Analysis of a microring resonator based ultra-compact transceiver for the access network

A. Driessen, D.H.Geuzebroek, D.J.W. Klunder, F.S. Tan.

Lightwave Devices Group, MESA+ Research Institute, Faculty of Applied Physics, P.O.Box 217, 7500 AE University of Twente, The Netherlands; email: D.H.Geuzebroek@el.utwente.nl

By cascading multiple microring resonators an ultra-compact transceiver is proposed in the framework of the European IST project NAIS. Microring resonators have been shown to perform desirable functions like filtering, multiplexing and switching of optical signals. This together with their compact size and the possibility to use well-known fabrication technologies, make it possible to design a low-cost, multi-wavelength transceiver for the multi-gigabit optical access network. Simulations based on experimentally obtained parameters show that it is possible to cascade large numbers of resonators without significant loss in signal power.

Introduction

The increasing demand for bandwidth involves an invasion of optical techniques from the core network to the metropolitan network and, eventually in a not so far future, the access network. Before the final goal, FTTX (fibre to the X, where X stands among others for home, office, computer) can be reached several hurdles have to be taken. One of these is an economic issue – the costs of the FTTX technology cannot be shared by many users. This issue leads to technological challenges, as reliable mass-producible devices are needed to reduce costs.

Integrated optic microring resonators (MRs) already have shown to exhibit attractive filter and switching behaviour in connection with extremely small chip-area for a single functional element [1-4]. Exploiting the unique properties of active and passive MRs one can realize an ultra-compact multi-wavelength transceiver module that meets the requirements of an advanced high-speed, multi-wavelength access network. In the following we describe briefly the functional behaviour of a single MR. Thereafter an example is given of a combination of two different MRs that can be used as a high-speed optical switch that eventually can be arranged in an array. This array is one of the building blocks of the proposed multi-wavelength transceiver module that will be presented in some detail. Finally the feasibility will be discussed including materials aspects of the technological implementation.

Single microring resonator

A single microring resonator is depicted in Fig. 1. The ring and the waveguides are weakly coupled. The functional behavior of the device is shown in Fig. 1b. By changing the wavelength of the input signal or the effective index constructive interference, also called resonances, will occur at certain values. At resonance almost all power can be transferred to the drop-port. By using an electro-optic material for the cavity, the resonator can actively be pulled OFF and ON resonance. This way a modulator or switch can be designed. Single microring resonators have been made in Si_3N_4-SiO_2 technology [4, 5]. These single devices with a diameter of 50 μm and a gap of 750 nm have promising specs like a Finesse of about 150 (FSR= 8 nm, FWHM=50 pm) and

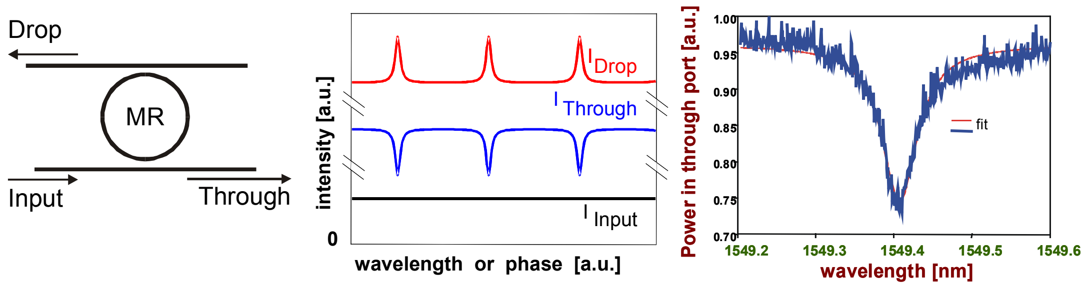

Figure 1. The single microring resonator: a) schematic top view, b) its functional wavelength/phase response; c) experimentally obtained wavelength response [4].

with an on-chip insertion loss < 0.15 dB. As shown in Fig. 1 the drop and through port show indeed the Lorentzian shape.

