Reconfigurable Multi-Channel Second-Order Silicon Microring-Resonator Filterbanks for on-Chip WDM Systems

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Abstract–**We report a precisely tuned and reconfigurable wide-band twenty-channel second-order dual filterbank, with tunable channel spacing and 20 GHz single-channel bandwidth, fabricated on a silicon-on-insulator (SOI) platform. The crosstalk between channels is <35 dB, and the thermo-optic tuning efficiency is about 28 μW/GHz/ring. This filterbank is suitable for on-chip wavelength-division-multiplexing (WDM) applications, and has the largest-to-date reported number of channels built on an SOI platform.**

I. INTRODUCTION

Multi-channel high-order microring resonators are essential components for low-cost highly integrated wavelength-division-multiplexing (WDM) systems and photonic integrated circuits. At wavelengths of 1.5 μm, silicon-on-insulator (SOI) platforms allow low-loss single-mode propagation in submicron structures and micron-sized bending radii [1]. The resonant frequency of a silicon microring resonator is extremely sensitive to fabrication errors. Therefore, in addition to high dimensional control and low sidewall roughness, post-fabrication trimming and tuning is normally required to achieve desired device parameters. The latter can effectively be achieved by thermal tuning, due to the large thermo-optic coefficient of silicon [2,3]. In silicon, multi-channel single-ring filters have been demonstrated [4], as well as second-order racetrack resonators [5] and tunable single-channel high-order filters [6]. Previously, we reported progress in fabricating twenty-channel second-order dual filterbanks, both in silicon and in silicon and in silicon-rich silicon nitride [7]. In this work, we report a similar twenty-channel second-order dual filterbank, along with the recently demonstrated precise tuning of eleven consecutive channels with reconfigurable channel spacing [8]. Each channel has a bandwidth of 20 GHz, and the channel-spacing is set to 124 GHz, resulting in less than -35 dB crosstalk between channels. The filterbank is intended as a multiplexer for a wavelength-multiplexed photonic analog-to-digital converter [9].

II. DESIGN AND FABRICATION

The filterbank was fabricated on an SOI wafer with a 3 μm-thick oxide undercladding, and a 105 nm silicon layer (thinned from 220 nm), similar to our previous work [6,10]. An optical micrograph of the fabricated device before the fabrication of the microheaters is shown in Fig. 1. The cross section of the material stack is illustrated in Fig. 2.

Fig. 1. Optical micrograph of the twenty-channel dual filterbank fabricated in silicon, before the fabrication of the layer with titanium microheaters that are used to individually tune the resonant frequency of each microring resonator.

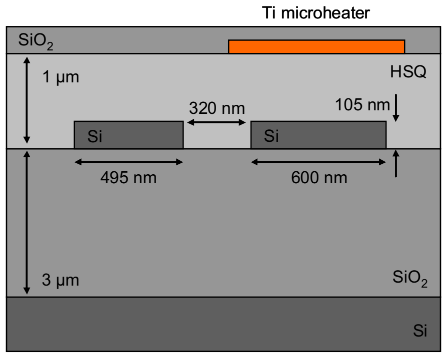

Fig. 2. Illustration of the cross section of the fabricated filterbank, showing the different material layers.

The filterbank was designed to have a channel-bandwidth of 20 GHz and >30 dB extinction at ±80 GHz from the channel center, with a free spectral range of about 2 THz. The silicon waveguide dimensions were optimized to reduce sensitivity to sidewall roughness and dimensional variations in width [11], with cross-sections of 600×105 nm (ring waveguides) and 495×105 nm (bus waveguides). The main dimensions are shown in Fig. 3. The device was coated with a 1 µm-thick hydrogen silsesquioxane (HSQ) layer [12], and titanium microheaters were fabricated on top of the HSQ for thermal tuning of the resonant frequency of each individual ring. Typical heater-resistance values were between 1 and 2 kΩ. Fig. 4 shows an optical micrograph of two adjacent channels, after the fabrication of the titanium microheaters on top of the microrings.

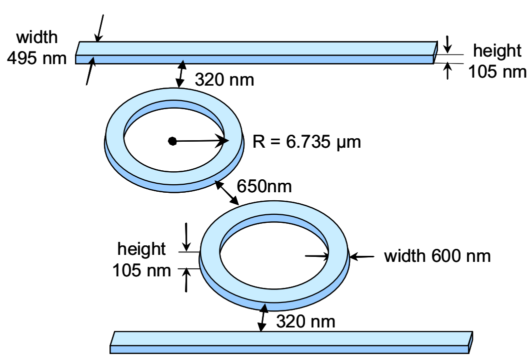

Fig. 3. Main dimensions of the second-order filter channel. The resonant frequency is defined by changing the ring radius and waveguide width of each microring resonator.

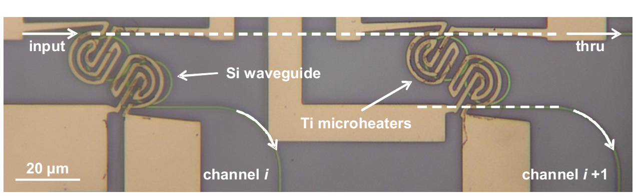

Fig. 4. Optical micrograph of two adjacent channels, with the titanium microheaters on top for thermo-optic tuning.

