12th Optoelectronics and Communications Conference/16th International Conference on Integrated Optics and Optical Fiber Communication (OECC/IOOC2007)
Technical Digest, July 2007, Pacifico Yokohama

13E1-3

Polarization Insensitive and Low-loss Tunable 3D Hollow Waveguide for Tunable Photonic Devices

Mukesh Kumar [1a)] and Fumio Koyama[1b)]
[1]*Microsystem Research Center, Tokyo Institute of Technology*
4259-R2-22 Nagatsuta, Midori-Ku, Yokohama 226-8503, Japan
Tel: +81-45-924-5077, FAX: +81-45-924-5977
a) kumar.m.aa@m.titech.ac.jp *b)* koyama@pi.titech.ac.jp

Abstract- The modeling and experiment of a new 3D hollow waveguide is presented for polarization insensitive tunable photonic devices. Low polarization dependence and low propagation loss can be expected at the same time by optimizing the shape of the 3D structure.

Key Words: hollow waveguide, tunable photonic devices, photonic integrated circuits.

1. Introduction

As the data traffic and transmission speeds in optical communications are increasing, the photonics technology has shown great progress and promise for future flexible photonic networks. Various tunable optical devices will play a key role in these photonic networks. We have proposed and demonstrated tunable hollow optical waveguide (HWG) with either dielectric multilayers or semiconductor multilayers, as well as a number of tunable optical devices based on the hollow waveguide, exhibiting unique features such as temperature-insensitivity, wide tunability and polarization-insensitivity [1]. The shape of hollow waveguides can be changed by using a MEMS element which leads to the tunability of propagation characteristics. In practical applications, 3D hollow waveguide is necessary for the purpose of compactness of photonic integrated circuits. We presented the modeling and experiments on 3D hollow waveguides with either etched groove or lateral periodic structure [2, 3]. In addition, there have been reports on integrated antiresonant reflecting optical waveguides (ARROW) with 3D hollow cores and a microelectromechanical optical switch inside a hollow waveguide [4, 5]. The investigation of low loss 3D hollow waveguide with polarization insensitive operation is necessary for the realization of widely tunable devices based on these waveguides. Though we have presented tuning characteristics and loss of 3D hollow waveguides but the loss of the 3D structure was considerably large [3].

In this paper, a low loss, polarization insensitive and simply fabricable 3D hollow waveguide (HWG), which we call a 3D nanostep hollow waveguide, is proposed. The modeling on its propagation loss, including the polarization dependence, spot size and tunability is presented. In addition, the fabrication of a nanostep 3D hollow waveguide is presented.

2. Structure of Nanostep Hollow Waveguide

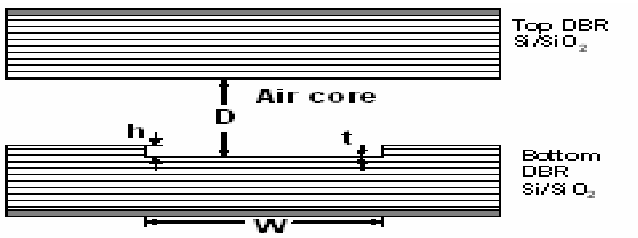


Fig 1. Schematic of 3D Nanostep Hollow Waveguide.

A 3D hollow waveguide has potential of a wider tuning range than that of a slab hollow waveguide [6]. The proposed 3D hollow waveguide is shown in Fig 1 in which light can be confined in three dimensions by the step in the top three layers of a bottom DBR. Both the top and bottom DBR layers consist of Si/SiO_2 for high refractive index contrast. We optimized the parameters h (step height in bottom DBR), W (width of air-core) and t (thickness of the remaining third layer, Si, in the bottom DBR) for lateral confinement, low loss and less polarization dependence. In assumed calculation models, 6 pair Si/SiO_2 in the top DBR and 7 pair Si/SiO_2 in the bottom DBR are assumed with thickness of quarter wavelength where the operating wavelength is chosen to be 1.55 μm. The width of the air-core is kept at 20 μm. In order to confirm the optical confinement in 3D step hollow waveguide we calculated intensity distribution with different step heights by Film-Mode Matching Method as shown in Fig 2. We note strong confinement of light in our new 3D hollow waveguide.

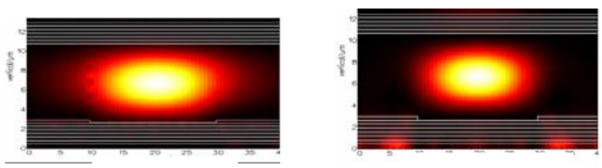


Fig 2. Calculated intensity distribution in 3D nanostep hollow waveguide with W = 20 μm, D = 8 μm and t = 40 nm.

3. Propagation Characteristics

The calculated propagation loss versus the thickness of a remaining layer of silicon in the bottom DBR is shown in Fig 3. The calculated loss is lowest for the case of the quarter wavelength thick layer. For comparison, the propagation loss of a slab hollow waveguide is also shown. The propagation loss of a 3D step hollow waveguide is much less than 0.1 dB/cm with h = 200 nm and it is around 0.1 dB/cm with h = 376 nm. So the calculated loss is in an acceptable level even at a narrower air core where its tunability will be larger [6].