Microring resonator arrays

By cascading multiple resonators not only the desired filter-shape can be adjusted, also useful functions can be made. Combining two MRs, one at a fixed resonance wavelength and the other electro-optically tunable, a high-speed modulator or switch can be made. An array of these MR based switches, SW1 to SWn as shown in Fig. 2a can be used as a WDM drop filter. Each pair of MRs has a slightly different resonant wavelength with respect to its neighbor. In this way a complete band of wavelengths can be covered. By selecting the appropriate switches one can drop the desired wavelength within the band. A small drift of the wavelength of the information band or a slight deviation in the center wavelength of the MR caused by the thermal drift of the receiver chip can be overcome, just by switching ON/OFF the relevant switches. Simulations have been done for an array of 11 switches. SW1 to SW11 with increasing center

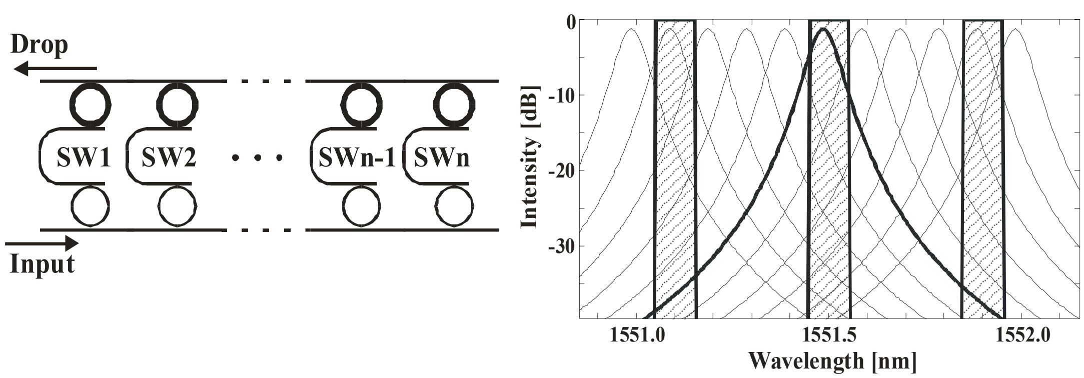

Figure 2. Schematic of a microring based array of switches and its functional wavelength response with an indication of three 50 GHz spaced WDM channels.

wavelength in steps of 0.1 nm. Fig. 2 shows the wavelength response of all individual switches together with the position of 3 WDM channels spaced 50 GHz. As mentioned before a specific wavelength band can be filtered out by at least two or three switches. The simulation result for wavelength dropping by three switches is shown in Fig. 3. As can be seen from this figure the information band can be dropped efficiently with an estimated insertion loss in the ON-state and OFF state of -3 and -13 dB respectively. A drawback of the current design is the rippled top of the filter characteristic. This can be overcome by reducing the distance of the resonance wavelength of the different switches

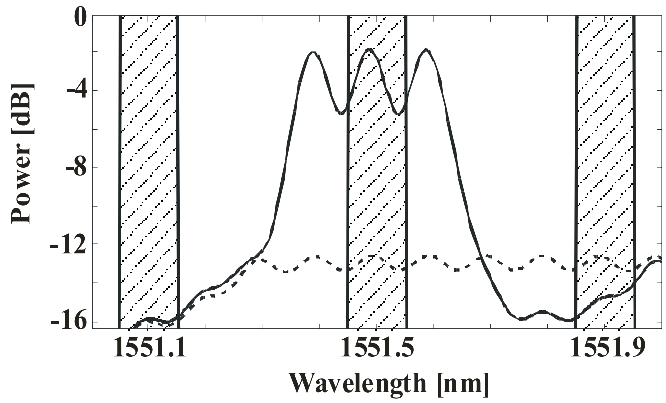

Figure 3. Wavelength response of a MR- based array: solid line: three MR pairs are switched ON; dashed line: all pairs switched OFF.

in the array, or as described in e.g. [6] by flattening the filter function by using multiple ring resonators instead of one.

