AWG-based integrated fiber-Bragg-grating interrogator with improved sensitivity

Dzmitry Pustakhod, Emil Kleijn, Meint K. Smit, and Xaveer J. M. Leijtens
COBRA Research Institute, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands
d.pustakhod@tue.nl

Abstract: A Fiber Bragg Grating interrogator based on an AWG with custom design of the inputs is described. The proposed modifications ensure a non-zero readout signal on at least two detectors for any wavelength. It is shown that the combined readout allows to track wavelength changes with a resolution better than 5 pm.

1 Introduction

Fiber Bragg Grating (FBG) sensors are used in many applications[1]. In such sensors, the FBG plays the role of a wavelength-specific reflector. Any change of the measured physical parameter, e.g. temperature or strain, leads to a change of the wavelength of the reflected signal. To track this change of wavelength, FBG interrogators are used. Integrated photonic technologies make it possible to use a miniaturized photonic circuit as such an interrogator. In this paper we present the design and measured performance parameters of a manufactured integrated FBG interrogator device.

2 Fiber Bragg Grating Interrogator Design

The design is based on an arrayed waveguide grating (AWG)[2]: light is coupled into the input of the AWG and is collected at the outputs of the AWG by an array of integrated PIN detectors. Depending on the incoming wavelength, the optical signal is directed to different outputs. In a standard AWG the passbands from a single input to the output channels are spaced by the channel spacing Δf_{ch}. Since there is only a small overlap between two adjacent channels, the signal is mainly present at a single output for a particular wavelength. For a wavelength close to the edge of a passband only a small signal is transferred to at most two outputs.

In order to ensure a readout on at least two detectors, we modify the input waveguide by inserting a 1×2 MMI (see figure 1, a) and connecting both outputs (α and β in figure 1) to the Free Propagation Region (FPR) of the AWG with a distance between them corresponding to $2.5 \times \Delta f_{\mathrm{ch}}$. Another way to guarantee readout on two detectors is to place the MMI directly at the FPR (figure 1, b).

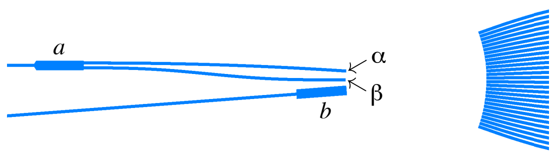

Fig. 1: Design of AWG input waveguides. a—1×2 MMI in the middle, α, β—outputs of the MMI. b—MMI at the end of input.

In this paper we study only the design shown in figure 1, a. Another modification of the AWG design was to reduce the spacing between the output waveguides from the normal value of $1\,\mu$m to $0.4\,\mu$m, thereby increasing the crosstalk between the channels, which is good for this application.

The manufacturing of the device was carried out as a part of Multi-Project Wafer (MPW) run, following a generic integration methodology, using standard building blocks such as waveguides, AWGs, and detectors. No detailed knowledge on the manufacturing process is required by the designer. Moreover, the costs of prototyping are shared among all the users participating in the MPW run.

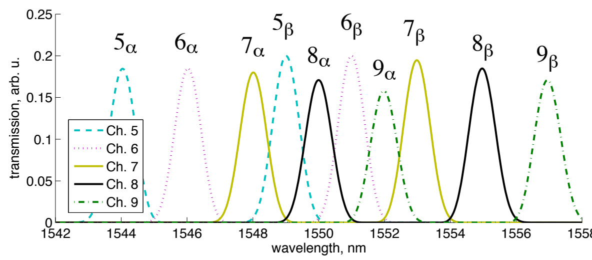

Fig. 2: Simulation of the AWG passbands. Only channels 5–9 are shown.

3 Simulations

The response of the AWG was simulated using an analytical model[3]. The results are shown in figure 2. Each output has two peaks in the passband (α and β), the separation between them $\Delta\lambda_{\alpha,\beta} = 2.5\Delta\lambda_{ch}$ is determined by the distance between inputs α and β in figure 1. Channel spacing is $\Delta\lambda_{ch} = 2\,\text{nm}$.

