Wavelength routing and dispersion compensation in a narrow-band integrated resonant router

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Abstract - *We demonstrate that a narrow-band resonant-router made of a matrix of integrated ring-resonators can combine wavelength routing and dispersion compensation operations, with neither significant signal distortion nor inter-channel crosstalk deterioration. The transmission of 10-Gbit/s NRZ data-streams through a 2×2 integrated SiON router with 4-GHz bandwidth is reported.*

Introduction

Reconfigurable architectures made of bi-dimensional arrays of ring-resonators (RRs), also known as resonant routers (ReRs) [1], are good candidates for implementing advanced routing and switching operations in a WDM optical network [2]. ReRs combine high flexibility, full reconfigurability and the capability of handling many WDM optical channels in small footprint devices. Recently, ReRs have been also proposed as cost effective solutions in access network applications [3].

One of the major limits of the ReR performance is the intrinsic trade-off between the bandwidth and the off-band rejection, the latter determining the inter-channel cross-talk of the ReR. To increase the ReR bandwidth with no crosstalk deterioration, RRs with a large free spectral range (FSR) can be employed, this approach requiring waveguides with a suitably high index contrast. On the other side, to reduce the crosstalk without narrowing the bandwidth, each ReR node can include several coupled RRs; besides a larger footprint, this solution increases the complexity of the RER configuration and management.

In this contribution, we demonstrate that the bandwidth of a ReR can be significantly narrowed with respect to the signal bandwidth, while corrupting neither the signal quality nor the crosstalk. To this aim, a small frequency detuning between the signal carrier and the ReR's frequency response is introduced. In this condition, the frequency chirp provided by the RRs dispersion can be also exploited to make the transmitted signals more robust against fiber chromatic dispersion. The routing of two intensity modulated 10 Gbit/s NRZ channels through a 2×2 integrated ReR with 4 GHz bandwidth is reported and the signal quality after propagation through several spans of optical fiber is evaluated.

Fabrication and characterization of a 2×2 integrated ReR

Fig. 1(a) shows a 2×2 ReR fabricated in 4.5% index-contrast silicon oxynitride technology [4]. It comprises a crossbar matrix of four identical racetrack RRs, which are side-coupled with four orthogonally-crossing straight bus-waveguides. The optical waveguide has $2.2 \times 2.2\ \mu m^2$-wide cross-section and 0.35 dB/cm propagation loss at 1550 nm. The bending radius of the RRs is 570 μm, corresponding to a FSR of 50 GHz. The resonance of each RR is independently controlled by means of a metallic heater deposited onto the waveguide, so that the ReR spectral response can be fully reconfigured.

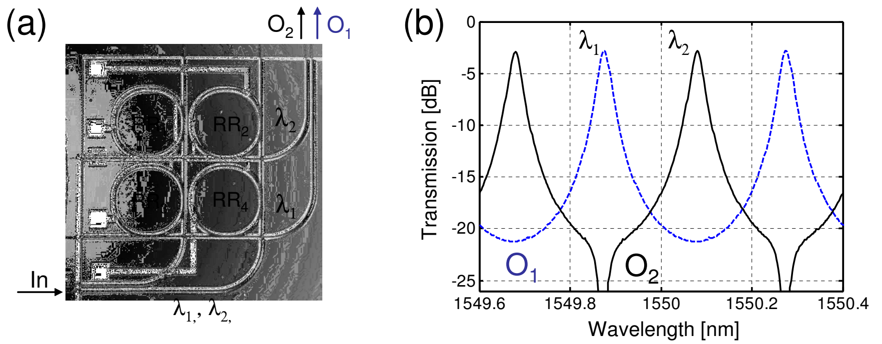

Figure 1: (a) Photograph of a 2×2 λ-ReR fabricated in SiON technology. (b) Measured frequency-domain response of the λ-ReR shown in (a) at the output ports O_1 (dashed line) and O_2 (solid line) when the signal is provided at the In port.

