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Thermo-optically Tunable DBR Resonator with Ultra-broad Rejection Band for Silicon Photonic Applications

Student paper

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A design of compact DBR resonators (~ 40 μm-long) integrated in SOI rib waveguide structure has been demonstrated, exhibiting a resonance bandwidth as low as 40 pm (λ_r ~ 1550 nm) with an extinction of ~ 35 dB over a rejection band of ~ 60 nm. The resonance peak has been thermo-optically tuned over a wide range of wavelength at a rate of ~ 95 pm/mW. The device is shown to be effective in ASE noise suppression of an amplified pump laser.
Keywords: *Silicon Photonics, DBR Resonators, Tunable Filters, Noise Suppression*

INTRODUCTION

Resonator devices find many applications in photonic integrated circuits (PICs). For example, microring resonators (MRRs) in all-pass and add-drop configurations are widely used in CMOS compatible silicon photonics technologies for filtering, switching, modulation, sensing and nonlinear signal processing [1]. Distributed Bragg reflector (DBR) based resonators can be a good alternative to overcome certain limitations of an MRR. To be specific, a DBR resonator can be designed to oscillate in a single longitudinal mode. Moreover, a suitably designed DBR resonator can potentially offer a broad sideband rejection, enabling noise suppression around the resonant wavelength of interest and it can be widely tuned via thermo-optic effect and plasma dispersion effect. Recently, some DBR based resonators have been demonstrated for various applications such as sensing, wavelength add-drop multiplexing, modulation and microwave signal processing [2] as well as quantum photonic applications [3]. The rejection bandwidth around the resonance wavelength of a singly resonant DBR has been reported to be ~ 15 nm for a device length of > 150 μm [4]. In this paper, we demonstrate a compact design of DBR cavity (device length of ~ 40 μm), resonating around λ ~ 1550 nm within an ultra-broad rejection band (~ 60 nm). We have also shown experimentally the thermo-optic detuning characteristics of resonance wavelength with a slab-integrated metal microheater and suppression of ASE noise associated with an amplified pump laser which is tuned to operate at resonance.

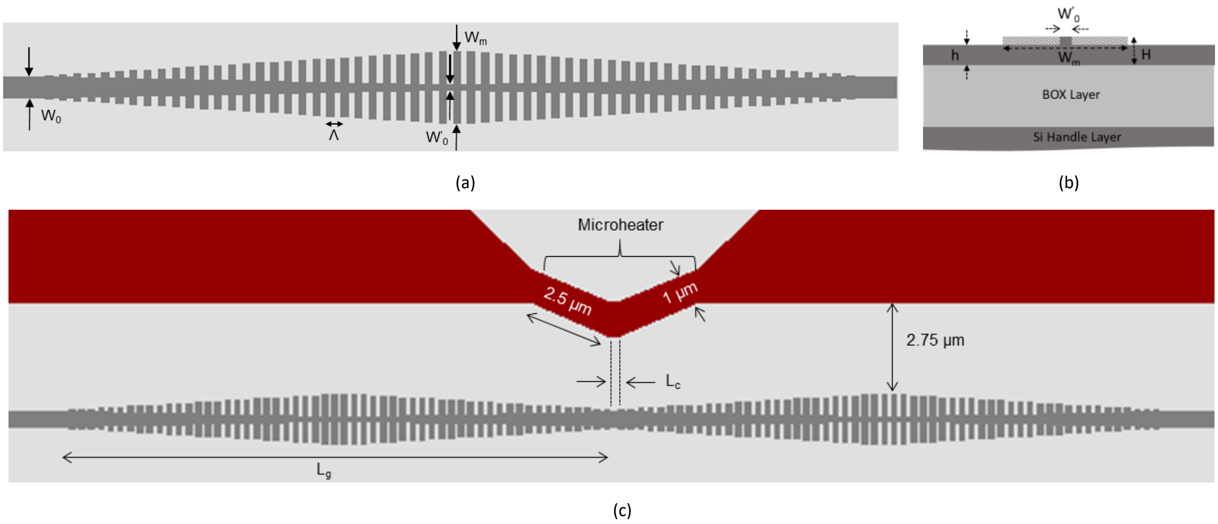


Fig. 1. Schematics of the proposed DBR resonator along with design variables and parameters: (a) top-view of DBR structure integrated into a single-mode rib waveguide used as cavity mirrors, (b) cross-section view of the DBR at the center, and (c) top-view of the proposed device integrated with Ti microheater. H - device layer thickness (220 nm), h - rib height (150 nm), W_0 - input/output waveguide width for fundamental TE mode guidance (~ 500 nm), W_m - maximum width of the DBR, W'_0 - minimum width of the tapered waveguide, Λ - grating period, L_g - length of the DBR mirror, L_c - length of the cavity.