III. Experimental Results

The individual rings show intrinsic quality factors of ~250k and ~130k, without and with the titanium heaters. This corresponds to propagation losses of about 2-2.5 dB/cm and 4.5 dB/cm, respectively. Due to limitations caused by interconnectivity of the silicon chip and the electronics control circuitry, only a total of eleven channels (out of the twenty) of one of the filterbanks were demonstrated. Fig. 6(a) shows the drop-port responses of those eleven channels before any thermal tuning, overlaid with a grid showing the targeted 124 GHz-spacing and 20 GHz-bandwidth. Most of the channels are misaligned, with up to 150 GHz frequency mismatch between the two rings of a channel, and the channel spacing is non-uniform. Both rings of each channel are first individually tuned in order to compensate for the frequency mismatch, and then the entire channel is tuned to its targeted channel frequency. Fig. 5 presents the thru and drop responses of one of the tuned channels, indicating a bandwidth of 20 GHz and more than the required 30 dB extinction of the channel at ±80 GHz. The relative magnitudes between the drop-port and thru-port responses off all channels indicate a drop loss of about 1.5-2.5 dB.

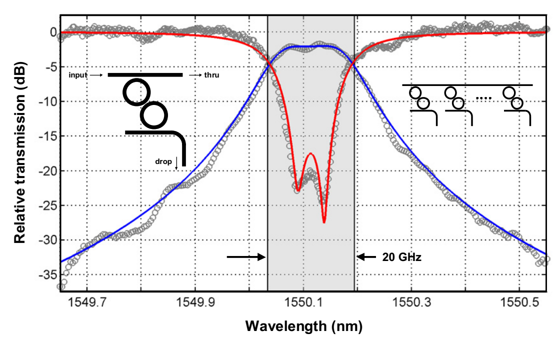

Fig. 5. Drop and thru response of a single channel of the filterbank. The bandwidth is 20 GHz and the extinction at ±80 GHz from the center frequency is over 30 dB.

Fine tuning every channel of the filterbank returns a well-defined frequency grid, spaced by the pre-defined interval of 124 GHz. The eleven drop-port responses are shown in Fig. 6(b). All channels are now sharply defined with 20 GHz single-channel bandwidths, channel-spacing of 124 GHz, and >35 dB extinction at adjacent channels. The measured tuning efficiency is ~28 µW/GHz/ring. The average power per channel required for complete tuning of the eleven channels at the targeted 124 GHz-spaced grid was about 16 mW, with a total power dissipated on the chip of about 180 mW. In order to achieve this result, all 22 microrings (of the eleven channels) were precisely tuned using a multi-channel DAC board which controlled the power of each ring-heater individually.

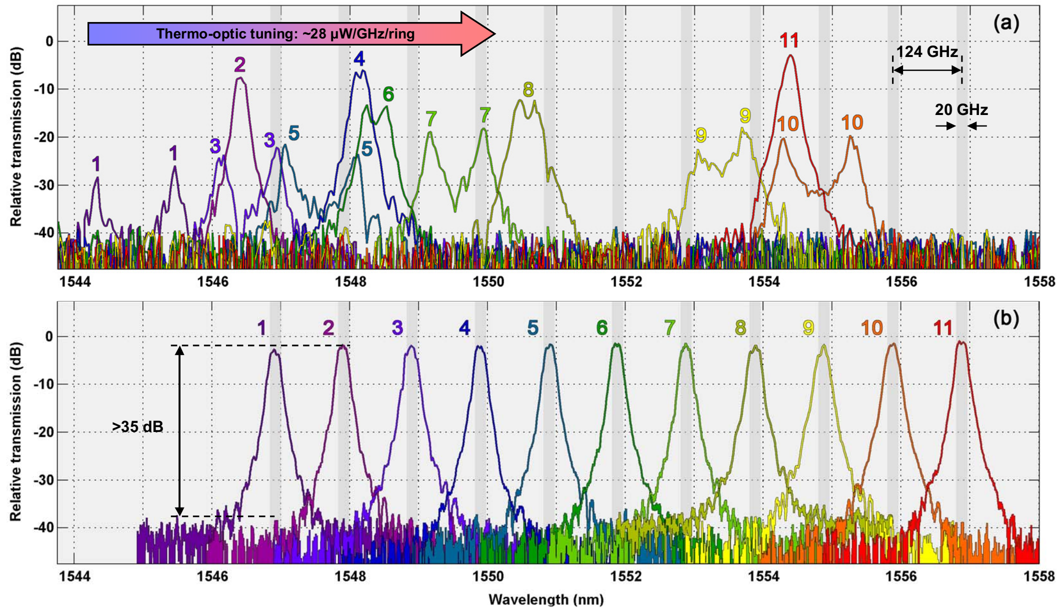

Fig. 6. Drop-port responses of eleven adjacent channels of the fabricated twenty-channel second-order dual filterbank (a) before and (b) after thermo-optic tuning of the resonant frequencies of the individual microring resonators. The single-channel bandwidth is measured to be 20 GHz, the channel spacing was set to 124 GHz, and the channel crosstalk is less than 35 dB.

Up to 5 channels were tuned simultaneously, limited only by the number of control ports available from our DAC. Thermal crosstalk between adjacent rings and adjacent channels is low and can easily be compensated for.

IV. Conclusion

We presented a twenty-channel second-order dual filterbank fabricated in a silicon-on-insulator platform, and demonstrated eleven precisely tuned and reconfigurable channels. The filterbank has a tunable channel spacing which was set to 124 GHz, and single-channel bandwidths of about 20 GHz. The tuning efficiency was measured to be ~28 μW/GHz/ring, and the average power dissipated on the chip was estimated to be around 16 mW per channel for the targeted channel spacing. This device has potential in applications in on-chip WDM systems, or as a multiplexer in optically sampled analog-to-digital converters.

Acknowledgments

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