Improved optical filter responses in cascaded InGaAsP/InP microdisk resonators

Y. Ma, S.H. Chang, S.S. Chang and S.T. Ho

Cascaded InGaAsP/InP microdisk resonators as optical filters are fabricated by deep dry-etching. Compared with single microdisk resonators, these higher-order filters show steeper rolloffs and flatter passbands. The bandwidth ratios of 15 to 3dB for the single, three and five cascaded microdisk resonator filters are ~2.4, 1.4 and 1.2.

Waveguide-coupled microdisk and microring resonators as optical filters have been of great interest due to their high wavelength selectivity and ultra-compact sizes [1 – 4]. Recently, higher-order filters based on microring resonators with improved performances have been demonstrated in compound glass and AlGaAs/GaAs material systems [3, 4]. These higher-order filters show steeper rolloffs and flatter passbands than single resonator filters. Basically, higher-order filters can be realised by using multiple microresonators in the arrangement of either latticed (series coupling) or cascaded (parrallel coupling) structures. In the former case, each resonator is mutually coupled, and a signal from the input port must go through each resonator sequentially to be dropped; in the latter case, each resonator is equally spaced and only coupled to the input and output waveguides. Therefore, resonators interact with each other not directly but through the coupling waveguide. It has been pointed out that although the latticed structure is supposed to have better filter performance than the cascaded structure it is more sensitive to fabrication error and loss [3]. In this Letter, we show experimental results on cascaded third-order and fifth-order microdisk resonator filters based on an InGaAsP/InP material system. An InGaAsP/InP material system is of particular interest since it provides the possibility of the monolithic integration of passive and active devices, which is crucial for integrated optical networks. We use microdisk instead of microring geometry in our devices since microdisk resonators suffer much lower scattering losses than microring resonators.

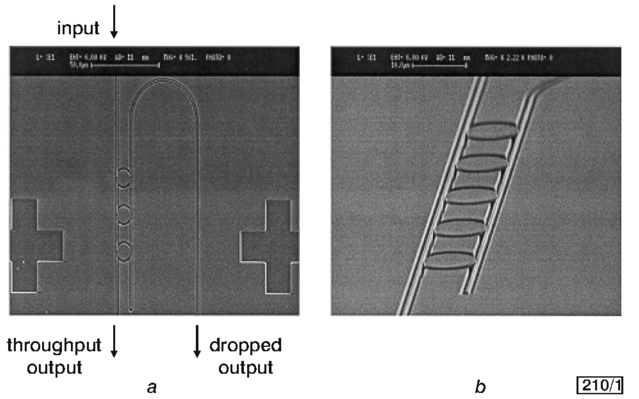

Fig. 1 *Scanning electron micrographs of third-order and fifth-order cascaded microdisk resonator filters*

a Third-order cascaded microdisk resonator filter
b Fifth-order cascaded microdisk resonator filter
All microdisk resonators have diameter of 10μm

The cascaded microdisk resonator filters are fabricated by electron-beam lithography and inductively coupled plasma (ICP) etching. The basic structure and fabrication process are similar to those described in [5]. An InGaAsP/InP wafer with a 0.45μm-thick InGaAsP guiding layer (λ_g = 1.25μm) sandwiched by a 1.0μm-thick InP cladding layer was vertically etched down to the InP substrate by ICP etching with a gas mixture of Cl_2:Ar^+ (2:3) at an elevated temperature of 250°C. The etching depth is ~2.66μm. This fabrication procedure defines a typical deeply etched ridge waveguide structure. In such a structure, there is a strong lateral mode confinement owing to the large index contrast (3.4:1.0), which ensures very low bending losses for the compact microdisk resonators. In the devices, all the resonators have a diameter of 10μm and are periodically coupled to the input and output waveguides but not to each other. The effective indices of the fundamental mode in the coupling waveguide and microdisk resonator are 2.94 and 2.98, respectively. The distance between two adjacent resonators is 23.85μm, which gives a π/2 phase-shift and introduces in-phase responses among those cascaded microdisk resonators. Therefore, a constructive interference can be formed at the drop port output and make the filter response box-like in comparison to the single resonator filter.

Fig. 1*a* shows the scanning electron micrograph (SEM) of three cascaded microdisk resonators coupled to the input and output waveguides. The straight waveguide is for input coupling and the U-shape waveguide is for output coupling. All the coupling waveguides are tapered from 2μm down to 0.44μm near the microdisk resonators. The length of the tapered region is 500μm. The untapered coupling region is 200μm in length. The radius of the U-shape waveguide is 25μm. The gap between the coupling waveguide and disk resonator is about 0.15μm. Fig. 1*b* shows a close-up SEM image of five cascaded microdisk resonators.

The waveguide coupling was achieved by using the end-firing method. The light from a tunable diode laser with a centre wavelength of 1540nm was coupled into the device from the input port using a high numeric aperture lens (N.A. = 0.55). The output from the drop port or the throughput port was focused by another lens and imaged on to an IR camera and a photodetector. A movable pinhole was placed in front of the photodetector to select either output.

