11D3-4

Novel Optical Interconnection for Silicon-on-insulator Waveguide Tap Monitor

Shih-Hsiang Hsu
Department of Electronic Engineering
National Taiwan University of Science and Technology
No. 43, Sec. 4, Keelung Rd., Taipei, Taiwan
TEL: +886-2-2737-6399
FAX: +886-2-2737-6424
E-Mail: shsu@mail.ntust.edu.tw

Abstract: A photodetector can be applied onto the silicon-on-insulator waveguide tap to monitor light signals on waveguide. The reflective silver metal layer integrated with 54.7-degree angles from silicon wet-etching demonstrated low polarization-dependent-loss of 0.2 dB.

Introduction

One or more tap waveguides, implemented in the optical components for monitoring, is usually utilized to extract a portion of the light signal traveling alone a primary waveguide. Furthermore, a photodetector can be positioned onto tap waveguides to receive the light signals on the tap waveguide. Since a portion of the light signal from the primary waveguide is carried by the tap waveguide, the output of the photodetector can be utilized to indicate characteristics on the primary waveguide. The tap waveguide typically ends at the edge of an optical component. The photodetector is then positioned at the edge of the optical component over the end of the tap waveguide and receives the light signals directly from the tap waveguide. As the complexity of optical circuits formed on optical chips increases, many tap waveguides can not be employed and terminated at an edge of an optical component. Hence, there is a need for a waveguide tap that is suitable for use with complex optical circuits and can be positioned on a wafer base.

Recently silicon-on-insulator (SOI) is a critical platform for integrated optoelectronic circuits since it offers the potential of monolithic integration for photonic and electronic functions on a single substrate [1,2]. Integrating photonics functions on a silicon platform will be a low cost solution if integrated optoelectronics circuits are feasible.

In a rib SOI waveguide, the interface roughness from core/cladding and etched silicon surfaces mainly plays the role of the scattering centers to contribute the optical propagation loss. If the SOI waveguide design is appropriate, the polarization dependent loss (PDL) can be controlled within 0.1 dB. 5 μm thick SOI waveguide was a good choice to demonstrate low birefringence and efficient interconnection [3]. Nevertheless many tap waveguide monitors/photodetectors are associated with an undesirably high level of PDL, which means that the detector will sense a result of significantly different polarization modes. Because the tap and primary SOI waveguides are usually showing very small PDL (<0.2 dB), the distribution of different polarity modes received by the photodetector cannot represent and monitor the polarization modes in the primary waveguide of an optical component. Accordingly, there is a need for a tap waveguide arrangement where the output of the photodetector can represent the conditions in the primary waveguide.

Optical Interconnection for Waveguide Tap Monitoring

A novel optical interconnection was demonstrated by a total internal reflection (TIR) mirror on the GaAs based platform. The TIR mirror was etched by chemically assisted ion beam etching (CAIBE) to couple the optical signal from the waveguide into the detector for monolithically optical interconnections [4]. This approach requires a special CAIBE etcher and a complex dry etch processing development. Another simple optical interconnection is utilizing the anisotropic wet etch on silicon, which can be implemented by an alkaline solution, KOH, and will be stopped at (111) planes slanted 54.7^0 for (100) silicon wafer, shown in Fig.1. The angles of 35.3^0, less than the angle for total internal reflection, can be utilized as the input angle from SOI waveguide to polyimide medium. The silver metal on top of SiO_2 in the direction-changing-region is reflecting the optical signals, traveling along the tap waveguide, away from the base toward a photodetector via an input angle of 81.08^0.

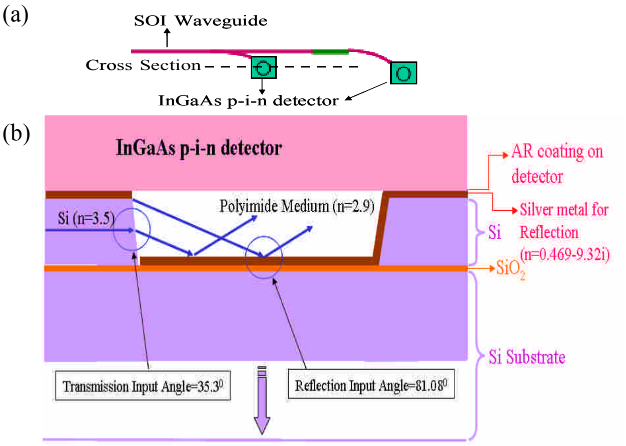

Fig. 1(a). Top view of an optical component having a primary waveguide and a tap waveguide positioned on a base. (b) A cross section of the optical component, taken at the dashed line labeled in (a).

