SEMI-ANALYTIC ANALYSIS OF COMPLEX PHOTONIC CRYSTAL STRUCTURES

Pablo Sanchez\(^1\), Javier Martí\(^1\), Jaime García\(^1\), Peter Bientinesi\(^1\) and Roel Baets\(^1\)

\(^1\) Nanophotonics Technology Center. Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain

\(^2\) Ghent University, Department of Information Technology, Inteniversity Micro-Electronics Centre (IMEC), Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium

SUMMARY

The transmission and reflection performance of complex photonic crystal structures coupled to dielectric waveguides are analyzed by means of a semi-analytic treatment based on previously derived closed-form expressions.

KEYWORD

photonic crystals, eigenmode expansion

ABSTRACT

Photonic crystals (PhCs), periodic structures with a period of the order of the wavelength of light, have been the subject of an intense research effort due to their ability for controlling the flow of light. However, efficient coupling is a key feature to ensure their optimum performance. In recent years, a large variety of different techniques have been proposed and evaluated by means of simulation to improve the coupling efficiency. However, only a few works have been focused on the modeling of the interference between PhC circuits and external media (fiber or dielectric waveguides) [1-5]. The modeling of PhC circuits with efficient and accurate approaches may significantly reduce the computation time, which is usually very long in conventional numerical methods such as the finite-difference time-domain (FDTD) method [6]. In this paper, previously derived closed-form expressions for the transmission and reflection at an interface between a dielectric waveguide and a semi-infinite PhC waveguide are used to analyze more complex structures by means of a semi-analytic treatment.

SEMI-ANALYTIC APPROACH

The proposed approach is valid for any kind of complex structures as long as the input medium has an index profile invariant along the propagation direction and the output medium is semi-infinite along the propagation direction or vice versa. The transmission and reflection matrices, derived on an eigenmode expansion technique and a Bloch basis [7,8], are defined as

\[
T = F^{-1} \left( B - R_{\text{eff}} B R_{\text{eff}} \right)^{-1} T_{\text{ref}}
\]

\[
R_{\text{eff}} = B_{\text{ref}} B_{\text{ref}} T_{\text{ref}} T_{\text{ref}} B_{\text{ref}}
\]

\[
R_{\text{ref}} = - \left( B_{\text{ref}} - R_{\text{eff}} F_{\text{ref}} \right)^{-1} \left( B_{\text{ref}} - B_{\text{ref}} F_{\text{ref}} \right)
\]

where \(F\) and \(B\) are the forward and backward components of the forward propagating Bloch modes while \(F\) and \(B\) are the forward and backward components of the backward propagating Bloch modes. The transmission and reflection matrices \(T_{\text{ref}}, T_{\text{ref}}, R_{\text{ref}}\) and \(R_{\text{ref}}\) depend on the structure placed between the invariant and semi-infinite periodic media and must be calculated with a numerical tool giving the semi-analytic character to the proposed approach. In this work, the forward and backward components of the Bloch modes as well as \(T_{\text{ref}}, T_{\text{ref}}, R_{\text{ref}}\) and \(R_{\text{ref}}\) matrices were calculated with a frequency-domain model based on a vectorial eigenmode expansion technique, known as CAMFR and freely available from the Internet [8].

REFERENCES

ECIO'05: 12th EUROPEAN CONFERENCE ON INTEGRATED OPTICS

ABSTRACT

The influence of the reflection is almost negligible. Therefore, the Fabry-Perot resonances do not appear in the transmission spectra calculated with FDTD (dashed line) at these frequencies.

Fig. 2: (a) Reflected power into the dielectric waveguide as a function of the normalized frequency for the structure depicted in Fig. 1. (b) Semi-analytic results for each of the guided modes in the dielectric structure deposited on the chip (different symbols). (c) Simulated results with a full-wave FDTD simulator for the same structure and for the reflection spectrum.

COUPLING INTO COUPLED-CAVITY WAVEGUIDES

The proposed approach can also be used to analyze the transmission and reflection properties of more complex structures, as shown in Fig. 3, which consists of a coupled-cavity waveguide (CCW) coupled to a coupled-cavity waveguide (CCW) composed of a coupled-cavity waveguide (CCW) coupled to a conventional PLC waveguide by using an adiabatic taper. The PLC waveguide is butt coupled to a 0.5μm-wide dielectric waveguide by choosing the coupling position to achieve negligible reflection back to the CCW. The transmitted power is also shown for the same structure used to couple light into and out of a PLC waveguide of finite length.

CONCLUSION

In summary, an efficient approach has been proposed for a semi-analytic treatment of complex PLC structures. The computation time may be significantly reduced with respect to other conventional numerical methods. Furthermore, it is also possible to analyze the reflection of a full structure without simulating the whole structure. Furthermore, it is also possible to analyze the reflection of a PLC waveguide, which can be very useful for testing novel designs and studying the influence of different parameters.

ACKNOWLEDGEMENT

This work has been partially funded by the Spanish Ministry of Science and Technology under grant TEC2002-01853. P. Sánchez acknowledges the Spanish Ministry of Education, Culture and Sport for funding his grant.

REFERENCES

8) http://www.surfer.fr
9) P. Sánchez, J. Martí, J. Baece, A. Martinez, and A. Garcia, "Mode matching technique for highly efficient coupling between dielectric waveguides and planar photonic crystal circuits", submitted for publication in Optics Express.
Optical Waveguide Theory and Numerical Modelling

13th International workshop
April 8-9 2005, Grenoble, France

Proceedings