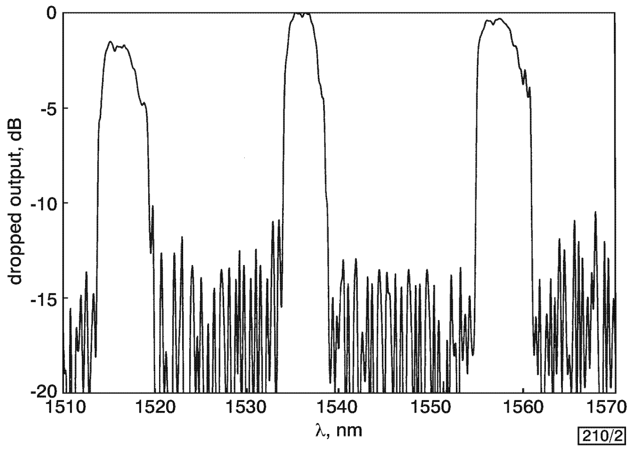

Fig. 2 *Measured filter responses of fifth-order cascaded microdisk resonator filter for TM polarisation*

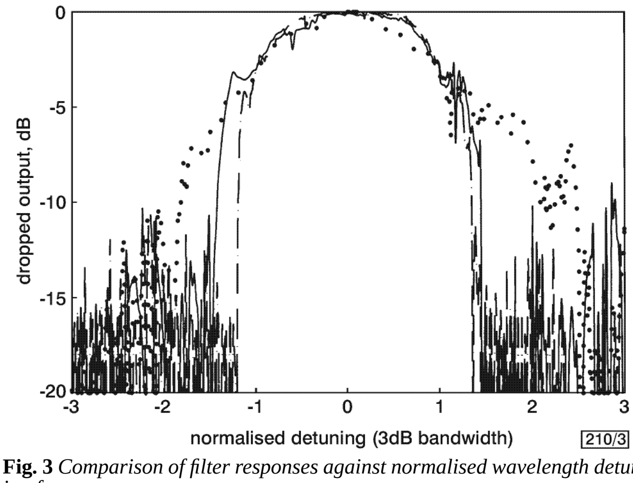

Fig. 3 *Comparison of filter responses against normalised wavelength detuning from resonance*

••••• single microdisk resonator
——— third-order cascaded microdisk resonator filter
— · — fifth-order cascaded microdisk resonator filter

Fig. 2 shows the dropped output of a cascaded filter with five microdisk resonators for the TM polarisation. The data have been normalised by the maximum dropped power and shown on a log scale. The free spectral range (FSR) is ~20nm and the full 3dB bandwidth is ~3.5nm. To demonstrate the improved filter responses in the cascaded microdisk resonators, Fig. 3 shows the dropped output as the function of wavelength detuning from the resonance normalised by the 3dB bandwidth for both three and five cascaded microdisk resonator filters (solid line is three and dash-dotted line is five). For comparison, we have also plotted the filter response of a single microdisk resonator with the same geometry (dotted line). In Fig. 3, the single resonator filter response shows the expected Lorenzian-like line shape, while the cascaded filters show much flatter passbands and steeper rolloffs. The bandwidth ratio of 15 to 3dB for the single microdisk resonator is ~2.4, while it is ~1.4 for the third-order filter and ~1.2 for the fifth-order filter.

In conclusion, we have demonstrated, for the first time, the improved optical filter responses in cascaded InGaAsP/InP microdisk resonator filters. The fifth-order filters show about two times faster out-of-band signal rejection and much flatter passbands in comparison to the single microdisk resonator filters. We expect that these InP-based devices have potential for applications in integrated optical network systems.

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References

1 RAFIZADEH, D., ZHANG, J.P., HAGNESS, S.C., TAFLOVE, A., STAIR, K.A., and HO, S.T.: 'Waveguide-coupled AlGaAs/GaAs microcavity ring and disk resonators with high finesse and 21.6-nm free spectral range', *Opt. Lett.*, 1997, **22**, (16), pp. 1244–1246

2 MADSEN, C.K., and ZHAO, J.H.: 'Increasing the free spectral range of silica waveguide rings for filter applications', *Opt. Lett.*, 1998, **23**, (3), pp. 186–188

3 CHU, S.T., LITTLE, B.E., PAN, W., KANEKO, T., and KOKUBUN, Y.: 'Second-order filter response from parallel coupled glass microring resonators', *IEEE Photonics Technol. Lett.*, 1999, **11**, (11), pp. 1426–1428

4 HRYNIEWICZ, J.V., ABSIL, P.P., LITTLE, B.E., WILSON, R.A., and HO, P.T.: 'Higher order filter response in coupled microring resonators', *IEEE Photonics Technol. Lett.*, 2000, **12**, (3), pp. 320–322

5 MA, Y., CHANG, G., PARK, S., WANG, L., and HO, S.T.: 'InGaAsP thin-film microdisk resonators fabricated by polymer wafer bonding for wavelength add-drop filters', *IEEE Photonics Technol. Lett.*, 2000, **12**, (11), pp. 1495–1497