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Integrated-Optics Interferometric Sensors on Glass for Chemical Applications

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A new two-wave interferometer is realized in integrated optics. Spatially distributed interference fringes give complete images of light absorption and phase variation in the interferometer. The fabrication method employed is ion exchange on a glass substrate. The interferometer includes two tapered waveguides. The advantages of this new interferometer are demonstrated through the realization and characterization of a complete setup for evanescent wave sensing.

1. Introduction

The principle of evanescent wave interaction is widely used in the fields of optical biosensors, and chemical sensors.(1-4) Commercial bulk optics solutions are already available. Optical integrated components realized by ion exchange on glass(5,6) is particularly suited for these detector applications. The technology inherits the advantages of integrated optics such as no alignment of the optical elements and wide operating temperature range. Ion exchange on glass provides the additional advantages of easily available raw materials and simple fabrication. Mass production is possible using methods already employed in the field of microelectronics.

The optical device fabricated using our technology has typical surface dimensions of about 60 × 10 mm^2. The refractive index of glass permits good coupling to optical fibers. Its planar optically polished surfaces allow spreading of active or passive materials by spin coating or other methods of thin-film deposition.

Our proposed interferometer may be practically used for the deposition of, *e.g.*, antibody-antigen solutions to fabricate a detector for use in immunological analysis, or special polymers for a chemical detector. This paper concentrates on the experimental verification of the interferometer's optical characteristics. A more detailed description of the various elements (interferometer design and analysis of the interference pattern) is given in ref. 7.

2. Materials and Methods

Our proposed optical interferometer resembles the well-known Mach-Zehnder interferometer (Fig. 1) since it is based on the interference between two coherent light waves. While the output signal from the conventional interferometer realized in integrated optics is a single light spot with time-varying intensity, our improved interferometer (Fig. 2) gives a complete spatial interference pattern. The collimated beams from the two tapers interfere at the edge of the glass substrate, and the near-field is recorded by an infra-red camera (Fig. 3).

The tapered waveguide(8) is a key part of our interferometer. Its role is to convert the fundamental mode of a straight waveguide into the fundamental mode of the output multimode waveguide exciting neither higher-order guided modes nor radiation modes. This corresponds to transforming a confined field into a collimated beam. The output beam of the tapers used in the experiments had a waist of 40 μm and a measured divergence angle of 1.2°.

Simple one-spot intensity detection does not always allow us to distinguish between the two evanescent wave interaction effects: light absorption and phase variation. The increased amount of information furnished by the interference pattern allows us to measure each of these phenomena simultaneously and independently. Light absorption is trans-

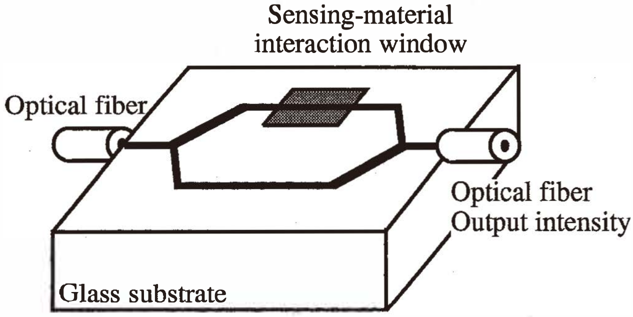

Fig. 1. Conventional Mach-Zehnder interferometer in integrated optics. The output signal is a single light spot of varying intensity.

formed into fringe contrast, and phase variation into fringe displacement. The direction of fringe displacement indicates the sign of phase variation.

The component was fabricated using K^+-Na^+ ion exchange on commercially available B270 glass (Desag). Laterally confined waveguides were defined by photolithography on a thin (0.2 μm) aluminium layer, which served as a mask for the ion exchange. Monomode operating conditions were obtained for a mask window of 3 μm and 20 min ion exchange at 450°C.

