waveguide and MMI Beam Splitter Fabrication and Characterization

Abstract— **In this work we present a locally developed optics technology for the fabrication and characterization of integrated optical components. The fabrication was carried out using the ion exchange in glass. Both single mode guides and Multi-Mode Interference MMI splitter are, for the first time in Egypt, fabricated and tested. For the characterization purpose, an automated setup is developed in order to scan for the reflection sites within the integrated optical structures.**

I. INTRODUCTION

One of the most important components in optical communication systems is the integrated optical channel waveguide, it plays the role of the connecting wires in the optical circuitry and in addition it is the essential element in any integrated optical circuit. The fabrication and characterization of such a component is thus greatly required for the advancement of optical communication systems [1], [2]. This usually requires a highly sophisticated engineering work in an advanced environment. The developing of this technology in Egypt is thus, a challenging engineering task. This task represents the main objective in our project.

To achieve this task, the following specific objectives have been targeted:

1- The fabrication of a 2 D channel waveguide /beam splitter using the technology of Ionic exchange on a glass substrate.
2- The development of an Optical Coherent Domain Reflectometry OCDR for the characterization of the channel waveguide.

The first task requires the development of the following technological process: Evaporation, Photolithography, Al etching, Ionic exchange, and Waveguide end polishing.

The second task required the development of an optical as well as an electronic circuitry for the light manipulation and control. This includes, fiber connector and fiber coupler handling, optical collimation and alignment, fiber back injection, and electronic circuitry for detection and motorized motion control. In the following, these specific tasks will be described in details.

II. 2D WAVEGUIDE AND MMI BEAM SPLITTER FABRICATION

For the fabrication of an integrated optical 2D waveguide, the ionic exchange technology is used. This simple technology enables to create a region of higher refractive index in the glass substrate by a simple thermal diffusion. To localize this diffusion in specific regions in the substrate, the photolithography technique is used to create an aluminum mask on the glass wafer to prevent the exchange in the masked region. The details of the process flow are shown in Fig. 1. The steps involved in the photolithographic process (as illustrated in Fig.1) are sample cleaning, photoresist (PR) application by spin coating, soft baking, mask alignment, UV exposure, PR development and etching, and Al etching. Each of these steps should be critically adjusted to allow for a perfect pattern transfer on the wafer. On our experimental work we have used microscope slides as well as BK 270 glass wafers as a substrate material. The photoresist used is the AZ1350 with its developer. The Al etching is achieved using the orthophosphoric acid. The specific technological parameters used are detailed in the next section. These parameters have been obtained after a systematic repeated investigation on similar samples. The optimization of such parameters was a great challenging technological effort in a non-clean room environment.

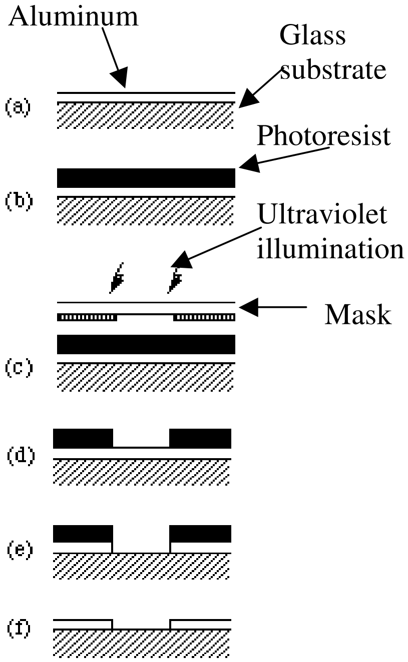

Fig.1. Photolithography process steps. (a) Sample preparation. (b) Photoresist application. (c) Mask alignment and exposure. (d) Development. (e) Aluminum etching. (f) Stripping of excess photo resist.

The spin coating machine and the UV mask aligner are shown in Fig. 2 and 3 respectively.

A. Process Parameters

To fabricate a channel waveguide, it was necessary to first try to optimize the process parameters particularly, the number of photoresist drops deposited over the surface, the spinning time, the spinning speed, the soft bake time, the development time and temperature, and the etching time.