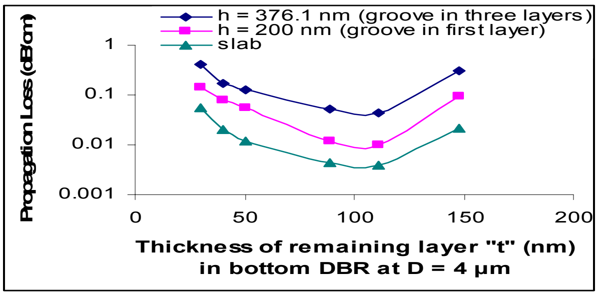
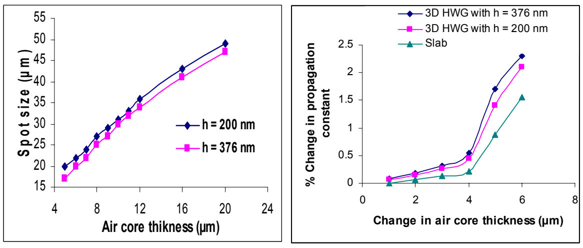


Fig 3. Propagation loss with “t”, at D = 4 μm and W = 20 μm.



(a) (b)

Fig 4. (a) Air core thickness dependence of spot size and (b) calculated tunability of 3D nanostep hollow waveguide.

The relation between lateral spot size and air core thickness is shown in Fig 4 (a). We note that the spot size is widely tuned with air core thickness and can be matched with that of single mode fibers. To investigate the tunability of the 3D hollow waveguide the change in propagation constant as a function of air-core thickness is calculated which is shown in Fig 4 (b). We note that tunability of 3D hollow waveguide is (around 2.4 % by changing the air core from 9 μm to 5 μm) wider than that in slab hollow waveguide. The tunability will be higher for narrower air cores [6].

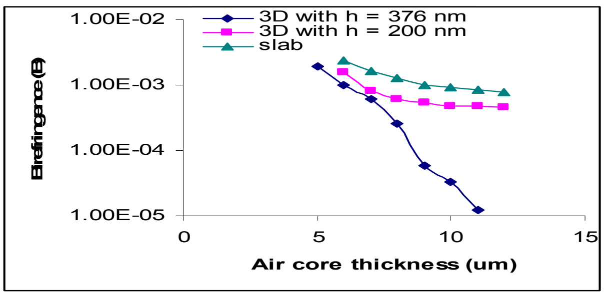


Fig 5. Polarization dependence of 3D nanostep hollow waveguide.

In a slab hollow waveguide, the polarization dependence is normally large due to strong polarization dependence of reflectivities of multilayer mirrors, while in case of 3D hollow waveguide, it is lower as shown in Fig 5. By decreasing the first layer thickness of the multilayer mirror, the birefringence B, defined by $B = (\beta_{TE} - \beta_{TM}) / \beta_{TE}$, where β is propagation constant, goes down. By optimizing the shape of 3D hollow waveguide polarization insensitivity can be realized. By making the step in three layers of bottom DBR and leaving the third layer silicon 40 nm thick, we found polarization-insensitive condition. The birefringence of this new polarization insensitive 3D hollow waveguide is less than 4×10^{-5} at air core thickness of 9 μm which is small enough to use in practical devices.

4. Fabrication

The 3D nanostep hollow waveguide was fabricated by wet etching (around 80nm silicon) the 6-pair Si/SiO2 DBR, followed by re-deposition of one pair SiO2/Si and then lifting off this newly deposited pair resulting in the required nanostep. The measured near field pattern of fabricated structure is shown in Fig 6. The measured lateral spot size is 55 μm at 20 μm thick air core and the calculated lateral spot size is 47 μm. The calculated and measured spot sizes are almost in agreement.

5. Conclusion

Our new 3D hollow waveguide (HWG) gives us simple fabrication, low loss, polarization insensitivity and wider tunability. This 3D waveguide also shows confinement of light in three dimensions and less polarization dependence with the optimized structure than a slab waveguide. Its spot size allows its coupling with a single mode fiber. The result will be useful for realizing temperature-insensitive, widely tunable and polarization-insensitive photonic devices based on the 3D hollow waveguide for future flexible photonic networks.

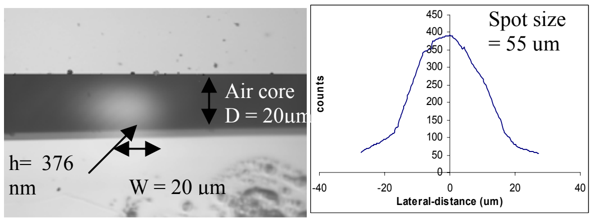


Fig 6. Measured near field pattern.

References

[1] T. Miura, F. Koyama, Y. Aoki, A. Matsutani and K. Iga, *Jpn. J. App.Phys*. 40(2001) L744-L746.

[2] T. Miura and F. Koyama, ECOC 2002, paper 04.4.4., Sep. 8-12, 2002.

[3] T. Miura and F. Koyama, *OECC/COIN*2004, 16F1-1.

[4] D. Yin and H. Schmidt, *Opt. Express*, vol. 12, no. 12, pp. 2710–2715, Jun. 2004.

[5] R Guerre, F Fahrini and F Renaud, *J.Lightwave Technol*.24, No.3 (2006) 1486.

[6] T. Miura, F. Koyama and A. Matsutani-*Optical MEMS* 2002, FB2.