Fig. 1(b) shows the measured transmission from the input port (In) to the output port O_1 (dashed line) and O_2 (solid line). The bell-shaped passbands in O_1 and O_2 are the drop-port responses of RR_4 and RR_2, respectively. The deep notch in O_2 is due to the through-port contribution of RR_4. The measured 3-dB bandwidth is 4.1 GHz (±0.1 GHz) and the overall insertion loss at the transmission maximum is 2.9 dB (±0.1 dB). This insertion loss partially comes from fibre-to-waveguide coupling, amounting to 0.2 dB/facet when small-core fibers with 3.6 μm mode field diameter are used. The round-trip loss of each 4-mm-long RR is about 0.2 dB/turn, where 0.15 dB come from propagation loss and the remaining 0.05 dB from bending loss and directional couplers' excess loss. The loss at each waveguide-crossing is 0.4 dB, but it can be reduced by tapering the waveguides profile at the crossing-sections. The unbalance between the peak transmission at the two output ports is below 0.3 dB. Thanks to the high finesse of the RRs, the off-band isolation exceeds 18 dB over more than 8 GHz at both the ReR output ports.
The fabricated ReR can operate either as wavelength router (λ-ReR) in a WDM system with 25 GHz spaced channels or as an optical cross-connect, if the channel spacing is 50 GHz. In the experiment reported in the following the operation as λ-ReR is discussed.

Two-channel wavelength routing at 10 Gbit/s

Fig. 2 shows the experimental setup used for the time-domain measurements of the 2×2 ReR of Fig. 1(a). Two optical sources λ_1 and λ_2, spaced by 25 GHz, are modulated by two intensity modulators, MOD_1 and MOD_2, in order to generate two 10 Gbit/s NRZ optical data-streams. The two signals, sharing the same pseudo-random bit sequence (PRBS), are decorrelated by making λ_1 propagate through few kms of optical fiber while a variable optical attenuator (VOA) is placed on the λ_2-path to compensate for fiber loss. Two polarization controllers are employed to control the polarization state of each channel at the ReR input. A 3dB coupler is used to couple λ_1 and λ_2 into the In port of the ReR. For back-to-back measurements (B2B), the signal outgoing the ReR output O_2 is directly supplied to an EDFA pre-amplifier followed by a VOA, which is employed to control the received power level. A small portion (10%) of the received signal is sent to an optical spectrum analyzer (OSA) for monitoring the ReR frequency response. The signal quality

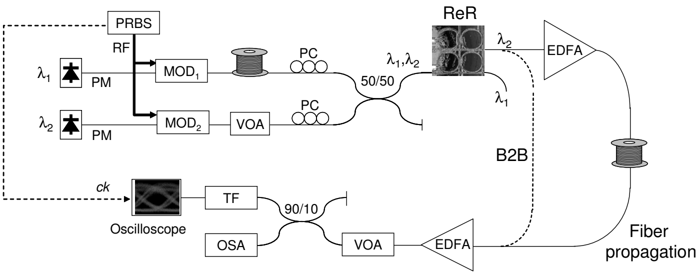

Figure 2: Experimental setup.

is evaluated by measuring the eye-diagram opening (system Q-factor) by means of an optical sampling oscilloscope. A tunable optical filter (TF) with 1-nm-wide bandwidth is placed before the detector to remove the off-band ASE noise produced by the EDFA. For propagation measurements, an EDFA booster is added at the ReR output and several spans of SMF fiber are inserted before the receiver apparatus.

The Q-factor of the received signal was measured for different detuning $\Delta\lambda = \lambda_R - \lambda_2$ between the ReR spectral response and the signal carrier λ_2, as shown in Fig. 3(a). Fig. 3(b) shows the measured Q in B2B transmission, when the received power is kept at a constant level. When $\Delta\lambda = 0$ the eye diagram is completely closed ($Q < 2$), because of the large intersymbolic interference introduced by the narrow ReR bandwidth. As the detuning increases, the Q-factor improves symmetrically with respect to λ_R. As shown in the insets of the figure, the eye-diagrams measured at $\Delta\lambda = \pm 28$ pm are almost indistinguishable. We observed also that if $\Delta\lambda < 30$ pm, the eye-opening is almost independent of the presence of the interfering channel λ_1, demonstrating that the crosstalk level is not significantly affected by the small detuning. This result is a direct consequence of the high off-band rejection of the narrow-band ReR.

