

# Compact full C-band tunable filters for 50 GHz channel spacing based on high order micro-ring resonators

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**Abstract:** Full C-band tunable filters for 50 GHz channel spacings based on 5<sup>th</sup> order micro-ring resonator filters are described. These filters are tunable over 40 nm and can accommodate one hundred 50 GHz channels.

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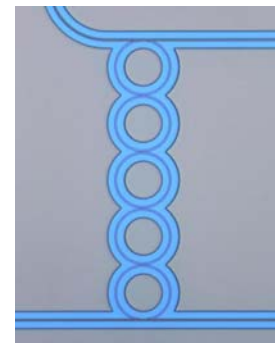
**OCIS codes:** (130.0130) Integrated Optics; (130.0250) Components

## 1. Introduction

Tunable bandpass filters find important applications in optical power and performance monitoring, broadcast and select networks, add/drop multiplexing, and filter sparing, to name a few. High order micro-ring resonator filters (MRFs) [1,2,3] yield flat top response similar to fixed frequency thin film filters (TFFs). Unlike TFFs, MRFs can be more easily tuned, since all their cavities can be simultaneously controlled. Further, micro-rings have four ports, and can be configured into Vernier architectures for wideband tuning. In this paper we report a high order MRFs that are combined in a Vernier architecture to yield tunable bandpass filters operating over a 40 nm wavelength span, and with performance suitable for commercial applications.

## 2. Micro-ring resonator tunable filter

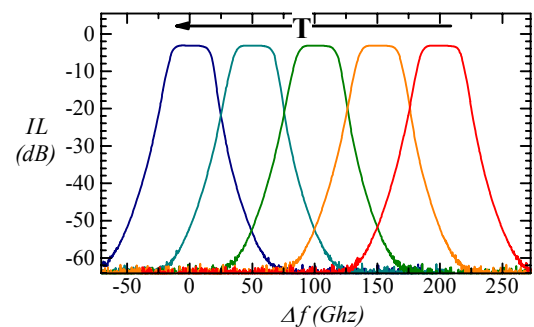
Micro-rings have been suggested for add/drop filter applications [4,5]. In particular, low loss high-order rings having from two to eleven cavities suitable for commercial applications have been demonstrated [6]. Figure 1 shows a photograph of a 5<sup>th</sup> order add/drop filter comprised of five mutually coupled rings. The rings have a radius of 42  $\mu\text{m}$ . The rings all lie in the same plane and are laterally coupled to their neighbors. The outer rings are vertically coupled to bus waveguides which form the input and output connections. The vertical separation between the bus and rings varies from 200 nm to over 1000 nm depending on the desired filter line width. The lateral gap between rings likewise varies from 500 nm to 1400 nm depending on the application. The rings are fabricated from low loss Hydex<sup>TM</sup> [7] with a core to clad index contrast of 17%. The ring and bus waveguides have nearly square cross sections with dimensions of 1.5  $\mu\text{m}$  x 1.5  $\mu\text{m}$ .



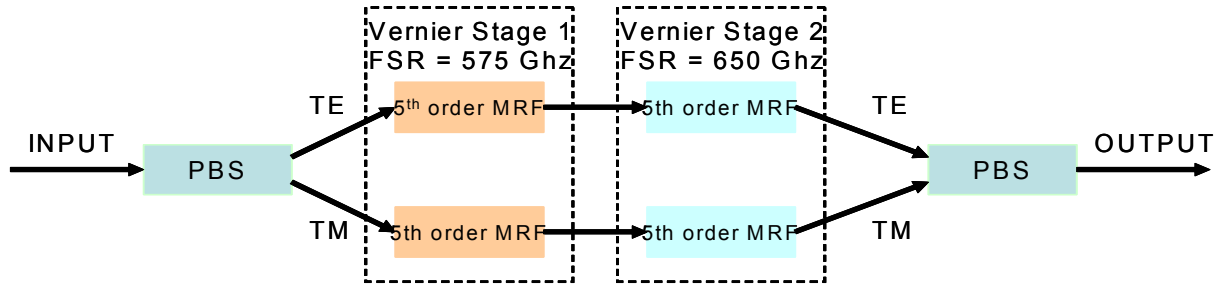
**Figure 0** Layout of the 5<sup>th</sup> order micro-ring resonator filter.

The measured drop response of a typical 5<sup>th</sup> order filter is shown in Figure 2. The drop loss through the 5<sup>th</sup> order filter is less than 1 dB, while the bypass loss is negligible. The unloaded Qs are in the hundreds of thousands. These filters are thermally tuned. The thermo-optic coefficient is approximately  $1.5 \times 10^{-5} / ^\circ\text{C}$ . Note that because all rings reside in the same layer, a thin film heater placed on the surface tunes all rings simultaneously, giving rise to little temperature induced distortion.