Ion-exchanged waveguides on glass can be surface waveguides or buried waveguides. For evanescent wave interaction, surface waveguides are required. In order to not modify the reference signal, the reference arm of the two-wave interferometer should be protected from the detection material, either by a low-index superstrate or partial burying of the waveguides. We have employed the former in the present study. The superstrate should be transparent at our wavelength (0.8 μm) and have an optical index lower than the index of

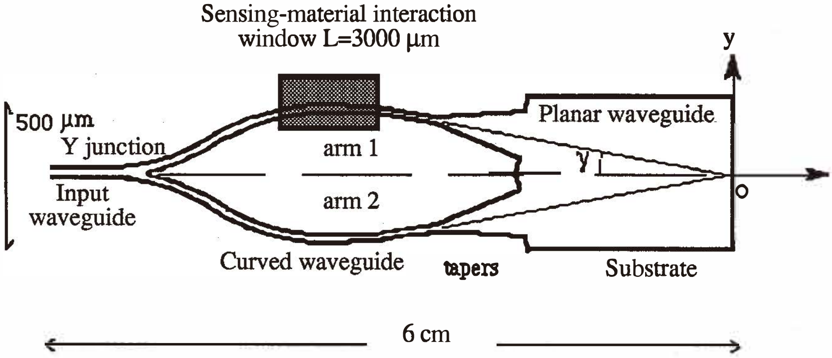

Fig. 2. New two-wave interferometer using two tapered waveguides to obtain interference fringes at the output edge.

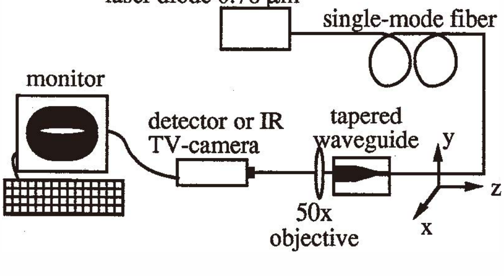

Fig. 3. Experimental setup used to characterize the output near field.

the glass substrate (B270: 1.52): SiO_2 and MgF_2 (refractive indices 1.46 and 1.36 respectively) are such candidates. They can be deposited in thin films on the glass substrate by cathodic pulverization or evaporation. The interaction regions (regions of uncovered glass) can be defined by the photolithographic lift-off technique.

We also propose a third simple and quick method to fabricate the protection layer. Polymers that reticulate during UV exposure are commercially available. The reticulated polymer is transparent with a measured optical index of 1.489 in our case. Optical glue is applied to the component surface, and a photographic film with the desired motive marking the limits of covered and uncovered regions is taped to the glass plate. The glass plate, film, glue and component are pressed together so that the glue forms a thin layer between the photographic film and the component. By UV exposure through the glass plate and photographic film, the glue reticulates in exposed areas. We then remove the film and the glass plate. Nonreticulated glue can be removed with acetone and alcohol. Small quantities of acetone do not attack the reticulated glue. Details as small as 30 μm could be reproduced by this simple method. We used Kodak ImageLink HQ 1461 microfilm and Vitralit 7256 optical glue.

The measurements are performed using a temperature-dependent-index liquid as the superstrate. Its refractive index is a linear function in our temperature range:

$$n_{\mathrm{liq}} = 1.53 - 4.01 \cdot 10^{-4} (\mathrm{T} - 25^\circ \mathrm{C}). \tag{1}$$

By controlling the component temperature with a Peltier element, we can control the refractive index of the superstrate. By this method, as confirmed earlier,(4) very small effective refractive index variations (10^{-6}) can be measured using the Mach-Zehnder interferometer depicted in Fig. 1. The effective refractive index change Δn_{eff} from the measured phase variation $\Delta\Psi$ is calculated by

$$\Delta n_{\mathit{eff}} = \frac{\Delta\Psi}{k_0 L}. \tag{2}$$

The length of the interaction window L is a component design parameter, and k_0 the free-space wave number.

