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Integrated structure for dual role: measuring the fibre – guide coupling losses and sensing the external medium variations

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A special structure using a selective buried waveguide is realised by ion-exchange technology. The structure can be used to measure the fibre – guide coupling losses and to detect some external parameter variations. Each extremity of this structure is connected to an optical fibre. In this compatible connection, the coupling fibre – guide losses is less than 0.5 dB. The structure has a non buried part, which is sensitive to any external physical or chemical effect. Using amplitude modulation, a temperature variation is tested with this structure. In range of 20° - 40°, the sensor dynamic is 13 dB. The general structure presents low total insertion losses, - 9 dB.

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1. Introduction

Integrated waveguides by ion exchange technology have many advantages: compatibility with optical fibres, potentially low cost, low propagation losses, and the ease of their integration into the system [1]. These waveguides can be obtained on the glass substrate surface by one-step ion exchange. Such kind of guide is well suited for integrated sensor applications, where the guide interacts with the substrate through the upper evanescent part of the guided wave. A buried waveguide can be obtained by the same technology, using two-step ion exchange [2]. During the second step the waveguide is embedded below the surface by application of an external electric field across the substrate. The compatibility, guide - fibre, reduces the coupling fibre-integrated guide losses and have a low propagation loss, less than 1 dB/cm. The technology flexibility *enables to* obtain the two kinds of guide in the same structure (selectively burring of the waveguide) [3] [4] [5]. The two kinds of guide are jointed by a smooth transition region. This part is characterized by a variable depth [3]. The guide extremities are buried in order to connect them to the fibres. In the guide centre a part will be kept at the surface in order to be interacted with the external medium. In this paper, the described selectively buried waveguide is included in an appropriate structure. In one hand, the structure permits to dissociate the coupling losses from the others and in another hand, it can be sensitive to the external medium variations.

In the first part, the structure scheme, the coupling efficiencies calculation and the transfer function are presented. As an application of the structure sensitivity, a temperature sensor is realised and some results are given, in the second part. Finally, the potentialities of such device applications are discussed.

2. Theoretical study

The studied structure scheme is presented in Fig. 1. It is composed of two symmetric Y junctions disposed as shown in the figure. Two mirrors are placed at the external arms ends of the two junctions. The mirrors are constituted by a thin chromatic film, realized by pulverisation on ends of Y junctions. A part of the common arm is kept at the surface to ensure the sensor function. In order to limit the propagation losses and to optimise the coupling guide-fibre, the rest of the compound is buried under the surface. The transfer function of the compound is given by two equations. The equations relate output intensities P_3 and P_1 in the fibres on each side of the sensor as a function of input intensities P_0 and P_2. Each side of the sensor is related by Y fiber junction to a photodiode (PD_1, PD_2) and light emitting diode (LED_1, LED_2).

The transmittance and reflectance are defined by:

$$T_{12} = \alpha P_{0} C_1 A_1 C_2 Sm$$

$$T_{21} = \alpha P_2 A_1 A_2 C_1 C_2 Sm$$

$$R_{11} = \beta P_0 (1 - C_1)^2 A_1^2$$

$$R_{22} = \delta P_2 (1 - C_2)^2 A_2^2$$

T_{12}, T_{21}: are respectively the transmittances from side 1 to 2 and from side 2 to 1

R_{11}, R_{22}: are respectively reflectance from side 1 to 1 and side 2 to 2

A_1 and A_2 are the unknown variables total fibre to guide coupling coefficients at both ends of the integrated optic chip. It is assumed that the coefficients are the same in both directions and for both transmitters.

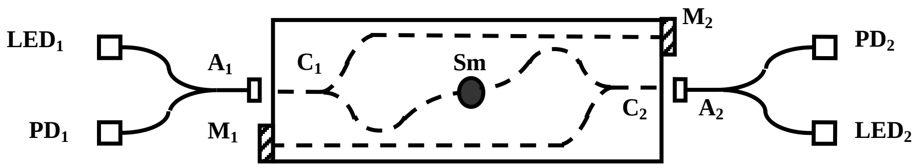

Fig.1. The structure scheme.

α represents the on-chip propagation loss of the transmitted signals.

and δ represents the on-chip propagation and reflexion losses of the reflected signals.

Sm is the transfer function of the sensor.

C_1 and C_2 are the coupling coefficients in the principal arm of Y_1 and Y_2 junctions.

We note that C_1=C_2=1/2 (symmetric Y junction).