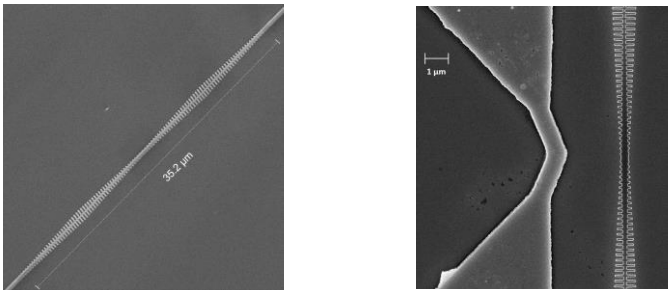
DESIGN AND FABRICATION

Based on our earlier reported experimental results and theoretical simulations, a compact design of single-stage DBR cavity has been optimized. The design scheme of the device has been shown in Fig. 1 along with design variables and parameters. The parameter values of the DBR structure have been optimized following the design rule in Ref. [5]. The values of L_g, W_m, W'_0 and the grating periodicity Λ (50 % duty cycle) are carefully chosen to obtain high reflectivity over a broad wavelength range around a Bragg wavelength of $\lambda_B \sim 1550$ nm. Higher reflectivity of the DBRs results into higher Q of the cavity, but at the cost of transmission loss at the resonance. Thus, for given values of W_m, W'_0 and Λ, we can simply control the L_g for a desired reflectivity and L_c for desired number of resonances within the stopband. For experimental demonstration, we have fabricated six different devices (D1 – D6) using two different DBR mirror lengths and three different cavity lengths as given in Table 1. Other design parameters were kept common for all the devices (W_m= 1.5 µm, W'_0 = 100 nm and Λ = 292 nm).

Table 1. Values of L_g and L_c used for device fabrication

Device	D1	D2	D3	D4	D5	D6
L_g (µm)	17.5	20.5	17.5	20.5	17.5	20.5
L_c (µm)	8		6		0.146	
Calculated no. of resonances	3		2		1	

A Ti-microheater (see Fig. 1) was integrated at the center of the DBR cavity for thermo-optic tuning of the resonances. The input/output waveguides were designed to support only the fundamental TE-mode (H = 220 nm, h = 150 nm and W_0= 450 nm). For characterization, the input/output waveguides were terminated with standard grating couplers. The length between input/output grating couplers has been set to ∼ 3 mm for all the devices. To obtain normalized transmission characteristics, a reference waveguide (same as input/output waveguide parameters) was also fabricated with a same length of ∼ 3 mm. The devices were fabricated using our in-house fabrication facilities and the details can be found elsewhere [6]. Fig. 2 shows the SEM images of a fabricated device of cavity length 0.146 µm (D5) and slab-integrated microheater.



(a) (b)

Fig. 2. SEM images of a fabricated device (D5): (a) single mode DBR resonator with waveguide DBR mirrors of cavity length 146 nm (45° tilted) and (b) zoomed cavity region with slab-integrated metal microheater.

EXPERIMENTAL RESULTS

The fabricated devices were characterized using a high resolution (0.8 pm) and high sensitivity (-75 dBm) optical source spectrum analyzer (APEX 2043B). The thermo-optic tuning of the cavity was achieved by biasing the microheaters using a Keithley source meter (model no. 2420). The normalized transmission characteristics of the devices with cavity lengths 8 µm (D1 and D2), 6 µm (D3 and D4) and 0.146 µm (D5 and D6) are given in Fig. 3(a), 3(b) and 3(c), respectively. As predicted, they are found to be triply-, doubly- and singly-resonant, respectively. It is observed from the transmission characteristics that the rejection bandwidth and extinction are found to be DBR length independent for a given cavity length. However, the Q values (transmission peaks) of the resonances are observed to be higher (lower) for the longer DBRs, which is in accordance with our theoretical prediction. The DBR rejection bandwidth is measured to be about ∼ 60 nm for all the fabricated devices (D1-D6) i.e., nearly same for both the DBR lengths as predicted by the simulation results. The number of resonances are found to be 3, 2 and 1 for cavity lengths of 8 µm, 6 µm and 0.146 µm which are also consistent with the theory. In case of multimode resonators, the free spectral range (FSR) between resonances for longer DBRs is found to be slightly lower than that of shorter DBRs. This is attributed to the longer effective cavity length for the longer DBRs: the coupling strength between forward and backward propagating waves expected to be lower in case of longer DBR (as the values of both W_m and W'_0 are same for both the DBR lengths). The Q value of a singly resonant cavity with L_g = 17.5 µm (20.5 µm) is found to be ∼ 39,000 (17,000) and corresponding out-of-band rejection is ∼ 35 dB (∼ 40 dB).