The symmetry of the Q curve versus $\Delta\lambda$ disappears when propagation through an optical SMF fiber is added. As shown in Fig. 4(a), fiber propagation makes the Q factor increase on the upper wavelength side of the RR's resonance ($\Delta\lambda > 0$), whereas the Q factor de-

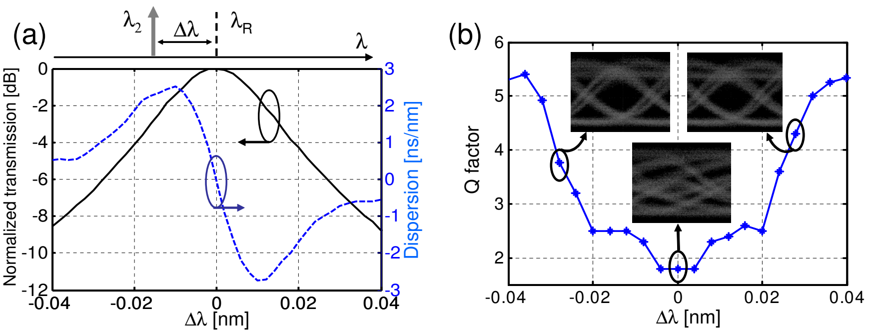

Figure 3: (a) Transmission (solid line) and dispersion (dashed line) of the ReR in the neighborhood of the O_2 port maximum; (b) measured Q-factor versus the detuning $\Delta\lambda$ in B2B measurements. The reported eye-diagrams are measured at $\Delta\lambda$ = -28 pm, 0 pm and +28 pm.

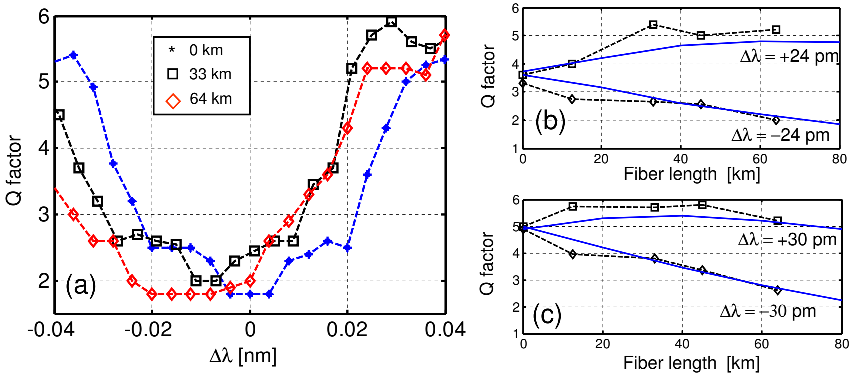

Figure 4: (a) Measured Q-factor versus the detuning $\Delta\lambda$ for increasing propagation length; measured (squares) and simulated (solid line) Q-factor versus the propagation length for $\Delta\lambda = \pm 24$ pm (b) and $\Delta\lambda = \pm 30$ pm (c).

creases for $\Delta\lambda < 0$. The minimum of the Q curve shifts towards shorter wavelengths. This effect is due to the combination of the fiber and the ReR dispersion, the latter assuming an opposite sign at the two sides, as shown in Fig. 3(a). For $\Delta\lambda > 0$ the ReR introduces a normal chromatic dispersion, which compensates for the anomalous fiber dispersion, so that the Q improves with propagation. Fig. 4(b) and (c) show the simulated (solid lines) and the measured (squares) Q versus the propagation length for $\Delta\lambda = +24$ pm and $\Delta\lambda = +30$ pm, respectively. The distance L_{max} at which the Q-factor reaches its maximum value (chirp-free signal) is 65 km (-1050 ps/nm ReR dispersion) in (b) and 40 km (-650 ps/nm ReR dispersion) in (c). The Q-factor decreases to its original value at $2L_{max}$. Since L_{max} depends on $\Delta\lambda$, the quality of the received signal can be optimized for a variable range of fiber lengths. On the other side of the RR frequency response, where the ReR dispersion is positive, the Q-factor monotonically decreases.

Conclusion

Our results demonstrate that wavelength routing and dispersion compensation can be both accomplished by a narrow-band λ-ReR. The control of the wavelength detuning between the signal and the device enables the optimization of the signal quality for a variable range of propagation lengths, with no significant deterioration of the ReR crosstalk level. The device can be usefully exploited either in a node or at the receiver side of a WDM network.

References

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