Channel dropping filters based on ring resonators and integrated SOAs (invited paper)

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Abstract: A key device in all-optical networks is the optical filter. Ring resonator filters on the basis of GaInAsP / InP with improved filter response and increased functionality using integrated semiconductor optical amplifiers are presented.

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1. Introduction

Different types of optical filters like Bragg gratings, thin film filters and arrayed waveguide gratings (AWGs) are used in the all optical network. An optical filter which has emerged in the last few years in integrated optics is the ring resonator filter. Ring resonator filters do not require facets or gratings for optical feedback and are thus particularly suited for monolithic integration with other components like semiconductor optical amplifiers (SOAs), receivers and semiconductor lasers. Ring resonators are, in general, versatile devices and are also used for many other applications, such as single mode lasers [1], tunable lasers [2], modulators [3], switching devices [4], biosensors [5] and dispersion compensators [6].

Wavelength division multiplexing (WDM) communication systems require optical components which can de-/multiplex closely spaced channels in the frequency domain. A device referred to as add/drop filter is required to separate (reload) the channel to be dropped (added) from those that pass through unaffected. There are mainly two classes of optical filters:

- Finite impulse response (FIR) / moving average (MA) filters: devices that do not rely on any feedback mechanism, i.e., do not rely on optical reflections. These filters are sometimes called feed-forward and examples are Mach-Zehnder based filters (MZF) and waveguide grating routers (WGRs).

- Infinite impulse response (IIR) / autoregressive (AR) filters: devices that do rely on a feedback mechanism. Examples of these include fiber Bragg gratings (FBGs), thin film filters (TFFs), and ring resonator filters (RRFs).

Channel dropping filters on the basis of ring resonators are of great interest due to their compactness and high wavelength selectivity [7].

The performance of passive ring resonators for filter applications is limited by internal losses. The incorporation of an SOA enables additional functionality (e. g. switchability) including the compensation of internal losses. The tuneability of the filter response is realized with the waveguide integrated Pt-resistors (Fig. 1).

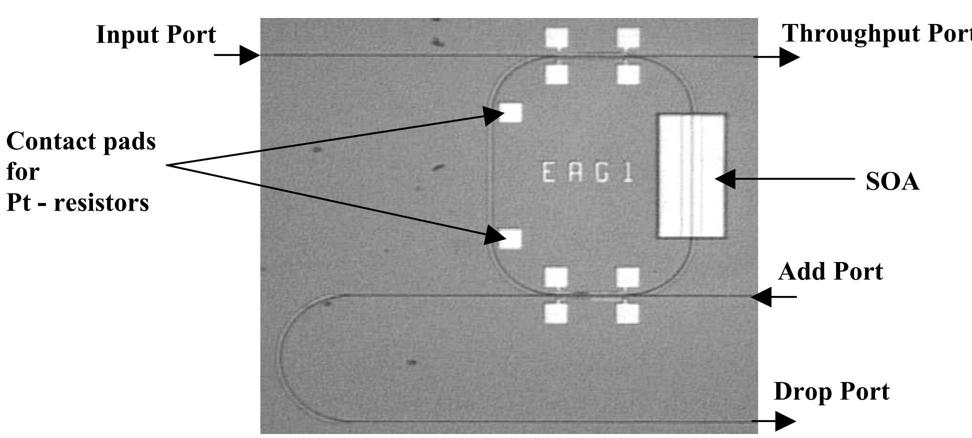


Fig. 1. Photograph of a single ring resonator with integrated SOA, radius R = 133 µm, SOA length = 300 µm, free spectral range (FSR) = 50 GHz, the integrated platinum (Pt) – resistors enable the thermal tuning of the resonance wavelength.

2. Features of optical filters

A data rate of 10 Gbit/s has a spectral width of 6.25 GHz, using a spectral efficiency of 1.6 bit/s/Hz [8]. The ideal passband of a filter with a rectangular amplitude response for this data rate would therefore be 6.25 GHz. For bandpass filter applications, several factors influence the required passband width beyond the fundamental limit set by the bit rate. The passband width must accommodate fabrication tolerances on the filter and laser center wavelengths as well as their polarization, temperature and aging characteristics. For high bit rate long-distance systems, filter dispersion and broadening of the signal due to nonlinearities within the channel window can also become an issue. An ideal optical filter should have the following features: no insertion loss, flat-top, sharp roll-off from passband to stopband, no dispersion, no polarization mode dispersion (PMD) and no polarization dependent loss (PDL). Specified deviations from these properties impact the quality of the output signals leaving the optical filter. A typical example of specification for an optical add drop multiplexer (OADM) filter with an ITU channel separation of 50 GHz: Insertion loss < 5 dB, PDL < 0.15 dB, passband at – 1 dB: 12.5 GHz (0.1 nm), adjacent channel isolation: 15 dB.