4 Measurements

The device was fabricated in an InP active-passive MPW carried out at Oclaro Technology Ltd. within the Memphis project. In order to characterize the transmission properties of the device, we couple light from a laser into the chip with a lensed fiber tip and record the photocurrent from reversely biased detectors. The photocurrent for three channels is shown in figure 3. The channel spacing of the fabricated device $\Delta\lambda_{ch} = 2.0 \pm 0.1\,\text{nm}$ and the distance between the peaks $\Delta\lambda_{\alpha,\beta} = 5\,\text{nm}$ correspond to the design values. The passbands are wider than simulated, due to a reduced etch depth in between the closely spaced output waveguides.

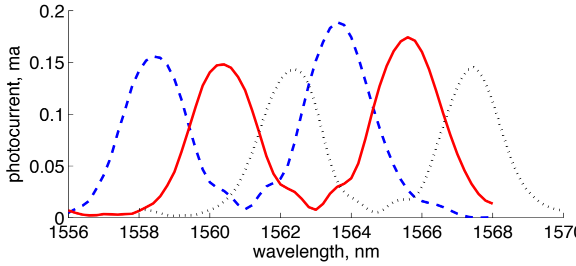

Fig. 3: Measured wavelength response of the AWG outputs.

5 Performance analysis

We calibrate the interrogator before the measurements. First, we record the readouts of each detector $I_i(\lambda)$ using a reference laser signal with a known wavelength. Based on this data we divide the AWG free spectral range (FSR) into wavelength regions and map each of them to a pair of detectors, which have a non-zero readout in this region. The readout signals from the corresponding detectors, I_a and I_b, are combined into $I(\lambda) = (I_a - I_b)/(I_a + I_b)$. To reconstruct the wavelength during measurements we use the readout from the two detectors with the maximum photocurrent, labelled a and b, and their combined response $I(\lambda)$.

The error in the wavelength value can be expressed as $\Delta\lambda = |d\lambda/dI|\,\Delta I = |dI/d\lambda|^{-1}\,\Delta I$. Based on the known detector responses $I_i(\lambda)$ the intensity noise ΔI can be translated into wavelength noise $\Delta\lambda$. In figure 4 the readout $I(\lambda)$ over time is shown for two wavelengths, λ and $\lambda + 5\,\text{pm}$. The change of the readout value due to wavelength change of 5 pm is clearly seen and the standard deviation of the readout corresponds to 0.8 pm.

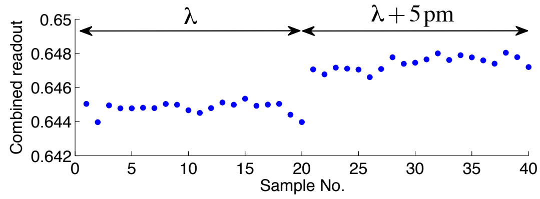

Fig. 4: Measured readout $I(\lambda)$ from a pair of detectors. A step change is due to wavelength change of 5 pm.

The current accuracy limitation is from a slow drift of the readout signal in our measurements due to the fiber-to-chip coupling which causes first order mode excitation. This effect can be reduced by improving the stability, e.g. by packaging the device.

6 Conclusions

We fabricated and characterised an integrated Fiber Bragg Grating interrogator with an FSR of 20 nm, 10 output channels, and a footprint around 1 mm^2, which can be used to track wavelength shifts with a resolution better than 5 pm, which corresponds to 0.025 % of the FSR.

Acknowledgements

This research is carried out in the ProCon Project 11369, supported by the Dutch Technology Foundation STW, which is part of the Netherlands Organization for Scientific Research (NWO), and which is partly funded by the Dutch Ministry of Economic Affairs.

References

[1] Hill, K. O. and Meltz, G. Aug 1997 *Journal of Lightwave Technology* **15(8)**, 1263–1276.
[2] Smit, M. K. and Van Dam, C. Jun 1996 *IEEE Journal of Sel. Topics in Quantum Electronics* **2(2)**, 236–250.
[3] Kleijn, E., Smit, M. K., and Leijtens, X. J. M. Oct 2013 *Journal of Lightwave Technology* **31(20)**, 3309–3314.