In Fig. 2(a), the ray optics simulation shows that the PDL is around +0.1 dB at the input angle of 35.3^0 for the transmission from silicon to polyimide layers. The positive PDL value means that the optic loss of transverse-magnetic (TM) polarization is higher than transverse-electric (TE). In Fig. 2(b), an aluminum metal, frequently utilized in silicon processing, was taken to calculate the PDL of around -0.75 dB, contributed by the reflection from polyimide medium to aluminum metal at the input angle of 81.08^0. The net PDL through silicon, polyimide, and aluminum is -0.7 dB. If the reflective light was simulated for different kinds of reflective metals with the variation of the real and imaginary parts of refractive index from 0.1 to 5, the PDL contributed by the polyimide and metals at 81.08^0 is shown in Fig. 3.

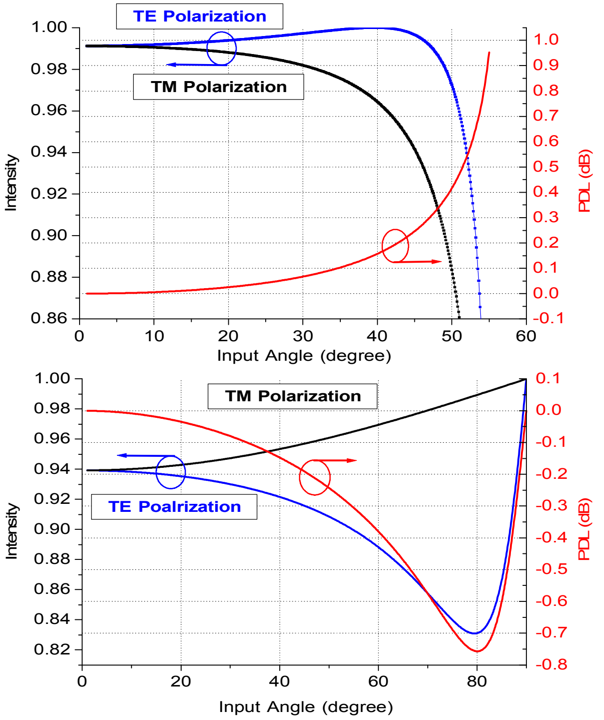

Fig. 2(a). Transmission from silicon to polyimide (b) Reflection from polyimide to aluminum metal