Vernier architectures, where two periodic filters having slightly different free spectral ranges (FSRs) are cascaded back to back, are particularly useful in achieving wide spectral tuning. Figure 3 schematically shows the micro-ring resonator tunable filter cascade in a Vernier configuration. The filter design utilizes polarization diversity where integrated polarization beam splitters (PBS) are deployed at the input and output ends of the device to first separate



**Figure 0** Measured response for a 5<sup>th</sup> order micro-ring resonator filter shown in Figure 1. The various curves correspond to the filter tuned in 50 GHz increments.



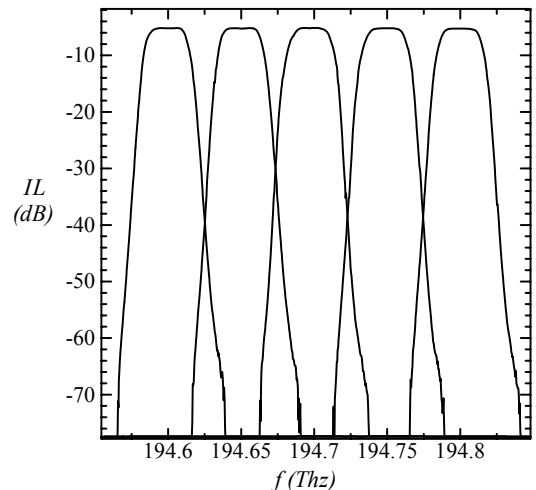
**Figure 0** Schematic of the micro-ring resonator tunable filter. Polarization beam splitters are used to separate the two polarizations so that it can be processed independently.

then to recombine the two polarizations. This allows each polarization to be processed independently thus relaxes the tight fabrication requirement of polarization independent ring resonators. The output of the first filter is connected to the input of the second. The rings in the first Vernier stage filters have radii of  $47 \mu\text{m}$ , while the rings in the second Vernier stage filters have radii of  $42 \mu\text{m}$ . This gives an FSR for the first filter of 575 GHz, and an FSR for the second filter of 650 GHz. The first filter drops a comb of wavelengths separated by 575 GHz. The second filter selects one channel from the comb while suppressing all others. The compound FSR exceeds 40 nm.

### 3. Measurement results

The compound filter shape for any particular channel is a result of being filtered by two 5<sup>th</sup> order cavities. The lineshape therefore has exceptionally fast roll-off on the passband edges. Figure 4 shows measured responses for five adjacent channels of the fabricated device. Beyond the 3 dB filter bandwidth, band-edge roll off is 3 dB/GHz. The 3 dB to 25 dB shape factor (or bandwidth utilization factor) exceeds 65%. The adjacent channel cross talk, at a clear channel bandwidth of 20 GHz, is below 60 dB.

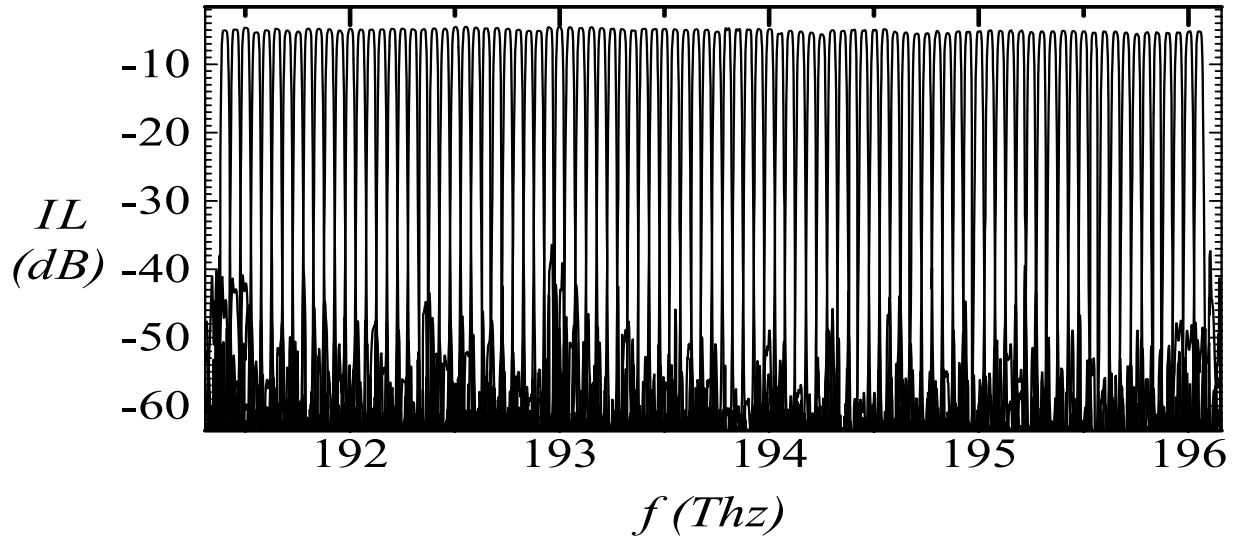
The composite spectra of the fully packaged and calibrated MRF tuned to 96 50 GHz spaced channels are shown in Figure 5. The average insertion loss measured across the clear channel bandwidth of each channel is 5.2 dB. The average PDL is 0.6 dB, and the average 1dB and 3 dB BW are 24.5 GHz and 33 GHz, respectively. Since the TE and TM polarizations are processed separately, the two polarization pass bands are tuned to the ITU grid independently and the polarization dependent frequency splitting (PDF) is reduced to less than 0.5 GHz and the channel setting accuracy to any ITU grid is likewise 0.5 GHz. Tuning is accomplished by the thermo-optic effect, the small thermal mass of the ring resonators allows fast tuning speed from any channel to any channel in approximately 5 msec.