3. Results and Conclusion

A two-wave interferometer (Fig. 2) was fabricated as described above. The interaction length L was 3000 μm, and the protection layer material was optical glue. We covered the detection window of our interferometer with index liquid, and observed the cooling of the component from 65°C to 26.5°C. This corresponds to increasing the index of the superstrate. Output intensity profiles were recorded at different temperatures, and are shown in Fig. 4. We can observe that the change in the refractive index of the superstrate results in fringe displacement, as expected. From about 38°C, the signal contrast is

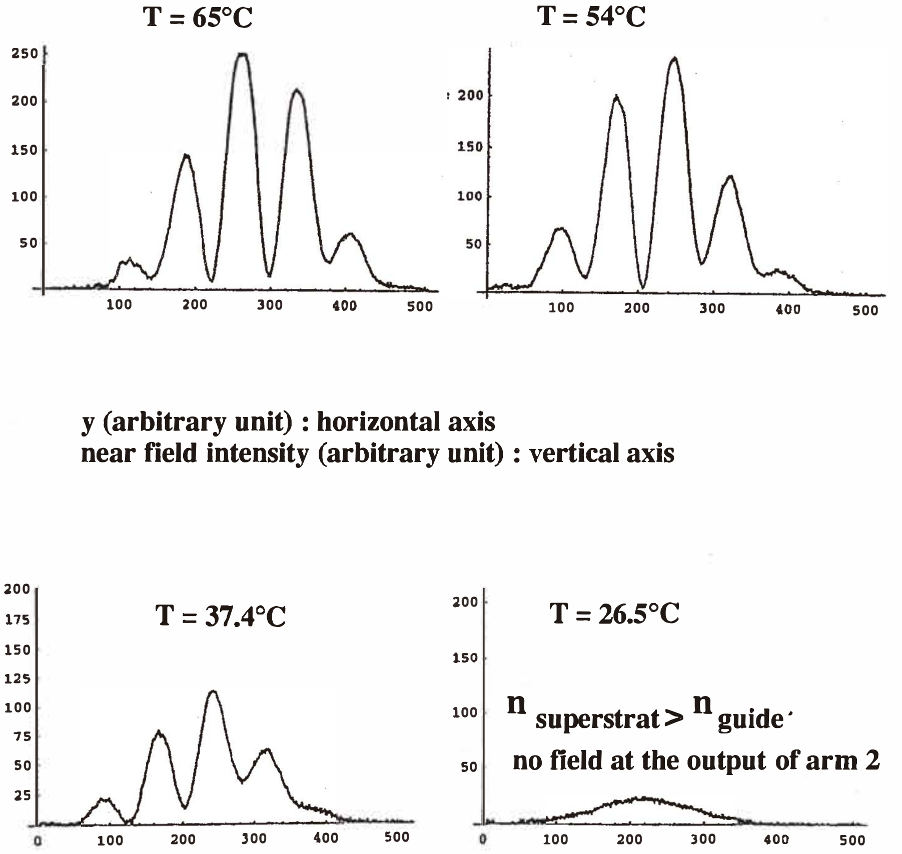

Fig. 4. Intensity profiles obtained with the interferometer in Fig. 2 recorded by a CCD camera. A special liquid with a known temperature-dependent refractive index was used as a superstrate. During measurement, the liquid was cooled from 65°C to 26.5°C.

reduced, which indicates that the refractive index of the liquid becomes higher than the waveguide index at this temperature. At 26.5°C, only light from the reference arm is observed.

We have experimentally demonstrated the advantage of our two-wave interferometer compared to the well-known Mach-Zehnder interferometer, namely, lightspot intensity variation has been replaced by displacement of interference fringes. We are currently investigating the practical use of our component as a chemical or biological sensor. For this purpose, the thin-film sensing materials that constitute the superstrate of our waveguide will likely be further developed, research which requires multidisciplinary collaboration between physicists, chemists and biologists.

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