Vertically-coupled Cascaded Microdisk Resonators in Silicon

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Abstract: *Cascaded microcavities on vertically integrated layers of silicon are created using the SIMOX 3-D Sculpting process. Sub-surface microresonators and waveguide are vertically coupled, through an oxide layer, to similar structures situated on a surface silicon layer. Fabricated two stage filters show superior band-pass characteristics in comparison to a single stage device.*
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1. Introduction

Micro-resonant optical cavities have applications ranging from add-drop WDM multiplexers, optical filters to microdisk lasers. Their compactness facilitates the dense integration of these devices on a chip [1-4]. It has been shown that cascaded resonator structures may be utilized to improve the filter characteristics of devices employing microcavities, including the flatness of the pass-band, the sharpness of the roll-off from the pass-band to the stop-band and the suppression of adjacent channel cross-talk [5-6].

Vertical integration of optical devices offer the inherent advantage of achieving densely integrated 3-D optical structures. Also, they offer more precise control over the critical dimension of the structure, than laterally patterned structures, where the limits are set by the photolithography. This paper reports the first realization of cascaded microcavities based on vertically coupled microdisk resonators in Silicon. Devices were fabricated using the SIMOX 3-D Sculpting process [7-9].

2. SIMOX 3-D Sculpting

SIMOX 3-D sculpting has been proposed and developed as a mean to fabricate complex nanophotonic devices on silicon [7-9]. The process involves the implantation of Oxygen ions into a Silicon substrate, followed by a high temperature (around 1300ºC) anneal of the substrate in order to cure the implantation damage. Figure 1 depicts the process flow of the fabrication of vertically integrated structures using the SIMOX process. Implantation of oxygen ions is performed on an SOI substrate that has been patterned with thermally grown oxide. The thickness of the oxide mask is chosen suitably to decelerate the Oxygen ions that penetrate into the area underneath the mask. The angled side wall of the buried waveguiding structures formed after the high temperature anneal arises due to the lateral straggle of the implanted oxygen ions. After the anneal, the devices may be defined on the top layer using conventional lithography and etching process, as shown in figure 1.
This approach has been utilized to fabricate devices that consist of two microdisk resonators vertically coupled to

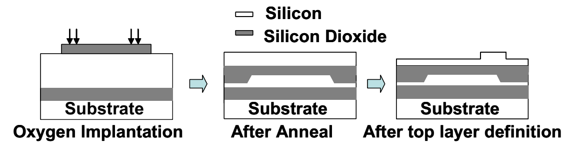

Fig.1 SIMOX 3-D sculpting process flow.

each other, through the oxide layer formed after the implantation and subsequent anneal. The resonators themselves are coupled to bus waveguides that act as the input and output ports of the device. Figure 2 represents a schematic of the device showing the vertically coupled microresonators and the bus waveguides, with the arrows indicating the direction of flow of light through these devices. It may be emphasized here that, we have

Fig.2 The 3-D cascaded device structure.

realized waveguides as well as microdisk structures on both layers of Silicon, coupled vertically through an intervening layer of SiO_2. These devices distinctly demonstrate the capability of the SIMOX 3-D sculpting to engineer 3-D structures in Silicon. In this work, the SOI substrate was implanted at 150 KeV, with an

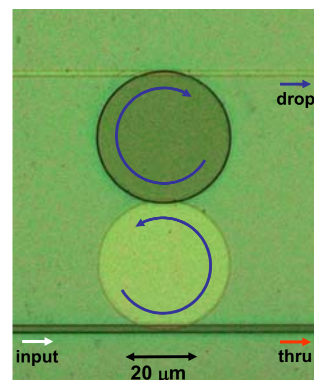

Fig.3 Top view of the fabricated device.

oxygen ion dose of $5\times10^{17}/cm^2$, which results in the formation of a buried oxide layer of ~100 nm thick, separating two layers of Silicon of thickness ~ 270 nm. The devices on the top Silicon layer were defined by thermal oxidation, using a patterned Silicon Nitride layer as the mask for the oxidation process. Figure 3 shows the top view of the fabricated two-stage device with cascaded microdisks of radius 20 µm, coupled to bus waveguides of width 2 µm. When optical energy is introduced to the input port of the device, resonant wavelengths are transmitted to the drop port, after traversing through the cascaded disk structure.

3. Experimental Results

The drop port responses of the filter were characterized using an Amplified Spontaneous Emission (ASE) source, by launching optical power at the input port and collecting the optical spectra at the drop port using a spectrum analyzer, the results of which are shown in figure 4. Fabricated disks show a free spectral range of around 5.7 nm, with maximum extinction ratios ~ 12 dB.

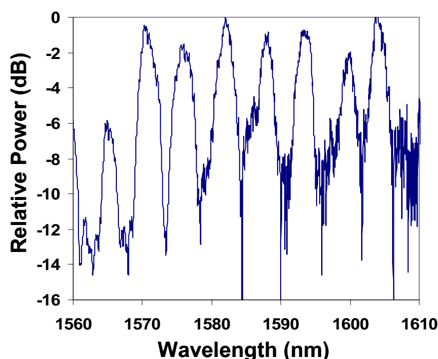

Fig.4 Drop-port spectrum of the cascaded device.

The spectrum displayed in figure 4 is corrected for the spectral shape of the ASE source. A comparison of the performance of the two-stage device to that of a single stage device, as shown in figure 5, illustrate the superior characteristics of the two-stage resonator in terms of its steeper roll-off, better out-of-band rejection and flatter pass-band. Note that the frequency scale in this figure is normalized to the 3-dB bandwidths of the individual filters. The shape factor, which is a measure of the flatness of the passband [6], defined as the ratio of the -1-dB bandwidth to the -10-dB bandwidth, is 0.47 for the two-stage device, compared to a value of 0.22 for the single stage device. Also, at twice the value of the 3-dB bandwidth, the two-stage device shows 4-dB improvement in the out-of-band signal rejection over the single stage device. It may be noted that the single stage device used for the purpose of this comparison is fabricated on the same chip as that of the two-stage device.

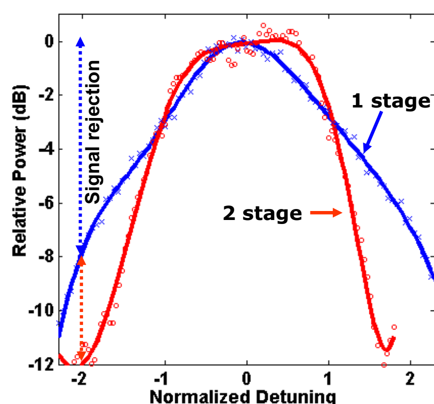

Fig.5 Comparison of 2-stage and 1-stage filter characteristics.

4. Conclusions

Waveguide-coupled, cascaded microcavities on vertically integrated layers of silicon are synthesized utilizing the process of SIMOX 3-D sculpting. These devices distinctly demonstrate the capability of SIMOX 3-D sculpting to engineer monolithically integrated 3-D nanophotonic structures in silicon. Fabricated two-stage devices show superior performance characteristics in comparison to a single stage device.

5. Acknowledgement

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