Customized spectral filters using cladding-modulated Bragg gratings in silicon waveguides

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Abstract. Waveguide Bragg gratings are expected to play an important role in diverse applications of photonic integrated circuits. Here, we present our latest progress in implementing Bragg filters with a customized spectral response in the silicon-on-insulator platform. Our filter comprises a silicon waveguide with an array of Bragg segments placed aside. The waveguide core is designed to have a reduced mode confinement, which enables an accurate control of the grating strength via modulation of the Bragg segment separation distance and allows for minimum feature sizes compatible with deep-UV lithography (>100 nm). Our design strategy is experimentally validated by demonstrating a filter with 20 non-uniformly spaced notches in the transmittance spectrum.

1. Introduction

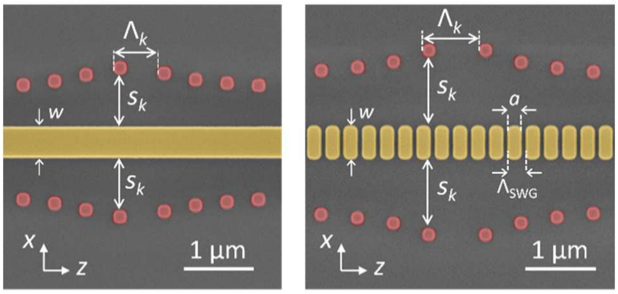
With the advantages of well-established CMOS manufacturing processes, silicon photonics has settled as a leading technology to implement low-cost small-footprint photonic integrated circuits (PICs) [1]. Among typical building blocks in PICs, waveguide spectral filters are important components demanded in many applications [2, 3].

The development of waveguide Bragg filters has attracted significant attention owing to their high spectral flexibility and selectivity. Typically, a waveguide Bragg grating is formed by implementing a periodic modulation in the waveguide sidewalls [4]. The filter bandwidth is mainly determined by the strength of the perturbation. However, in the silicon-on-insulator (SOI) platform, the filter performance becomes very sensitive to small variations of the corrugation width due to the high index contrast between silicon and silicon dioxide, which hinders the practical implementation of the filters.

An alternative to implementing Bragg filters in SOI is to place the periodic perturbation near the waveguide core, in the lateral cladding region [5]. By designing the waveguide core to have a reduced mode confinement, it is possible to control the filter bandwidth in a wide range (from a few hundreds of pm to several nm) while keeping the structural dimensions compatible with standard deep-UV lithography [6]. More recently, this geometry has been used to design other optical components such as delay lines [7] and millimetre-long optical antennas [8]. In this talk, we present our latest results on the development of Bragg filters with arbitrary spectral shape in the SOI platform [9].

2. Geometry and filter design

Figure 1 shows the proposed Bragg filter geometries. Our structure comprises a waveguide core (yellow) and an array of silicon segments at both sides forming the Bragg grating (red). The key strategy of our design is to delocalize the waveguide mode, thereby enabling a precise control of the grating strength (and the corresponding spectral shape) via modulation of the lateral separation s_k, where k is the period number. We have studied two filter implementations: (i) a homogeneous Si-wire core with reduced width [Fig. 1(a)] and (ii) an SWG metamaterial core with reduced equivalent index [Fig. 1(b)]. Both structures are designed



(a) (b)

Fig. 1. Bragg grating geometries of filters with a customized spectral response, with: (a) Si-wire waveguide core and (b) SWG waveguide core.

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to operate with TM light, which has a lower mode confinement compared to TE light.

The overall design strategy can be summarized in the following steps:

(1) The dimensions of the waveguide core and the size of the lateral segments are chosen. The waveguide core is designed to increase mode delocalization. In the Si-wire design, this is done by controlling the waveguide width w. In the SWG design, which can achieve a higher mode delocalization, we also adjust the duty cycle $\mathrm{DC} = a/\Lambda_{\mathrm{SWG}}$ while the SWG period Λ_{SWG} is kept small enough to suppress diffraction and reflection. The dimensions of the lateral segments are chosen to be large enough to meet minimum feature size constraints.

(2) Taking the target reflection spectrum as an input specification, we use the layer-peeling algorithm (LPA) [10]. This method provides the required modulation profile of the grating in terms of the complex, local reflection coefficients ρ_k to be synthesized at each Bragg period.

(3) Finally, the obtained local reflection coefficients ρ_k are mapped onto the key filter geometrical parameters, s_k and Λ_k. The varying separation distance s_k is used to adjust the grating strength along the filter length. The Bragg period modulation Λ_k allows to achieve spectral responses requiring a complex impulse response, as well as to correct for small deviations of the effective index due to the modulation of the separation parameter s_k.

3. Experimental results

As a proof of concept of the proposed Bragg filter topologies and design methodology, we have fabricated and experimentally evaluated a filter with a transmission spectrum comprising 20 non-uniformly spaced notches near a wavelength of 1550 nm, with a 3-dB linewidth of about 400 pm. Filters with such spectral features are of relevant interest to perform ground-based astronomical observations, for the elimination of undesired spectral lines at specific wavelengths produced by OH emissions in the Earth’s atmosphere. To our knowledge, this type of filters has been previously demonstrated for a low-index contrast silicon-nitride platform [3], but not in SOI.

Our Bragg filter has been designed for the two different geometries, Si-wire core and SWG core, by following the methodology described in section 2. Both designs are compatible with deep-UV lithography, which typically requires a minimum feature size on the order of 100 nm. The total length is about 3.6 mm for the Si-wire filter and about 6.4 mm for the SWG filter. This length difference is due to the different group indices of each waveguide. Both filters have been fabricated in an SOI wafer with a 220-nm-thick Si layer and a 2-μm-thick buried oxide (BOX). Figure 2 shows the measured transmission spectra normalized by the insertion losses of the unperturbed waveguide core. All 20 notches of the target spectrum are clearly observed and the spacing between them is synthesized with good accuracy, thus confirming the validity of our design strategy.

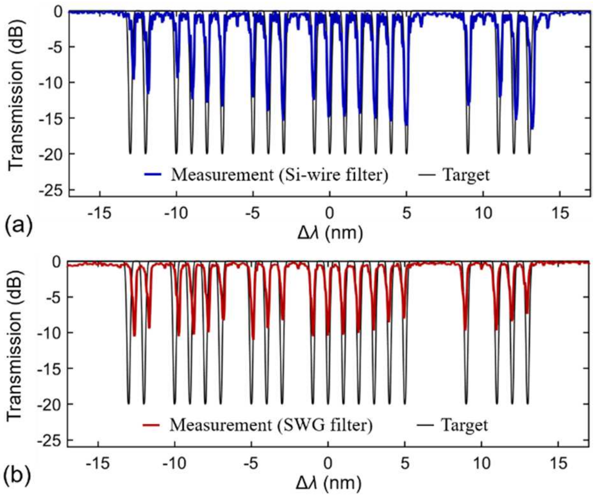

Fig. 2. Experimental results of the designed astrophotonic filters: (a) Si-wire-based filter and (b) SWG-based filter. The original target spectrum is shown in black.

4. Conclusions

We have proposed and investigated a novel geometry to implement Bragg filters with arbitrary spectral response in SOI. Our design approach is advantageous to achieve flexible filter designs while keeping structural dimensions large enough for ease of fabrication. The proposed strategy has been experimentally tested by demonstrating a complex filter with 20 non-uniformly spaced notches in the transmittance spectral response.

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