**Figure 0** Composite responses of the Vernier micro-ring resonator filter.

### 4. Conclusion

In conclusion, we have demonstrated the commercial viability of widely tunable micro-ring resonator filters for WDM applications. Fifth order cavities in Vernier configurations have shown fiber to fiber average losses across all channels in the C band of approximately 5 dB, PDL of 0.6 dB, and bandwidth utilization factors of larger than 65%. Microrings can accommodate a wide range of channel spacings and mark an important advancement in WDM filter technology. These particular filters were designed for 50 GHz applications, narrower bandwidth filter, such as 25 GHz and 12.5 GHz applications have also been demonstrated using the same filter configuration with correspondingly narrower lineshapes. In addition to superior performance, MRFs are also suitable for VLSI Photonics applications calling for the dense integration of functionality.



**Figure 0** Composite spectra of the fabricated device tuned to 96 50 GHz spaced channels.

## 5. References

- [1] B. E. Little, S. T. Chu, and H. A. Haus, "Micro-ring resonator channel dropping filters," *Proceedings of the Lasers and Electro-Optics Society 8<sup>th</sup> Annual Meeting*, vol. 2, pp. 233-234, 1995.
- [2] B. E. Little, S. T. Chu, H. A. Haus, J. Foresi, and J.-P. Laine, "Microring resonator channel dropping filters," *IEEE J. Lightwave Tech.*, vol. 15, pp. 998-1005, 1997.
- [3] Rafizadeh, J. P. Zhang, S. C. Hagness, A. Taflove, R. C. Tiberio, K. A. Stair, and S. T. Ho, "Waveguide-coupled AlGaAs/GaAs microcavity ring and disk resonators with high finesse and 21.6-nm free spectral range," *Opt. Lett.*, vol. 22, pp. 1244-1246, 1997.
- [4] K. Djordjev, S.-J. Choi, S.-J. Choi, P. D. Dapkus, "Microdisk tunable resonant filters and switches, *IEEE Photonics Tech. Lett.*, vol. 14, pp. 828-830, 2002.
- [5] S. T. Chu, W. Pan, S. Sato, T. Kaneko, Y. Kokubun, and B. E. Little, "An eight-channel add/drop filter using vertically coupled microring resonators over a cross grid," *IEEE Photonics Tech. Lett.*, vol. 11, pp. 691-693, 1999.
- [6] D. J. W. Klunder, E. Krioukov, F. S. Tan, T. van der Veen, H. F. Bulthuis, G. Sengo, C. Otto, H. J. W. M. Hoekstra, and A. Driessen, "Vertically and laterally waveguide-coupled cylindrical microresonators in Si<sub>3</sub>N<sub>4</sub> on SiO<sub>2</sub> technology," *Appl. Phys. B*, vol. 73, pp. 603-608, 2001.
- [7] B. E. Little, S. T. Chu, P. P. Absil, J. V. Hryniewicz, F. G. Johnson, F. Seiferth, D. Gill, V. Van, O. King, and M. Trakalo, "Very High Order Microring Resonator Filters for WDM Applications," submitted to *IEEE Photonics Tech. Lett.*

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