SOI photonic wire Bragg gratings for interferometric sensor arrays

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Abstract— **A novel wavelength multiplexing concept for an integrated sensor array based on SOI photonic Mach-Zehnder interferometers is presented. The characteristics of the entire device are discussed and the design of the key element – a photonic wire Bragg grating with SU8 cladding for quasi-TM polarisation – is optimised on the basis of 3D FDTD simulations.**

Integrated optics, Bragg grating, silicon photonics

I. INTRODUCTION

Evanescent wave sensors for the detection of biomolecules employing integrated Mach-Zehnder interferometers (MZI) or micro rings resonators (RR) [1] based on SOI technology have attracted much interest due to their potential for a high level of integration. In order to keep the coupling of light into and out of the sensor chip as simple as possible an efficient multiplexing scheme is required. A single grating coupler input port with subsequent passive power splitting is certainly one option for addressing either multi channels of MZI or RR sensing elements. Passive power splitting inherently decreases the optical power level supplied to each channel and, moreover, prevents the use of a common output port. In the case of MZI array it would, however, offer the possibility to operate at a fixed wavelength [2]. Active optical routing by means of electro- or thermo-optical path switches would in principle be another option [3]. Considering the large area that the switching array would consume and the increased complexity in fabrication and operation this approach does not appear to be the best choice for single-use sensor chips. The third option is wavelength multiplexing employing a wavelength tunable laser source. Efficient SOI based grating couplers can be realized with <1dB coupling loss over a operation wavelength range of 35 nm [4]. In the case RR are used as sensing elements this approach allows allocating several RR provided that their resonance wavelengths are not overlapping. Since the RRs change their resonance wavelength in the course of the sensing event additional spectral distance between the individual channels has been allocated. Instead of employing the RR as sensing elements, we propose to use them as drop ports to route the optical power to MZIs that provide the sensing function. Arrayed waveguide gratings (AWG) could also be used for distributing the different wavelengths to individual channels but they have a much larger foot print than RRs. Regardless whether RRs or AWGs are used as wavelength routing component, the multiplexing of the different wavelength channels after passing through the sensing elements would require the identical spectral characteristic of the components. In particular, in case of RRs, this represents a highly challenging task because even very small deviations in the fabrication process result in a wavelength shift of the resonance characteristic.

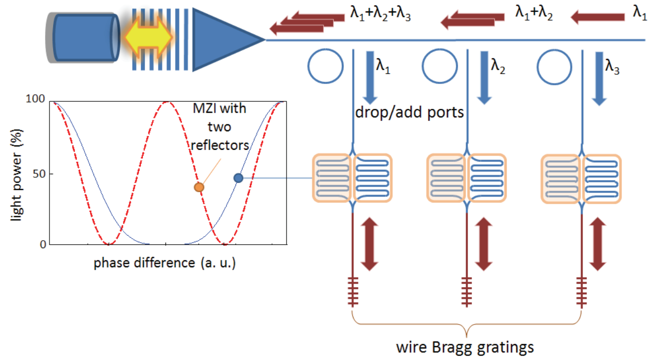

Figure 1. Wavelength multiplexing concept with one ring resonator per channel employing wire Bragg grating reflectors. The inset shows the characeteristics of an MZI with one wire Bragg grating reflector (line) and of an MZI with reflectors in both interferometer arms (dashed).

II. CONCEPT

We propose the use of photonic wire Bragg gratings that reflect the light back to the same RR that dropped the light from the input waveguide in order to eliminate the risk of a wavelength mismatch between drop and add port. This also offers the advantage that light can be coupled into and out of the chip via the same grating, which reduces the alignment effort. A fiber optic circulator is employed to separate input and output light path.

There are two possible implementations of this scheme: a) each MZI arm is terminated by a reflector, and b) the reflector is placed after recombining the light of the two MZI arms as shown in Fig. 1. In the first case, a doubling of the phase response is achieved but an almost identical reflectivity of the two Bragg gratings is required to ensure a high modulation depth of the interference pattern. The output-to-input power ratio of the light after passing forth and back through the MZI can be written as

$$P_{out}/P_{in}= (1+\cos(2\Delta\phi))/2, \qquad (1)$$

where $2\Delta\phi$ represents the accumulated double pass phase difference between the sensing and the reference arm.