The optimum parameters for aluminum etching are:

1. Prebaking for 10 min at 80 degrees Celsius.
2. Resist drops are deposited during spinning and are centered.
3. The spinning speed should be 5000 rpm and the spinning time is 40s.
4. Soft baking: 30 minutes at 80 degrees Celsius.
5. Developer solution concentration: 1:1 ratio of deionized water to developer (by volume).
6. Etchant concentration: 100:70 ratio of deionized water to orthophosphoric acid (also by volume).
7. Development time is 9s and temperature is 50 degrees Celsius.
8. Etching time: 1minute, 40s.
9. Etching temperature: from 60 to 65 degrees Celsius preferably 60.

Fig.2. The spin coater used during the photoresist application to obtain a uniformly deposited photoresist layer.

Fig.3. The mask aligner used for the sample exposure to UV radiation.

B. Results

Fig.4 shows one of the samples fabricated using the optimum parameters mentioned above. The photo was taken from the eyepiece of a transmission microscope with a 400x magnification. The transparent parts represent the etched aluminum while the opaque parts represent the area of glass coated with aluminum. This photo contains two sets of integrated optical structures, the first is a simple single mode (at a wavelength of 0.65µm) waveguide with mask opening of 2 µm and the second is an MMI beam splitter with about 48 µm width fed by two single mode guides. The sample is then subjected to the ionic exchange process in KNO3 for about 50 min. in a temperature of 380^{o}C.

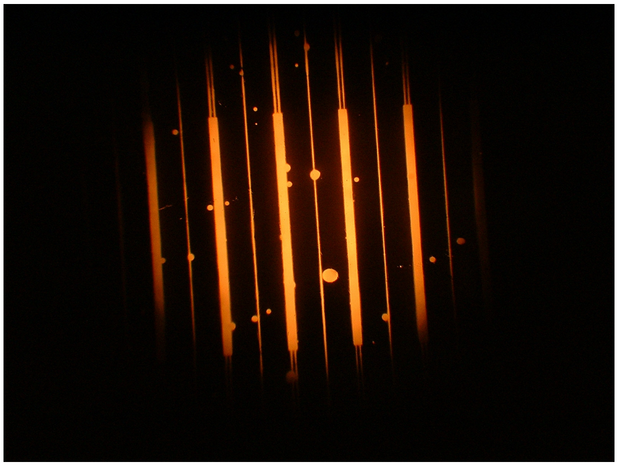

Fig. 4. Example of the samples fabricated using the optimized parameters.

Fig.5 shows the setup used for testing the waveguide. The laser beam emerging from the SM fiber is injected into the sample and a CCD camera is used to monitor the output. The microscope objective is used to image the near field at the guide output on the CCD sensor area of the camera.

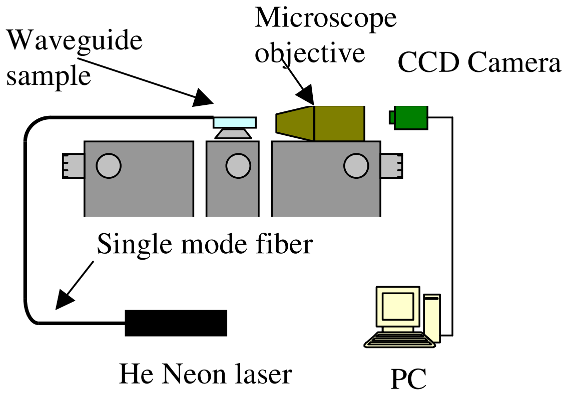

Fig.5 setup used in the characterization of the fabricated integrated optical components.

Fig.6 shows the resulting field distribution measured at the output of a single mode waveguide, indicating clearly single mode operation. On the other hand Fig.7, 8 and 9 show the field distributions at the output of the MMI beam splitter under different excitation conditions. The effect of the input excitation conditions on the output power splitting ratio is clearly observed.

