Design of Silicon Hollow waveguide Polarizer using Multilayer Structures

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***Abstract* - Integrated in-line polarizers based on hollow waveguide with multilayer sidewalls compatible with MEMS technology are proposed. The proposed design of 4 layers can achieve an extinction ratio of 11 dB/mm with propagation loss of 0.9 dB/mm**

I. Introduction

During the last decade, [1] integrated inline polarizers have attracted the attention due to their important role in future 40 GHz optical communication circuits. Many realizations have been reported in literature. The ARROW waveguides (Anti-Resonant Reflecting Optical Waveguide), where multilayers of semiconductors are used, [2,3] has demonstrated an extinction ratio of 14.8 dB and an insertion loss of 1.1 dB. Polarizers based on embedded thin metallic layer with an extinction ratio of 12 dB and an insertion loss of 0.075 dB has been also reported [4]. Several groups have demonstrated fiber optic polarizers made of a thin metal layer on top of a polished fiber block and overlay layer [5]. Taking advantage of the efficient coupling between the TM fiber mode and a surface plasmon polariton mode, they obtain high extinctions ratios (50 dB) and low insertion losses (0.5 dB) [6]. In this work, we propose a hollow Si waveguide [7] to act as a polarizer by transforming the two sidewalls of the guide into 1D photonic crystal [8] or multilayers of alternating Silicon and Air. The main advantage of the structure is its compatibility with MEMS technology as it can be fabricated by one mask and single Deep Reactive Ion Etching DRIE process, which allows patch processing and thus low cost in mass production. In addition the structure is designed to be compatible with single mode fiber dimensions to reduce the coupling loss. The basic idea of the structure is presented in section II. In Section III the structure design and performance are presented and finally a drawing conclusion is given in Section IV

II. Basic Idea and Polarization Analysis

The hollow guide is an anti-resonance structure with light propagating in air (low index) surrounded by a cladding of Silicon (high index). The idea of hollow waveguide polarizer is based on the fact that TM modes suffer from high propagation loss than TE modes due to the difference in their reflection coefficients at the Air/Si interface. The propagation loss analysis of TE and TM modes in hollow slab waveguide, presented in [9], gives an attenuation coefficient α as:

$$\alpha = \frac{4\pi K}{\lambda} \qquad (1)$$

where

$$K = -\frac{\lambda^2 m \ln R}{8\pi h^2 N} \qquad (2)$$

$$R = \left(\frac{m\lambda n_s^{2p} - 2hn_w^{2p}\sqrt{n_s^2 - N^2}}{m\lambda n_s^{2p} + 2hn_w^{2p}\sqrt{n_s^2 - N^2}} \right)^2 \qquad (3)$$

where R is the reflectivity coefficient, m is the mode number, h is the waveguide dimension, N is the real part of β (the waveguide complex propagation constant), n_s and n_w are the refractive indices of the substrate and waveguide respectively, p = 0 for TE modes and 1 for TM modes. Fig. (1) shows the propagation losses for both modes for a silicon hollow waveguide with. n_s =3.6 and n_w =1. In our analysis we assume that only the fundamental mode (with m =1) is excited in the guide, however, the guide might be multimode. Higher order modes are expected to have higher propagation losses than the fundamental mode. Also all calculations are made for wavelength of 1.55 μm.

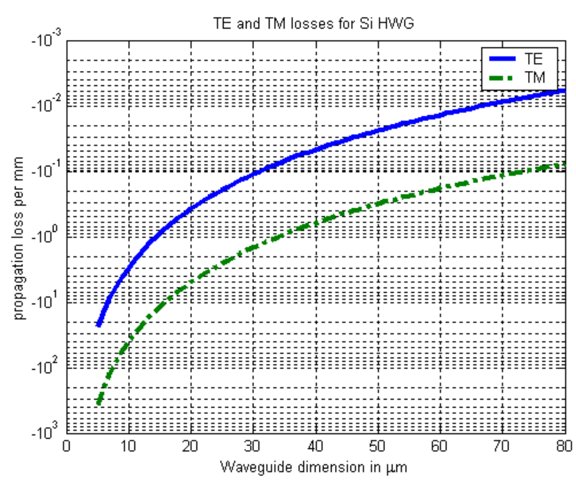

Fig. (1) The propagation losses for the TE and TM modes for the hollow waveguide.

For two-dimensional guides, the modes can be decomposed into two slab modes, as a first order approximation; one in the x-direction and the other in the y-direction. They can also be classified as, parallel polarization (P) and normal polarization (S) modes, as shown in Fig. (2). Thus, each mode will be TE with respect to one boundary and TM with respect to the other boundary as in Fig. 2.

