Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp248-249

Basic Study of Coupling on 3D Cross of Si Photonic Wire waveguide for Optical Interconnection on Inter/inner-chip

Katsumi Furuya[1,2], Ryohei Takei[1,2], Toshihiro Kamei[1,2], Youichi Sakakibara[1,2] and Masahiko Mori[1,2]

[1] National Institute of Advanced Industrial Science and Technology (AIST)
Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan
Phone: +81-29-861-5501 E-mail: k-furuya@aist.go.jp
[2] Institute for Photonics-Electronics Convergence System Technology (PECST)
Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

1. Introduction

The Speed-up and energy-saving of signal transmission on inter or inner chip of the semiconductors are expected. For the purpose, replacing the metallic wiring with optical one has been proposed. Especially, photonic waveguide and the devices on the Silicon (Si) substrate are desired because of the decrease of the fabricating cost. The Si photonic wire waveguide is an effective means for the Si photoics. For such waveguides, hydrogenation amorphous silicon (a-Si:H) is promising material[1]. The multilevel wiring is possible unlike conventional crystal Si (c-Si). We have been made initial devices that have three-dimension (3D) structure of the waveguides[2] and the theoretical study has been also done[3]. The wiring of such waveguides at actual application is to be expected to become extremely high density. The loss, crosstalk and so on that caused on the intersection part are problems. For the waveguide intersections that formed by the two waveguides on the same plane, a lot of examinations have been reported up to the present[4, 5, etc.]. In this report, however, we evaluate the problem for above-mentioned 3D crossing with not only orthogonal but also 45° corner quantitatively by numerical analysis.

2. Analysis

Orthogonal crossing that consists of two photonic wire waveguides and is the basic composition of the 3D structure is shown in Fig. 1. The distance between the waveguide cores is to be "d" as a variable. The core section (Si) of the wire waveguide is 200x400nm^2. The square of refractive index, that is relative permittivity, of the core and clad (SiO_2) is about 12.2 and 2.1 respectively. Such a waveguide is often used for the Si photonics [for instance, 6]. It is known well that the waveguide realize two propagation mode (TE like & TM like) at the same time for a wavelength of optical band. The ratio of the width to the thickness of this waveguide (200nm/400nm) is almost an upper limit to suppress the number of propagation mode to two described in the above. It is confirmed by the mode solver function of Femtet of Murata Software Co., Ltd. that the propagation modes other than the above-mentioned appear when the width of the waveguide increase further. Such 3D crossing structure is expected to be low loss by keeping away the over and under waveguides mutually.

HFSS of ANSYS Japan K.K. is used for the numerical analysis of the electromagnetic field propagation for the waveguides. The analysis is executed to the C-band for the optical communication wavelength. On the band, the permittivity of c-Si and a-Si:H is almost equal[7].

Both ends of each waveguide are to be port 1-4 as shown in Fig. 1, and the scattering matrix[8] coefficients (S-parameters) about outputs on each ports are derived for input of TE/TM like mode on port 1. For instance, the transmission coefficient from port n to m is Smn. (m, n:1-4.) Moreover, coupling between the different modes caused by the electromagnetic field scattering in the crossing part are also derived. Here, the output in a different mode from an incidence mode is written as Smn' in this report as notation.

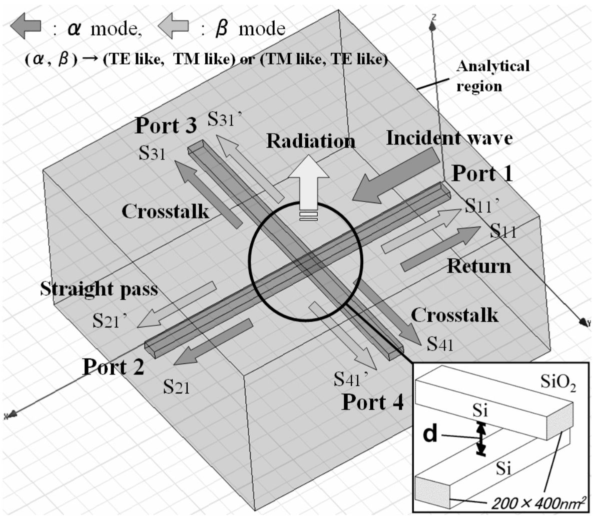


Fig. 1 Crossing photonic wire waveguide

3. Analytical results and discussion

In outputs shown in Fig. 1, there are combinations that the value becomes equal because of the analyzed structural symmetry, reciprocity theorem[9] and so on. Therefore, all of the outputs including repetition are not necessarily shown in this report. It can be considered that the characteristics depending on wavelength of the results don't change rapidly within the C-band. Therefore, the results for 1.55μm as typical wavelength are shown in the following.

Reflection and pass

As shown in Fig. 2, if incidence at port 1 is TE like mode, the reflection becomes -50dB or less when over and under cores of the crossing are 400nm or more away in the stacking direction of the multi-layer structure. At the same time, the loss of the pass lightwave through the crossing of TE like mode is suppressed to almost a few of 0.01dB (Fig. 3). Here, S_{11}' and S_{21}' always fall below -50dB regardless of which the input mode is, though not shown in figure.

Cross-talk

In case of the orthogonal crossing, as shown in Fig. 4(a) by circle, as for TE like mode incidence, the cross-talk is almost -50dB or less when the over and under cores are 400nm or more away.

Especially, for intersection whose two cores are on same plane; d = -200nm, the couplings of mutually different modes are hardly induced.