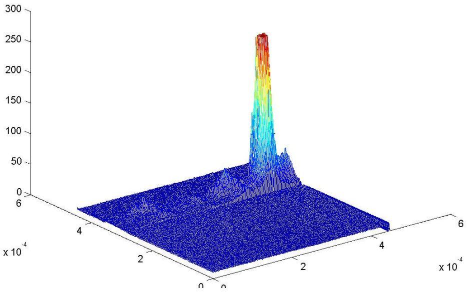

Fig.6 SM waveguide output intensity versus transverse coordinates.

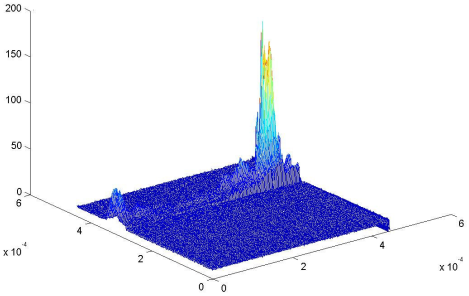

Fig.7 MMI output intensity versus transverse coordinates for the first excitation position.

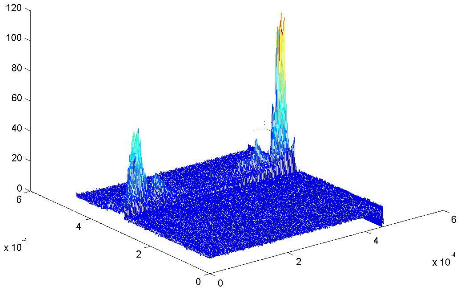

Fig.8 MMI output intensity versus transverse coordinates for the second excitation position.

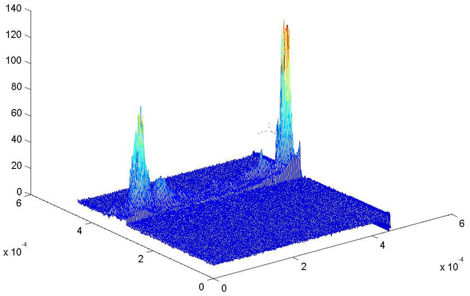

Fig.9 MMI output intensity versus transverse coordinates for the third excitation position.

III. DEVELOPMENT OF THE OCDR FOR WAVEGUIDE CHARACTERIZATION

With the increasing development of sophisticated miniature optical components, such as integrated-optics subsystems, composite laser-diode structures, and micro-bulk-optic configurations, the need for supportive test equipment has arisen. In particular, an instrument capable of determining the position and the magnitude of reflection sites within such optical assemblies has been singled out as having high potential utilization. The small size of the devices to be examined prevents the use of optical-time-domain reflectometry (OTDR) [3], which is currently limited to resolutions of a few centimeters. Another proposed alternative is the use of optical-frequency-domain reflectometry (OFDR) [4], which can achieve resolutions down to one millimeter but suffers from frequency sweep nonlinearities and interferometric phase noise. On the other hand, optical coherence domain reflectometry (OCDR) [5] demonstrates higher resolutions and larger dynamic range.

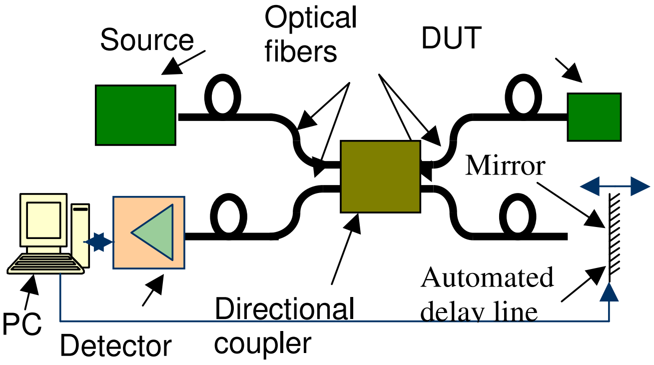

Fig.10 Schematic diagram of the OCDR setup.

