Optical Frequency Domain Reflectometry for Characterization of Distributed Bragg Reflectors

Dan Zhao[1*], Dzmitry Pustakhod[1], Luc Augustin[1,2], Jeroen Bolk[1], 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 present the characterization of the reflection spectra of distributed Bragg reflectors (DBRs) created using DUV scanner lithography in indium-phosphide (InP) with the optical frequency domain reflectometry (OFDR) method.

Introduction: The Distributed Bragg Reflector (DBR) is an important waveguide component for achieving wavelength selective filter functions. To enable the DBR as a standard building block in the COBRA platform [1], a main challenge is the development of a high precision lithography technology on indium-phosphide (InP) wafers. Recently, we have successfully used the 193 nm DUV scanner to fabricate DBRs on InP wafers, for the first time [2]. Another challenge is to characterize the reflection spectra of fabricated buried DBRs. With a direct measurement of reflections from anti-reflection coated chips, the coupling loss between the fibre and sample is hard to be estimated. With cleaved chips, which enable self-referenced analysis, the coupling loss can be estimated. However, the contribution of the Fabry–Pérot cavity introduced by the facets need to be de-embedded to separate the pure grating reflection. In the optical frequency domain reflectometry (OFDR) method, we can separate the facet reflections from the grating response in the spatial domain [3].

The OFDR system: The schematic diagram of the OFDR system used for the characterization of DBRs on a cleaved chip is shown in Fig. 1. The sample has a 1950 μm long waveguide with a DBR positioned at 1000 μm from the front facet. The intensity modulation resulting from the interference of reflections from the cleaved facets and the DBR (green arrows) are recorded by the power meter when sweeping the wavelength of the tunable laser. Taking the Fast Fourier transform (FFT) of the recorded signal, it is then possible to spatially map the reflection distribution.

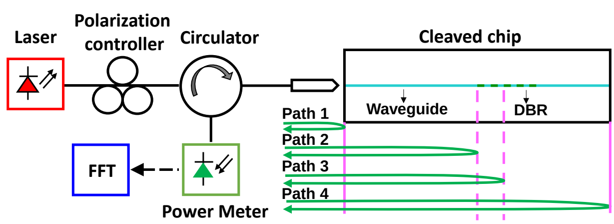

Fig. 1. The schematic diagram of the OFDR system.

The reconstruction of the DBR reflection is carried out in the following steps: first, remove those reflections in the spatial domain that correspond to a path difference longer than the DBR length, in this way we keep only interference between paths 2 and 3. Second, correct the magnitude of the FFT by eliminating the coupling and propagation losses. The coupling loss can be calculated from the average loss in the wavelength range outside the grating reflection peak. Third, apply an inverse Fourier Transform to the corrected FFT signal. Simulations have been done in our optical extensions implemented in Agilent's Advanced Design System (ADS) to demonstrate the accuracy of the method. Fig. 2(a) shows the comparison of the FFT results between the reference DBR (blue) and the sample with cleaved facets (red). It shows that the sample with cleaved facets has extra reflection peaks and extra losses compared to the reference. The reconstructed FFT signal of the sample, shown as the light blue curve in Fig. 2(b), matches well with the reference. By applying an inverse FFT, the extracted grating reflection matches well with the reference reflection (Fig. 2(c)).

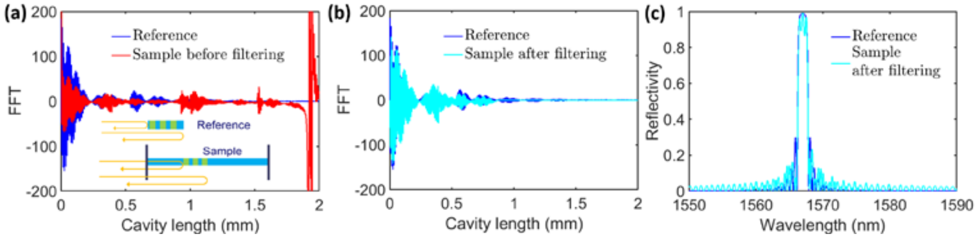

Fig. 2. FFT of simulated reflection from the reference and the sample (a) before and (b) after filtering. (c) Reference and reconstructed grating reflection spectrum.

Measurement results and discussions: A set of DBRs fabricated in the COBRA platform with periods of 236.3, 237.8, 238.5, 239.9 and 240.1 nm and lengths of 200, 400, 500, and 600 µm were characterized. Fig. 3(a) and (b) show the measured and extracted reflection spectra for DBRs with a fixed period of 240.1 nm. The DBR reflection spectrum is not directly visible in the measurements due to the losses induced by coupling, waveguide propagation and Fabry–Pérot interference. The extracted results show the reflection spectra of the DBRs. It shows that the same grating period results in the same Bragg wavelength and that a longer length of grating results in higher peak reflectivity. The Bragg wavelength of in total 40 different samples over a wafer has been analyzed. The mean values at 5 periods are shown as blue dots in Fig. 3(c). The standard deviation at each period is smaller than 0.7 nm, which is sufficient to target the wavelength for tunable DBR gratings. The Bragg wavelength increases linearly as the period increases, which indicates the reproducibility of the lithography process over a large area.

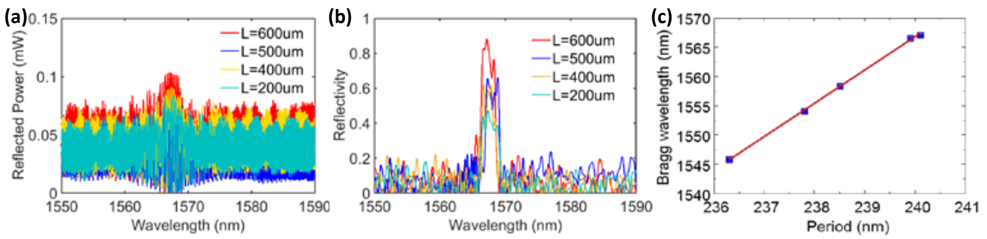

Fig. 3. (a) Measured and (b) extracted reflections of DBRs at different length, (c) Measured Bragg wavelength (blue spots) as a function of period and its linear fit (red line).

Conclusion and acknowledgement: We have developed a method based on OFDR with a subsequent filtering in the spatial domain to extract the pure power reflectivity of DBRs. The fabrication with 193 nm DUV technology is demonstrated to be reproducible over a large area. We acknowledge support by the Dutch Technology Foundation STW for project 13538.

References

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