In the second case, the output-to-input power ratio can be expressed as

$$P_{out}/P_{in}=(1+\cos(\Delta\phi))^2/4. \quad (2)$$

The quadratic cosine term increases the gradient of the power characteristics as shown in the inset of Fig. 1.

III. SIMULATION RESULTS

The key component in this concept is a photonic wire Bragg grating that reflects the light back to the input port. In a photonic wire Bragg grating the width of a wire waveguide varies periodically. The high degree of freedom with respect to the geometry of the structure provides a good control of the optical characteristics such as reflectance and wavelength dependence. In-depth studies by Gnan et al. [5,6] demonstrated that photonic wire Bragg gratings can fulfil the requirement of a band gap over a wavelength range of several tens of nanometers.

3D FDTD studies so far focused on the quasi-TE polarisation [5], which is less sensitive than the quasi-TM mode of a SOI photonic wire. Moreover, in these studies the maximum wire width in the Bragg region w_2 is kept at the width of the wire w (see Fig. 2).

In our studies, 3D FDTD simulations were carried out for varying geometry parameters (w_1, w_2, Λ) using MEEP [7]. For that purpose, the reflected and transmitted fields of photonic wire Bragg gratings were calculated for structures as depicted in Fig. 2 by placing monitors in front and behind the grating structure. The thickness of the silicon photonic wire was set to 220 nm. Figure 2 shows the transversal electric field component for a CW excitation at a wavelength of 1.57 µm of an optimised structure with an outer Bragg grating width of w_2=650 nm. The low field amplitude at the output on the right side indicates the existence of a band gap.

The wavelength response was analysed with the implemented DFT algorithm for a Gaussian pulse as source. For the structure shown in Fig. 2 more than 80% of the light is reflected over a wavelength range of ~50 nm (see Fig. 3). About 10% of the power is transmitted, whereas the remaining 10% can be attributed to radiation losses.

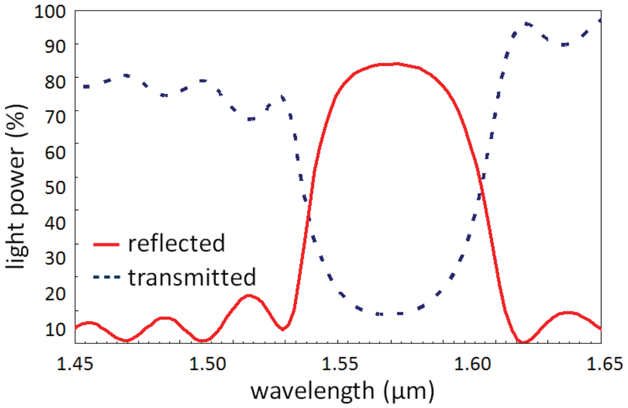

Figure 3. Reflected and transmitted optical power of the simulated photonic wire Bragg grating reflector for quasi-TM polarisation.

IV. SUMMARY

A novel concept for the realization of a wavelength multiplexed MZI sensor array based on SOI technology was presented. The key element - a photonic wire Bragg grating reflector with SU8 cladding for quasi-TM polarisation - was designed employing 3D FDTD simulations.

ACKNOWLEDGMENT

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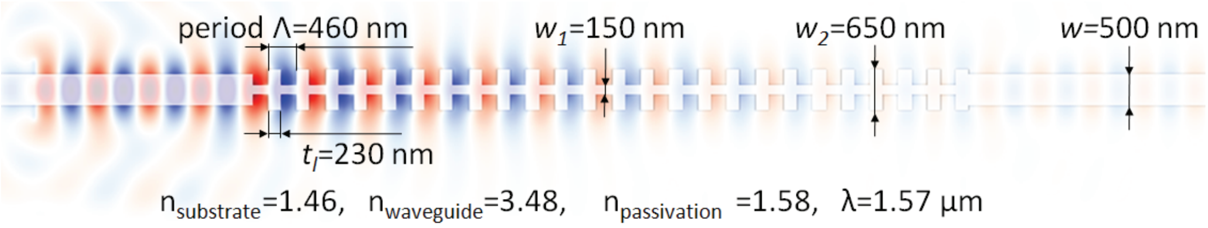

Figure 2. 3D FDTD simulation result of a 220 nm thick photonic wire Bragg grating with quasi-TM polarized CW excitation at λ=1.57µm. The transversal electric field component is shown.