Fig.12 shows a schematic of the OCDR setup. In OCDR we use the same concept and setup of the Michelson interferometer [6]. However, we replace the two mirrors by a sliding mirror and the device under test. Also, a directional coupler replaces the beam splitter. In addition, we use a low coherent source. Interference between these two beams occurs only when the temporal delay between the two beams is comparable, i.e. when the difference between their delay times is lower than the coherence time of the used source [6]. This gives a means for measuring the distance to the reflection sites in the DUT by measuring the distance to the variable mirror. In addition, the decay of the interference signal with the delay time indicates the decay of the optical signal reflected from the corresponding position in the guide. It can thus be used to measure the attenuation of the optical signal propagating in the waveguide.

A. Practical Implementation

The delay line proves to be the most difficult part of the setup, because the power back injected into the fiber should be insensitive to the position of the mirror. We have succeeded in building such a delay line (with fully automatic control through a computer), covering a range of about 5 cm, with a resolution in the order of 10 µm and a good stability. To obtain good stability, the delay line should be robust and highly accurate, because of the difficulty of maintaining practically a constant back-injected power over a long path.

As shown in figures 11 and 12, the setup consists of a fiber placed on a Z translator, followed by a collimating lens placed on an X-Y translator. The emerging laser beam, after passing through the lens, moves a distance in space before it is reflected back at the mirror surface (the mirror position is fully controlled through a stepper motor-micrometer system). The reflected beam couples back into the fiber, with minimal losses. A detector is used to monitor the back-injected power.

The beam emerging from the fiber tip diverges significantly before being reflected from the movable mirror surface. This explains the need for a collimating lens to obtain an emerging beam with very low divergence. The position of the lens with respect o the fiber end is also a critical parameter.

The mirror itself is mounted on an adjustable stage that enables the mirror tilting with two angles to facilitate the back-injection into the fiber. The setup alignment is performed manually at the beginning of the measurement and should be kept unchanged all over the experiment. This shows the importance of the setup automation. For the movable part of the system we have used an interferometric table to mount our components on and we mounted the collimating setup (fiber and lens) on the movable part of the table. This enables to move the mirror with 10µm mechanical resolution and 2.5 mm dynamic range. To increase the dynamic range another mechanical stage is designed and fabricated to allow for the coarse motion. This stage provides a 5cm range of motion.

Fig.11 Photo of the real practical setup

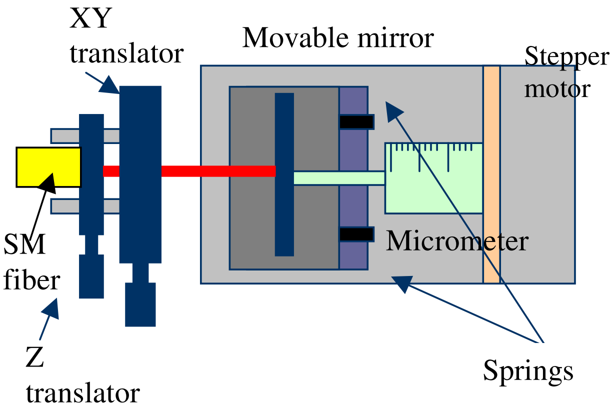

Fig.12 Schematic plan view of the setup.

For the setup automation, stepper motors controlled by the PC (through interfacing circuit shown in fig.13) are used. The circuits used for the control and interface of the motors with the computer are designed and fabricated using PCB techniques. For the feedback signal from the detector, a current to voltage converter circuit is also designed and integrated with the interface circuits on the same board. The schematic illustration of the integrated board is illustrated in Fig. 14.

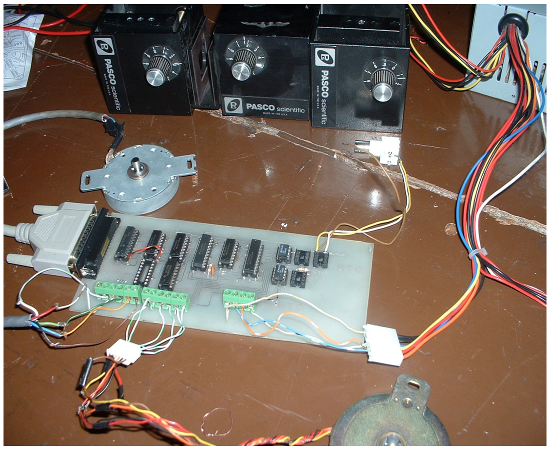

Fig.13 Photo of the interfacing circuit.