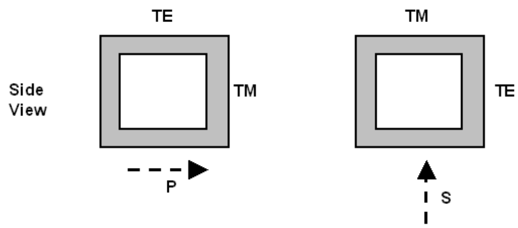

Fig. (2) The Two different polarizations of the hollow waveguide (P and S)

III. Polarizer Design and Performance

To evaluate the polarizer performance, two parameters are calculated, the insertion loss (IL) and the extinction ratio (XR). The IL is defined as the propagation losses of the P polarization, while the XR is defined as the difference between the propagation losses of both the P and S polarizations.

$$IL = (Losses_{TE} + Losses_{TM})_P$$
$$XR = (Losses_{TE} + Losses_{TM})_S - (Losses_{TE} + Losses_{TM})_P \quad (4)$$

Fig. (3) shows the polarizer suggested structure, where the hollow waveguide has 2 facing-sides formed of alternating Si and Air multilayers, while the other two sides are bulk Si. The guide dimensions are 15x15 μm^2. The multilayer structure could be fabricated by a single DRIE with a depth of 15 µm. Such technology has already been used for the fabrication of a hollow waveguide with high performance at 1.55 µm [7]. The layer thicknesses are designed such that they satisfy total field reflection at the operating wavelength using the photonic crystal effect. However, to avoid very narrow openings in the Si in the DRIE process, the layer thickness is multiples of the quarter of the operating wavelength. The minimum Si thickness used is 0.55µm while the air opening is in the order of 7.5 µm. The top Si is assumed to be a single crystal wafer attached to the bottom one using wafer bonding.

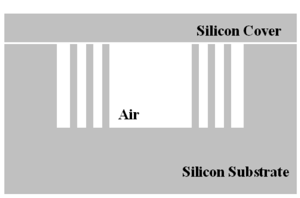

Fig. (3) Hollow waveguide with Multilayers of Si and Air

Fig. (4) shows the (XR/IL) ratio for different number of multilayers, using both Analytical and Numerical (Full Vectorial BPM) methods. The Stack theory is used for the analysis of the multilayers and the calculation of both the TE and TM reflection coefficients. Using 4 multilayers on each side of the Hollow waveguide, an IL in the order of 0.9 dB/mm could be obtained, while the XR is in the order of 11 dB/mm.The 1dB bandwidth of the structure is in the order of 0.9 µm and could be increased by increasing the number of layers.

IV. Conclusion

In this paper, in-line integrated Si polarizer is proposed and analyzed. The polarizer has low insertion loss (<1 dB) and moderate XR (12 dB), however, it can be fabricated by MEMS technology using a single step DRIE and wafer bonding. This opens the door for all Si MEMS compatible polarization control photonic circuits.

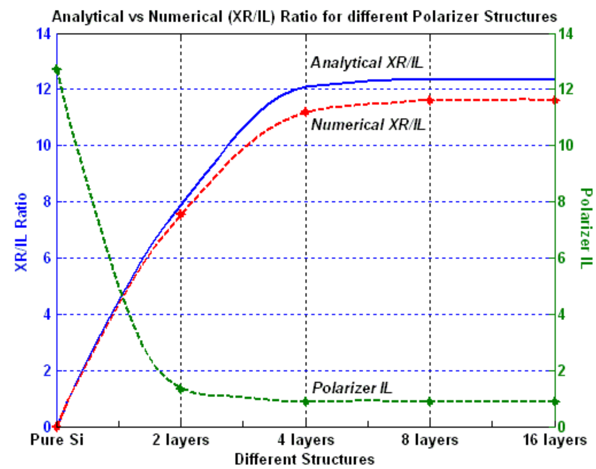

Fig. (4) Analytical vs. Numerical (XR/IL) Ratio for different number of multilayers

References

[1] Willner, A.E., Nezam, S.M.R.M., Yan, L., Zhongqi Pan and Hauer, M.C., "Monitoring and control of polarization-related impairments in optical fiber systems", IEEE Journal of Lightwave technology, Volume 22, Issue 1, Jan. 2004

[2] Shuichiro Asakawa and Yasuo Kokubun, "ARROW-B Type Polarizer Utilizing Birefringence in Multilayer Stripe Lateral Confinement", IEEE Photonics technology letters, vol. 7, No. 1, Jan. 1995

[3] Y. Kokubun and S. Asakawa, "ARROW-Type Polarizer Utilizing Form Birefringence in Multilayer First Cladding", IEEE Photonics technology letters, vol. 5, No. 12, Dec.1993

[4] Junichiro Fujita, Miguel Levy, Robert Scarmozzino, Richard M. Osgood, Jr., Louay Eldada, and James T. Yardley, "Integrated Multistack Waveguide Polarizer", IEEE Photonics technology letters, vol. 10, no. 1, Jan. 1998

[5] W. Johnstone, G. Stewart, T. Hart, and B. Culshaw, "Surface plasmon polaritons in thin metal films and their role in fiber optic polarizing devices," Journal of Lightwave Technology, vol. 8, pp. 538–544, 1990.

[6] M. N. Zervas, "Surface plasmon-polariton fiber-optic polarizers using thin chromium films," IEEE Photonics Technology Letters., vol. 2, pp. 597–599, 1990.

[7] Kareem Madkour, Hesham Maaty, Tarek Badreldin, Bassan Saadany, and Diaa Khalil, "Silicon Hollow Waveguide for MEMS Applications", ECOC, 2003

[8] Thomas F. Krauss, Richard M. De La Rue, "Photonic crystals in the optical regime -past, present and future", Progress in Quantum Electronics 23 (1999) 51 – 96.

[9] Nicholas J. Goddard et al., "Leaky Waveguide Devices as Simple Sensitive Optical Detectors for use in µTAS Applications", MicroTec 2000, 25th-27th September 2000, Hanover, Germany