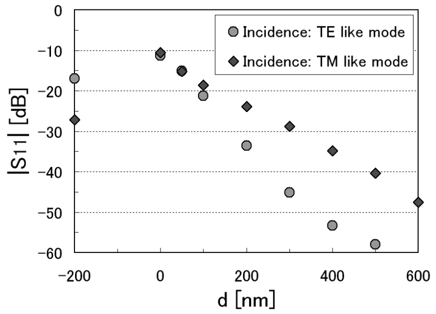


Fig. 2 Reflection coefficient (on the orthogonal crossing).

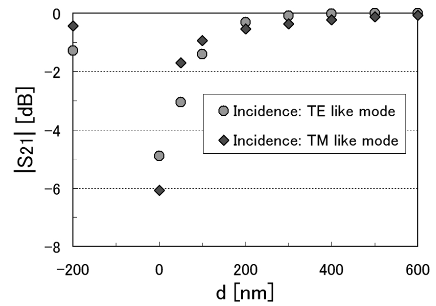


Fig. 3 Transmission coefficient (on the orthogonal crossing).

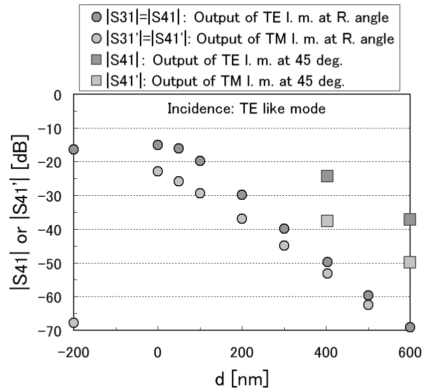
Dependency on the angle of crossing

As for the intersection waveguides, there are a lot of examinations of not orthogonal [for instance, 6]. Then, in this paragraph, cross-talks in case that crossing angle is 45° (Fig. 5) when the cores are 400 and 600nm away are also shown in Fig. 4 by square. In this case, unlike the case of the right angle, cross-talk output on port 4 is more than the one on port 3. For incidence of TE like mode, when the cores are 400nm away, cross-talk of same mode is about -25dB and more than the one of the orthogonal crossing. It, however, settles down into almost -40dB by "d" increase of only 200nm , while, though not shown in figure, when "d" is 400nm, S_{11}, S_{11}', S_{31} and S_{31}' falls below -50dB and S_{21} is a few of 0.01dB. S_{21}' is less than -45dB at the same time.

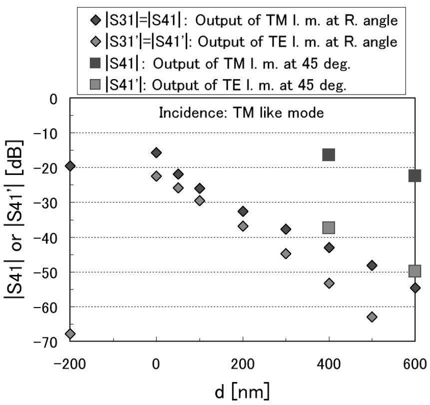
When TM like mode is adopted as incidence, "d" is needed to be more than the one in the case of the TE like mode from the viewpoint of the optimization of the reflection, crosstalk and through-pass. It is because that the electromagnetic field distribution of TM like mode around the waveguide core is larger than the one of TE like mode.

3. Conclusions

The S-parameters on the 3D crossing of Si wire photonic waveguide is evaluated by the numerical analysis, where the distance between the cores is a variable. When the distance is 400nm and typical 200x400nm^2 cross-section of the core, orthogonal crossing, dominant mode (TE like mode) for light propagation are adopted, it is confirmed that the loss seems to be little enough within C-band. Moreover, for the angle of the crossing is 45 degrees, it is shown that the coupling between the waveguides is almost negligible by the distance between cores that is not different from the order of the core size. Therefore, an important index for fabrication of practicable devices of multi-layered structure is obtained.



(a) TE like mode input



(b) TM like mode input

Fig. 4 Coupling between over and under waveguides (on the orthogonal crossing and the one at 45 degrees).

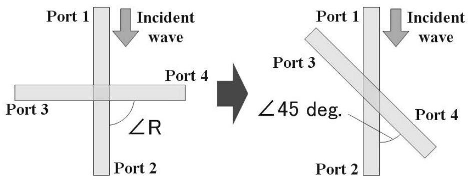


Fig. 5 The angle of crossing (Top view).

Acknowledgements

This research is granted by the Japan Society for the Promotion of Science (JSPS) through the "Funding Pro-gram for World-Leading Innovative R&D on Science and Technology (FIRST Program)," initiated by the Council for Science and Technology Policy (CSTP).

References

[1] Y. Shoji, et al., Optics Express, Vol. 18, No. 6, pp.5668, 2010.
[2] Y. Sakakibara, et al., *IEICE Tech. Rep.,* OCS2009-66, OPE2009-132, LEQ2009-91 (2009-10) [in Japanese].
[3] K. Furuya, et al., *The 15th Optoelectronics and Communications Conference (OECC2010)* TECHNICAL DIGEST, 8P-71.
[4] T. Fukazawa, et al., Jpn. J. Appl. Phys. **43** (1998) 646.
[5] D. Tanaka, et al., *OECC2010,* 9E2-3, Japan (Jul. 2010).
[6] K. Yamada, et al., Optics Lett., vol. 28, No. 18, pp.1663, 2003.
[7] E. D. Palik, Edit., "Handbook of optical constants of solids", Academic Press, 1985.
[8] T. Iwasaki, "Maikuroha, hikari-kairo keisoku no kiso, " CORONA Publishing Co., Ltd., The Society of Instrument and control Engineering, 1993 [in Japanese].
[9] T. Yabu, "Hikari-douharo Kaiseki Nyuumon," Morikita Publishing Co., Ltd., 2007 [in Japanese].