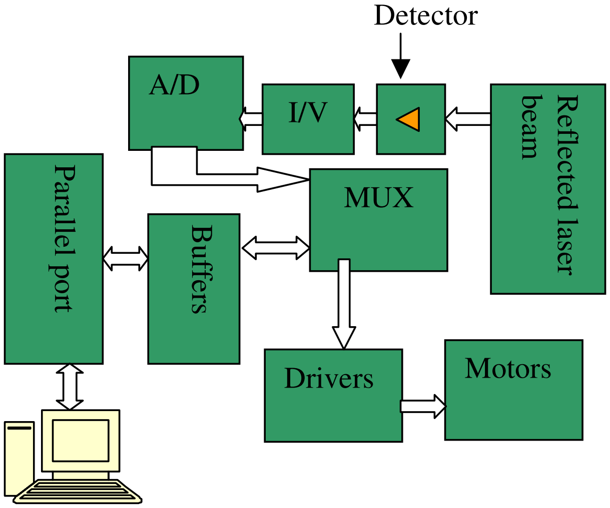

Fig.14 Schematic of the whole automated apparatus.

B. Practical Results

Figure 15 shows the power back injected from the delay line versus the distance traversed by the mirror. As can be seen, the reflected power is constant along a large range of distance. The dip in power that appears in the figure is due to an opaque screen placed between the mirror and the fiber during the mirror motion to illustrate that the measured power is due to the reflection from the mirror. The back injection efficiency, defined as the ratio of back injected power into the fiber to the power emitted from the same fiber end, is found to be around 42%.

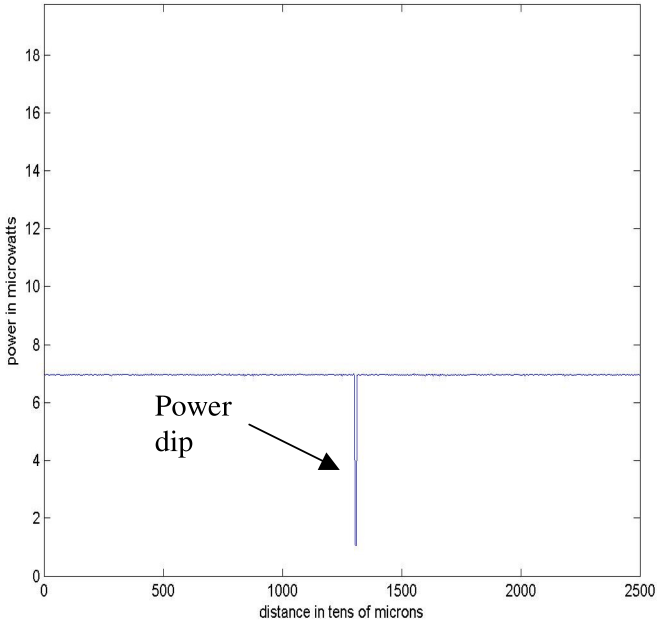

Fig. 15 Graph showing the back injected power versus distance traversed by the mirror.

IV. CONCLUSION

In this project we have investigated the development of a local integrated optics technology. The technology parameters have been precisely determined. Both Single mode guides and multimode beam splitters are fabricated using the developed technology and tested using the near field technique with a CCD camera. The main problem to be solved for the future development of such a technology is the cleaning process that requires a clean room environment. A computer-controlled optical delay line is also implemented for the development of an automated OCDR setup. The implemented line has a dynamic range of 5 cm with a resolution of 10 µm. The project could be continued in a second phase that considers the complete OCDR with data acquisition, analysis and display.

V. REFERENCES

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