ECIO 2016
18TH EUROPEAN CONFERENCE ON INTEGRATED OPTICS 2016
18–20 MAY | WARSAW | POLAND

Optical frequency domain reflectometry for characterization of waveguide crossings

Dan ZHAO[1*], Dzmitry PUSTAKHOD[1], Luc AUGUSTIN[1,2], Kevin WILLIAMS[1] and Xaveer LEIJTENS[1]
[1]Eindhoven University of Technology, Den Dolech 2, 5612 AZ, Eindhoven, the Netherlands
[2]Smart Photonics, Horsten 1, 5612 AX, Eindhoven, the Netherlands
[*]d.zhao@tue.nl

Abstract: We have analysed crossings of shallow etched waveguides with a self-calibration high-accuracy optical frequency domain reflectometry method. The power reflection coefficient of crossings was measured to be $(1.4 \pm 0.6) \cdot 10^{-5}$.

Introduction: In photonic integrated circuits (PICs) spurious reflections may play an important role, especially for circuits containing active components. Properly designed waveguide crossings have near 100% transmission and very small reflections. These small reflections are difficult to characterize and little has been published. Optical frequency domain reflectometry (OFDR) is a powerful method for characterization of small localized reflections in PICs[1]. In this work, we develop a self-calibration high-accuracy OFDR method to characterize the power reflection coefficient R of shallow etched waveguide crossings. The samples were fabricated by Smart Photonics through the JePPIX.eu multi-project wafer service.

The OFDR system: The schematic diagram of the OFDR system in Mach-Zehnder configuration for characterization of waveguide crossings is shown in Fig. 1. Light from a swept tunable laser is coupled into the sample which has a 4600 μm long shallow etched straight waveguide with 8 crossings at distances 1170, 1200, 2250, 2350, 2470, 3400, 3850 and 3950 μm from the front facet, respectively. The intensity modulations resulting from the interferences between the direct signal, acting as reference, and the signals with multiple reflections between cleaved facets and waveguide crossings are recorded by the power meter when sweeping the tunable laser. Taking the Fast Fourier transform (FFT) of the output signal, it is then possible to determine the position and the reflectivity of the crossings. A wavelength span of 120 nm with a step of 0.01 nm is used, which contributes to a high theoretical resolution $\delta L = c/2n_g\Delta f$ of about 3 μm[2].

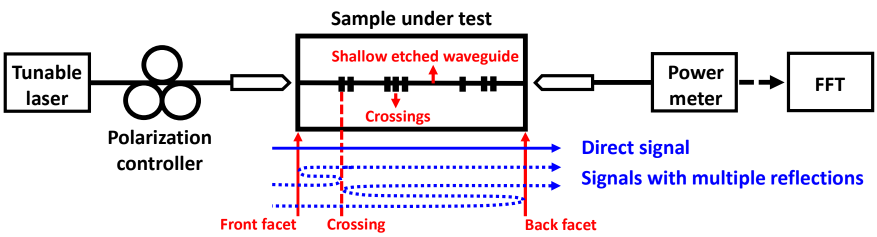

Fig. 19. The schematic diagram of the OFDR system in Mach-Zehnder configuration.

Results and discussions: The FFT of the measured signal is normalized to the maximum intensity and is shown as a function of cavity length L in Fig. 2(a). The positions of the facets and crossings match accurately with the design values. In this figure the group index n_g is assumed to be constant. The relative intensity RI of the back facet is underestimated as -17 dB, much lower than the calculated value of