With $P_1 = T_{12} + R_{22}$ and $P_2 = T_{21} + R_{11}$

The measurement calibration of the sensor is given by [6].

$$Sm' = \sqrt{\frac{T_{12}T_{21}}{R_{11}R_{22}}} = \frac{\alpha}{\sqrt{\beta\delta}} Sm$$

If we make the following change of variables:

$$a_1 = \left(\sqrt{\delta/2}\right) A_1 \quad \text{and} \quad a_2 = \left(\sqrt{\beta/2}\right) A_2$$

the system will be described by:

$$P_1 = a_1 a_2 Sm' P_0 + a_2^2 P_2$$

$$P_3 = a_1 a_2 Sm' P_2 + a_1^2 P_0$$

The input signals, transmitted by the 2-connectorized ends of fibres are P0 and P2. These are known quantities in relation to a control signal.

If we discriminate the modulated and no modulated parts of the signals received by each photodiode, the measurement of P_1 and P_3 yield three terms a_1 a_2 Sm', a_2^2 and a_1. Therefore, the calibration procedure is done by Sm' measurement and not by Sm measurement. The subsequent measurements will yield Sm'. a_1 and a_2 to help to evaluate coupling variations. In particular, temperature variations are no longer a problem:

- as long as α, β, δ are temperature insensitive if the sensor is not a temperature sensor;
- without any additional constraint if the device measures the temperature, because in that case possible variations of α, β, δ will be accounted for in the experimental Sm' (T).

3. Experimental results

The compound is carry out by two-step ion exchange on glass substrate. The realisation conditions are chosen in the aim to obtain single mode structure at 785 nm of wavelength. The geometry of the structure is made in order to minimise the different losses. The angle between the two arms of the Y junction is equal 1°. The bend radius of the Y junction arms is 8 mm. For this radius, the losses of curved waveguide can be neglected (Fig. 2). In these conditions, a total insertion loss of -9 dB is obtained. The losses are divided as fellow:

* -6 dB at the Y1 and Y2 junctions;
* -2 dB in the selectively buried waveguide part;
* - 1dB correspond to input and output coupling losses included the propagation losses of the completely buried waveguide part.

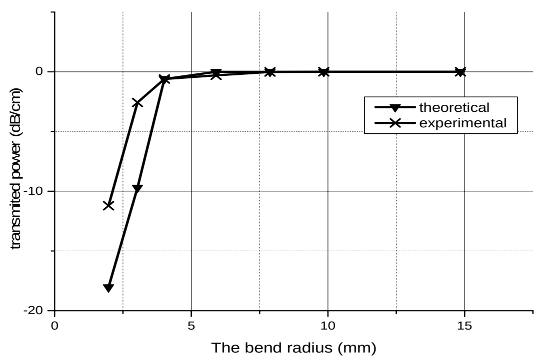

Fig. 2. The effect of the bend radius on the transmitted power.

A polymerised glue is deposited on the surface waveguide. The glue changes its refractive index depending on the temperature. The total losses are measured for different temperature in the range of 20° and 40°. The results are presented in Fig. 3. In this range, the dynamic is of 13 dB.

To increase the temperature sensor sensitivity, the polymerised glue must be replaced by another polymerised material. Such material changes its refractive index slowly with the temperature. The proposed structure can be exploited to measure other physical, chemical, biological and biochemical parameters by the disposition of the appropriate *polymerised material*. Such structure can replace for example the polished fibre method [7] witch is very hard to realise, and hybrid glass and sol gel waveguide method [8]. The last method requires two technologies sensitive structure, and the extremities of the waveguide are not compatible with the fibre.

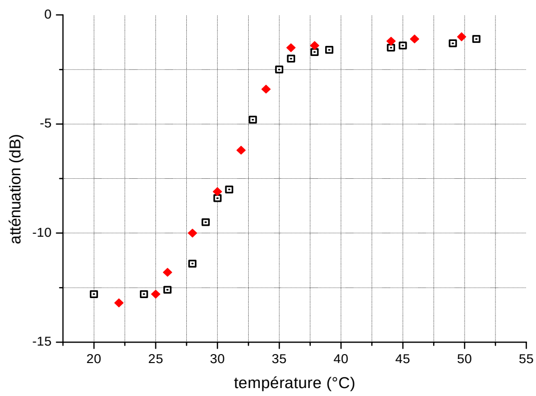

Fig. 3. Response of the sensor for increasing and decreasing temperature.

4. Conclusion

In summary, the proposed structure presents low insertion losses and very sensitive to the external medium changement. Such property shows that a simple measurement is possible taking into account temperature variations, with an amplitude modulation sensor, provided a double source is available. The structure permits also to evaluate separately the coupling fibre – guide losses from the others. The sensitive structure can replace other exist methods.

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