3. Ring resonator filters

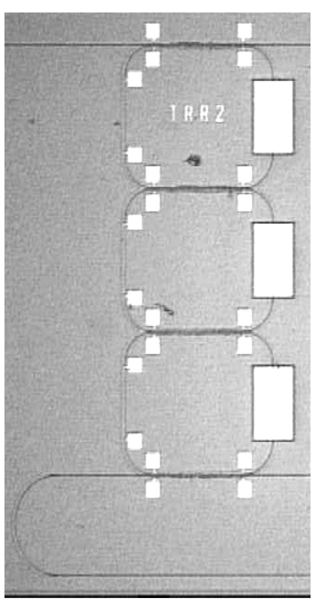
The implementation of integrated resonant filter devices can be achieved in different ways. In the case of a linear resonator the cavities can be defined by Bragg gratings or highly reflective coatings resulting in multiple bi-directional reflections. In the case of microring coupled to one ore more bus waveguides the resonator features are determined by the coupling ratios and the internal waveguide losses. The Free Spectral Range (FSR) of a cavity is determined by the cavity roundtrip period. An increase of the FSR is inverse proportional to the cavity length

Integrated rings can be easily coupled forming novel filter functionalities in analogue to electronics. The FSR of the fabricated devices for example can be increased in multiple coupled ring resonators with different radius owing to the Vernier effect [9], [10]. Another approach, which is shown here, is the use of multistage ring filters in order to get a box like filter response for a desired pass-bandwidth.

The Lorentzian-like filter response of a single ring resonator filter is not suitable for practical applications in wavelength division multiplexing (WDM) systems. The tailoring of the filter response shape in the wavelength domain is required to improve the performance. The use of multiple coupled ring resonators is one of the solutions.

As the filter quality and resonance enhancement is very sensitive to the resonator losses an integrated SOA function is indispensable for cascaded ring structures and for high efficiency and high performance devices. A drawback of resonant devices is the polarization dependence which behaves like a funambulist on a tightrope if no specific input polarization is used.

We designed and fabricated double and triple coupled ring resonator add/drop filters with a box-like filter response [11].



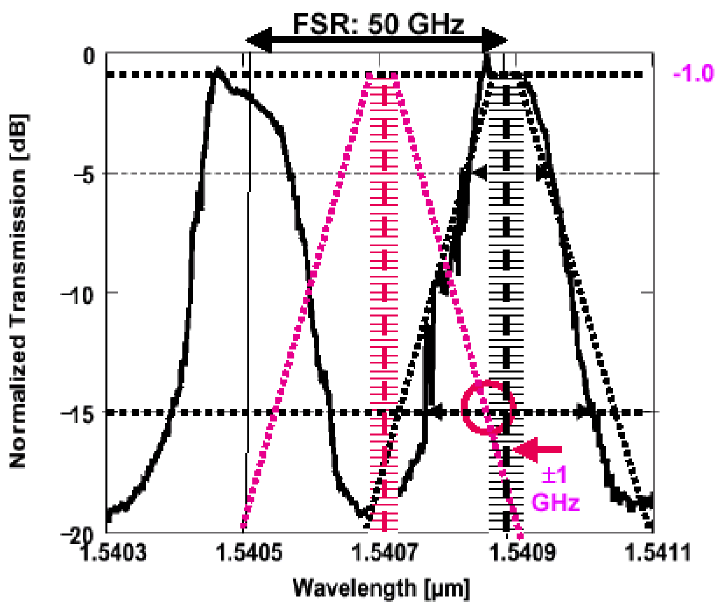


Fig. 2. Photograph of a triple ring resonator with integrated SOA and measured drop port response, R = 133 µm, SOA length = 300 µm, FSR = 50 GHz, full width at half maximum (FWHM) = 12.5 GHz (0.1 nm).

5. System operation

Concerning the device feature in the time domain, the filter's system performance depends on the cavity response time of the resonator and the switching speed of the SOA. The application of our devices in high bitrate systems is mainly limited by the time required to charge / deplete the ring cavity. The respective response time scales with the roundtrip time and is increased by lowering the power coupling factor κ. So far, the response is characterized in the wavelength domain. System experiments including dispersion measurements will be performed in a following step.

The "photon lifetime" is determined by the cavity roundtrip period and the degree of cavity "isolation". A reduction of the photon lifetime requires a cavity length reduction, however, decreasing the SOA length and consequently the gain. In the case of ring resonators the ring losses are also culminating. Therefore a trade off between the SOA length and the ring radius has to be found which leads to a physical "speed limit". The design of multiring devices is an adequate option for high bit rate applications.

4. Conclusion

The availability of well engineered and compact optical filters is essential for photonic networks and optical signal processing in the wavelength domain in general. Compact optical filters with steep roll-off features can be designed by exploiting resonance effects. Optical ring circuits take advantage of the omission of the costly fabrication of Bragg gratings for the realization of a high order filter response. However, the resonance feature adheres to sharp operating windows which are far from practical use. Consequently, multi-ring architectures become indispensable for the realization of plat-top spectral windows compatible with ITU specifications. As the losses are increasing in multi ring arrangements and the filter performance is extremely sensitive to the resonator losses integrated SOA functions become relevant. Individual tuning of ring resonators to the verified interresonator coupling strength is a further demand. Concerning the device feature for high bit rate applications a reduction of the photon lifetime in microring resonators by miniaturization has to be a main issue. Here, vertical coupling approaches will come into focus. They enable to fabricate the micro couplers with sub-µm control of the coupler gap via single epitaxial growth of the complete vertical layer stack. The development of a reliable technology for the up-side-down wafer bonding meeting challenges on heat dissipation and polarization tolerance is still outstanding. The evaluation of the potentials and limits will be a main issue.

More than for filter applications where the competition to alternative technological solutions (e.g. fiber Bragg grating and arrayed waveguide grating components) is very crucial the incorporation of an SOA function in ring resonator devices emphasizes their potential for the realization of e.g. modulators, channel switchable single mode lasers, and "loss less" wavelength converters. This field will gain in importance in the near future.

5. References

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