-13.23 ± 1.36 dB according to $RI = |r_{\mathrm{f}}|^2 e^{-2\alpha\Delta L}$[2], where $r_{\mathrm{f}} = \sqrt{0.328 \pm 0.01}$ is the reflection coefficient of each facet, α is the propagation loss measured to be 2.1 ± 0.3 dB, ΔL is the chip length measured to be 4600 ± 15 μm. The accuracy can be much improved by including the quadratic term in the dispersion of n_{eff} versus wavelength λ. The result is shown in Fig. 2(b), with a relative intensity of the back facet of -12.32 dB. We use this method to derive the reflection coefficient of the waveguide crossings from eq. (1)[2] based on the condition that the crossing reflections are much lower than those from the facets, $R = |r_{\mathrm{c}}|^2 \ll |r_{\mathrm{f}}|^2$:

$$r_{\mathrm{c}} = RI_{\mathrm{c}}/(r_{\mathrm{f}} e^{-2\alpha z_{\mathrm{c}}}), \tag{1}$$

where z_{c} is the actual position of the crossings. The power reflectivity of the crossings is analysed to be $(1.4 \pm 0.6) \cdot 10^{-5}$ by taking into account the variations from each crossing and the parameter errors. A minimum design distance of 30 μm between crossings can be resolved, as shown in the inset. In Fig. 2(c), the group index $n_{\mathrm{g}}(\lambda)$ is extracted from simulations and measurements using the OFDR analysis, by doing the FFT for a small portion of the spectrum per step, according to eq. (2)[2].

$$n_{\mathrm{g}}(\lambda) = \big(\tau_{\mathrm{b}}(\lambda) - \tau_{\mathrm{f}}(\lambda)\big)c/\Delta L, \tag{2}$$

where λ is the central wavelength of each portion of the spectrum, τ_{f} and τ_{b} are the group delay for front and back facet reflections. The value of $n_{\mathrm{g}}(\lambda)$ obtained from simulation matches perfectly with the modelled refractive index[3], which therefore validates the method. The coefficients of the Taylor expansion of $n_{\mathrm{g}}(\lambda)$ and $n_{\mathrm{eff}}(\lambda)$ can be derived from the measured $n_{\mathrm{g}}(\lambda)$ from the OFDR system[4].

$$n_{\mathrm{g}}(\lambda) = a - b\lambda_0 - 2c(\lambda_0 \cdot \Delta\lambda),\ n_{\mathrm{eff}}(\lambda) = a + b\Delta\lambda + c(\Delta\lambda)^2 \tag{3}$$

The derived $n_{\mathrm{eff}}(\lambda)$ is used for improving the accuracy of analysis shown in Fig. 2b.

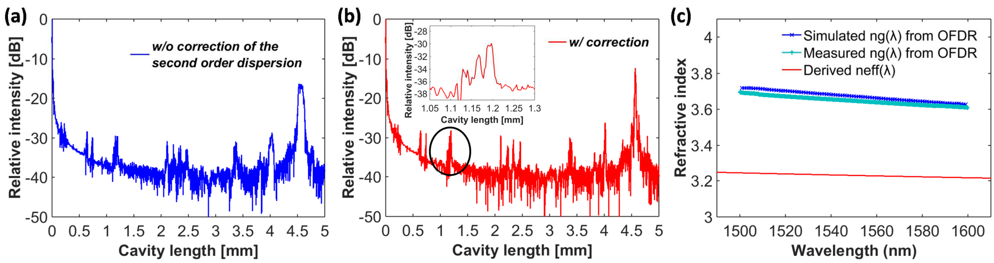

Fig. 2. OFDR measurements of the waveguide crossings.

Conclusion and acknowledgement: We demonstrate a high-accuracy OFDR analysis to measure the power reflectivity of waveguide crossings: $R = (1.4 \pm 0.6) \cdot 10^{-5}$. The position of the crossings is detected with a spatial resolution better than 30 μm. We acknowledge support by the Dutch Technology Foundation STW for project 13538.

References

[1] B. J. Soller et. al, Optics Express, vol. 13, no. 2, pp. 666-674, 2005
[2] D. Melati et. al, Advances in Optics and Photonics, vol. 6, no. 2, pp. 156–224, 2014
[3] F. Fiedler and A. Schlachetzki, Solid-State Electronics, vol. 30, no. 1, pp. 73-83, 1987
[4] S. Dwivedi et. al, Journal of Lightwave Technology, vol. 33, no. 21, pp. 4417-4477, 2015