Single chip transceiver

As discussed above, cascading multiple microring resonators allows the realisation of attractive functions with low chip areas. Based on this feature a fully integrated transceiver based on microring resonators is proposed. The complete transceiver is depicted in Fig. 4. This figure also shows the use of MR combinations in different functions like switches, modulators and filter arrays. For clarity, only a restricted number of up-stream and down-stream WDM channels are drawn. The single-chip transceiver needs only one fibre-chip connection and, hybrid attached with non-critical passive alignment, two photodiodes and one (superluminescent) LED. In the following a brief description of the proposed transceiver is given to show the different functions of the cascaded MRs.

The downstream signal channels follow a polarisation diversity circuit with polarisation conversion in one of the two channels. In this way the two orthogonal polarised WDM signals are transformed to signals with the same polarization state that can be de-multiplexed by two identical arrays of MRs optimised for a single polarisation. The MR

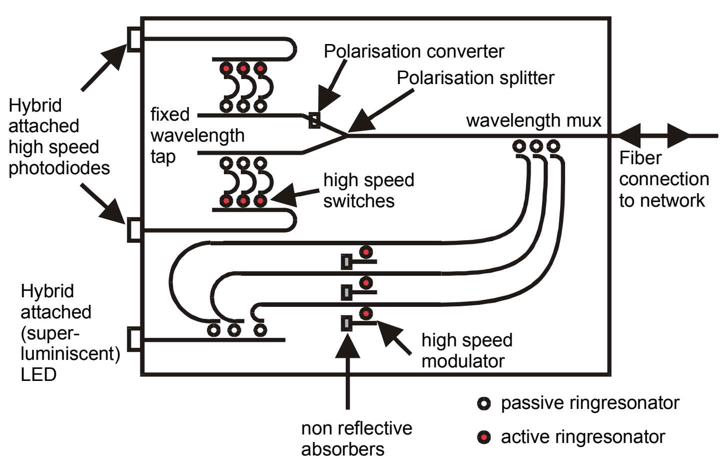

Figure 4. The proposed single-chip transceiver module

switches in the array have a centre wavelength only slightly shifted with respect to their neighbour so that any signal wavelength can be sampled by at least two MR switches. In addition the number of these MR switches in the array is sufficient to span the complete comb of incoming WDM signals. Switching ON or OFF the desired MR switch combinations can electronically compensate any drift in the incoming wavelength or any drift in the centre wavelength of the MR switches. The selected WDM channels are eventually directed to the high-speed photodiodes.

In the upstream direction the transmitter part starts from a high-intensity broad-band source, e.g. a (superluminescent) LED. The first set of resonators serves as narrow-band filters to generate the up-stream WDM channels by spectral slicing. The following set consists of active MRs, which act as independently driven intensity modulators for each wavelength. The unused light in the ON-state of the MR is directed to a non-reflective absorber. With the last set of MRs the modulated signal of the WDM channels is coupled into the waveguide connecting to the fibre.

Discussion

Essential for demonstrating the feasibility of the proposed transceiver are the technological specifications of the MRs. The on-chip insertion loss of the off-resonance MR should be low enough to allow the signal to pass along a set of MRs nearly without attenuation. For the active MRs electro-optic organic materials can be used that in other geometries have shown efficient modulation behaviour up to more than 100 GHz [7]. The realisation of MRs with polymeric waveguiding layers has been demonstrated by us [4] and others [8]. Much work has still to be done on the system as well technological aspects of this proposed transceiver before arriving at the final goal, an ultra-compact WDM transceiver for the access network. With the joint effort of the partners in the recently started EC funded IST project NAIS [9] interesting new results can be expected in the near future.

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