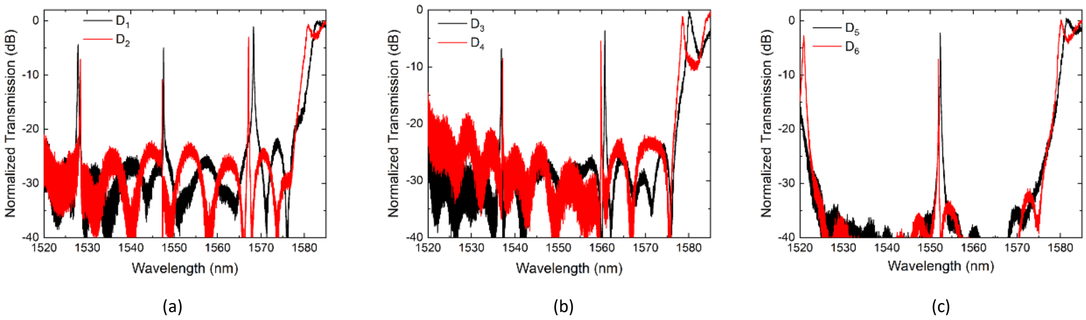


Fig. 3. Transmission spectra of fabricated devices normalized with respect to the reference waveguides. DBR resonators with cavity length of (a) 8 µm, (b) 6 µm and (c) 0.146 µm (inset the zoomed resonance peak of D5).

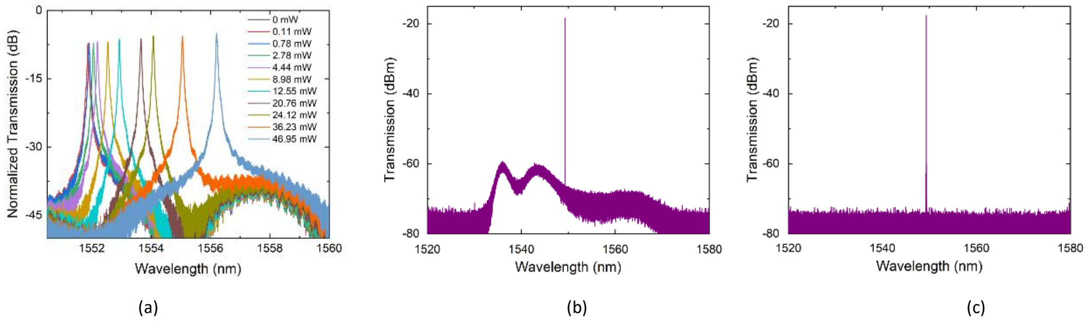


Fig. 4. Application use cases for a singly resonant DBR cavity (D6): Thermo-optic detuning of resonant wavelength for different heater powers (a), transmission of a pre-amplified pump laser through a reference waveguide (b) and ASE noise suppressed pump laser through the DBR cavity (c).

Fig. 4 shows experimental demonstrations of two application use cases of a singly resonant DBR cavity (D6). The first application is the wide range tuning of resonant wavelength using a microheater as shown in Fig. 4 (a). The tuning slope is obtained as $\sim$ 95 pm/mW, which could be improved by introducing trenches through slab as well as BOX layer. However, the slab integrated microheater design (without trenches) can facilitate a faster switching response as reported in Ref. [6]. We also observed that the switching response for our fabricated devices is relatively faster ($<$ 3 µs). We have also shown experimentally that the fabricated singly resonant devices are efficient to filter noisy pump laser source, which is essential for quantum photonic applications. Fig. 4(b) shows a pump laser associated with ASE noise transmitted through a reference waveguide, whereas Fig. 4(c) shows the filtered pump laser (with noise suppressed to the detection limit of the optical spectrum analyzer) when passed through the device.

CONCLUSION

In summary, we have reported the design and demonstration of a compact DBR cavity which can be potentially useful for various silicon photonic applications such as tunable narrow bandpass filters, faster thermo-optic switching and high-speed electro-optic modulators (by integrating pn-junction across the cavity). The experimentally obtained figure-of-merits can be improved further by reducing waveguide losses and by integrating efficient active elements.

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References

[1] Wim Bogaerts et al. "*Silicon microring resonators*", Laser & Photonics Reviews, vol. 6, no 1, pp. 47-73, 2012
[2] W. Zhang et al., *"A fully reconfigurable waveguide Bragg grating for programmable photonic signal processing,"* Nature communications, vol. 9, no. 1, pp. 1-9, April 2018
[3] Shengjie Xie et al., *"On-chip Fabry–Perot Bragg grating cavity enhanced four-wave mixing,"* ACS Photonics, vol. 7, no. 4, pp. 1009-1015, March 2020
[4] Fabio Falconi et al., "*Widely tunable silicon photonics narrow-linewidth passband filter based on phase-shifted waveguide Bragg grating*", 2018 International Topical Meeting on Microwave Photonics (MWP), IEEE, pp. 1-4, 2018
[5] Sumi R et al., *"Integrated optical linear edge filters using apodized sub-wavelength grating waveguides in SOI,"* IEEE Photonics Technology Letters, vol. 31, no. 17, pp. 1449-1452, September 2019
[6] Ramesh K. Gupta et al., "*Performance analysis of metal-microheater integrated silicon waveguide phase-shifters*," OSA Continuum, vol.1, no. 2, pp. 703-714, 2018