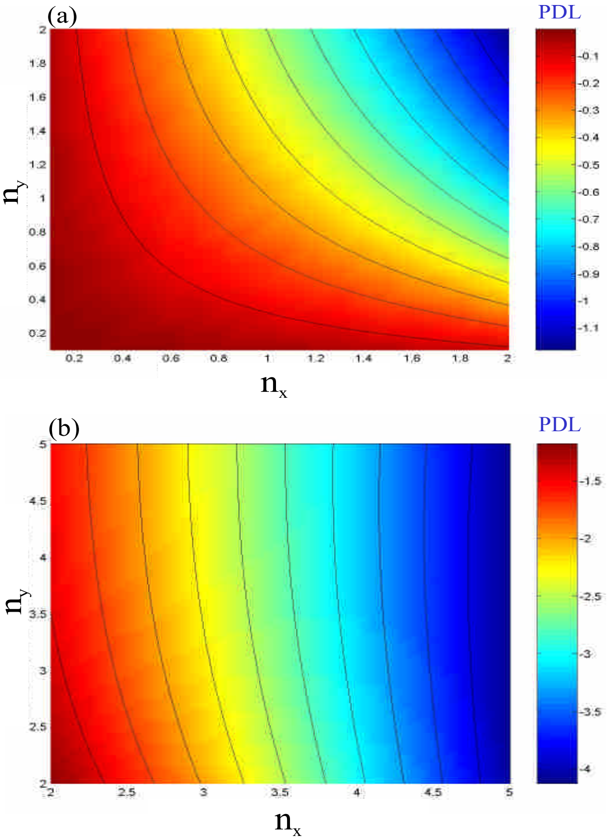

Fig. 3. PDL at the incident angle of 81.08^0 between polyimide and various kinds of reflective metals with the change of the real (n_x axis) and imaginary parts (n_y axis) of refractive index for (a) $0.1 \leqq n_x, n_y \leqq 2$ and (b) $2 \leqq n_x, n_y \leqq 5$

The usual metals utilized in the processing laboratory are listed in Table 1. The corresponding PDL performance can be demonstrated between -0.3 and -4.1 dB, which means that the propagation loss from TE polarization mode is always higher than TM. A silver (Ag) reflective metal integrated with SOI waveguide and polyimide medium is a suitable layer in directing light signal up to the photodetector, excluding SOI tap waveguide in the PDL budget, to achieve the lowest net PDL of -0.2 dB, +0.1 dB coming from the transmission from silicon to polyimide layers and -0.3 dB coming from the reflection of silver layer.

Optical Constant N=n-ik & λ is around 1550nm			
Metal	**n**	**k**	**PDL between polyimide and metal**
Cu	0.606	8.26	-0.4
Ag	0.469	9.32	-0.3
Au	0.559	9.81	-0.4
Al	1.44	16	-0.7
W	2.22	4.85	-1.6
Ni	3.38	6.82	-2.6
Ti	4.04	3.82	-3.1
Cr	4.24	4.81	-3.3
Pt	5.31	7.04	-4.1
PS: PDL<0 means that TE loss is higher than TM			

Table 1. Refractive indices of different metals

It is also clear that as the waveguide is increased in size, the TE and TM modes become similar and the polarization dependence is reduced [5]. A beam propagation method employed by BeamPROP shows that the PDL for SOI waveguides will be increased and the propagation loss from TM polarization is higher than TE when the waveguide dimensions are getting compatibly small with the order of the operating wavelength. In that way, the PDL from the tap SOI waveguides of thinner core will not be as low as 5 μm thickness. Platinum (Pt) and chrome (Cr) are then the suitable layers to compensate this kind of higher PDL from the small core of tap SOI waveguides.

If the polyimide medium is replaced by the air, the incident angle for the reflection on the metal layer is changed to 74.5^0 and the PDL will be different in the direction-changing-region area. For example, the PDL of -0.7 dB for an aluminum in the polyimide medium will be reduced to -0.3 dB in the air medium. Under this situation, more than one metal will be qualified to be the reflective layer in the tap waveguide monitoring applications.

Summary

A novel optical interconnection was demonstrated via a SOI waveguide tap monitor using the silver metal as the reflective layer under the detector to get the lowest PDL. The different metals as reflectors and filling media for reflection can be resources to compensate the significant PDL contributed by other optical components utilized in the waveguide tap monitoring system.

References

[1] S. H. Hsu, and J. Chan, “Photonic Bus with Loop Signal Routing and Multichannel Wavelength Selection on a Single Silicon-on-Insulator Platform”, *Optics Letters*, 31(14), pp. 2142-2144, 2006

[2] R. Jones, L. Liao, H. Rong, and M. Paniccia, “Silicon Photonics: Opportunity, Applications and Recent Results, *IEEE LEOS Annual Meeting*, pp. 377-379, 2005

[3] S. H. Hsu, “Low Birefringence Silicon-on-insulator Waveguide and Its Optical Interconnection using Numerical Aperture Fiber”, Submitted to OECC/IOOC 2007

[4] S. H. Hsu et al., “10Gb/s monolithic integrated optical waveguide and pin photodetector for WDM applications”, *ECOC*, Madrid, Spain, p. TuB18, 1998

[5] G. T. Reed and A. P. Knights, “Silicon Photonics – an introduction”, (John Wiley & Sons Ltd., 2004), Chapter 7