Behaviour of picosecond and femtosecond pulses in SiO_2/Si_3N_4 microring resonator filters

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When pulse lengths are shorter than the roundtrip time of a microring resonator filter, interference effects in the spectral response as shown with cw signals (both through and drop) are not that obvious. In order to clarify the behavior, a number of measurements have been performed on different SiO_2/Si_3N_4 microring resonators: a cw measurement, a measurement where the pulse length (1.8 ps) is in the order of the roundtrip time (1.9 ps) and finally a measurement where the pulse length (200 fs) is much shorter than the roundtrip time (4 ps). In all cases the spectral and time domain responses are presented.

Introduction

The fundamental limit for filtering very high speed signals with integrated optic microring resonators (MRs) is reached when the duration of the pulse becomes smaller than the roundtrip time of the MR cavity. Since the duration of the pulse is so short, no interference of multiple roundtrips of the MR cavity can be observed and the MR can not be described in a CW modus but exhibits only a transient response behaviour.

General specifications of ps pulses

Measurements have been performed with ps pulses to observe the influence of the MR on the time and frequency behaviour of the pulses. With the use of a 40 GHz modelocked

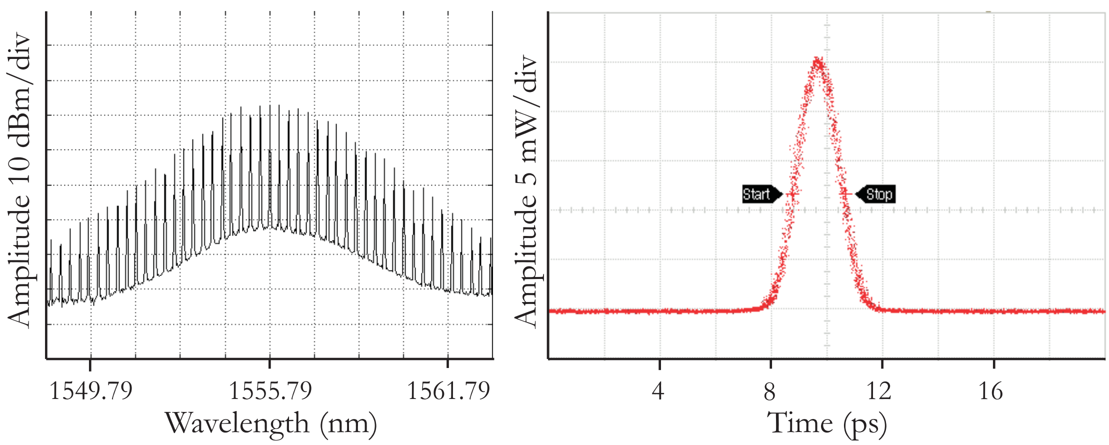

Figure 1: Measured wavelength spectrum and shape of detected 1.8 ps pulse of the generated pulse train with a repetition rate of 40 GHz.

ringlaser, a pulse train was generated with pulses having a FWHM of 1.8 ps and a 25 ps interval as is shown in Figure 1. In the right picture in this figure the ps pulse measured by an optical autocorrelator is shown. The individual pulses have a duration in the order of the roundtrip-time (τ_r) of the microring which is 1.9 ps according to:

$$\tau_r = \frac{2\pi R n_g}{c} \tag{1}$$

with a groupindex n_g of 1.82 following from the measured 4.2 nm FSR as described in [1]. The measured wavelength spectrum of the generated pulse-train is shown in the left picture of Figure 1. It has a broad spectrum with a FWHM of 3.5 nm according to [2]

$$FWHM_\lambda \approx \lambda_0^2 \frac{TBP \cdot n_g}{FWHM_t c} \tag{2}$$

with $FWHM_\lambda$ and $FWHM_t$ the 3-dB width of the wavelength spectrum and the pulse in time, respectively. The Time-Bandwidth Product (TBP) of a Gaussian pulse is ≈ 0.44 [2]. The spikes in the wavelength spectrum are the resonances of the ringlaser. Alternatively, they can be considered as a consequence of the pulse train with a repetition rate of 40 GHz, being exactly the distance between the spikes in the wavelength spectrum.

ps pulses filtered by microring resonators

When a pulse train as described above is filtered by the mentioned MR there are two states that can be distinguished: 'ON' and 'OFF' resonance. Since the pulse duration is a little shorter than the roundtrip time, the definition of resonance conditions for the CW case can not be used. When the MR is tuned such that the main part of the pulse trains spectrum does not overlap the normal resonance peaks, the state is called 'OFF' resonance. When the center of the pulse train coincides with the resonance wavelength in the CW case, the state is called 'ON' resonance. The measured SiO_2/Si_3N_4 MRs have a

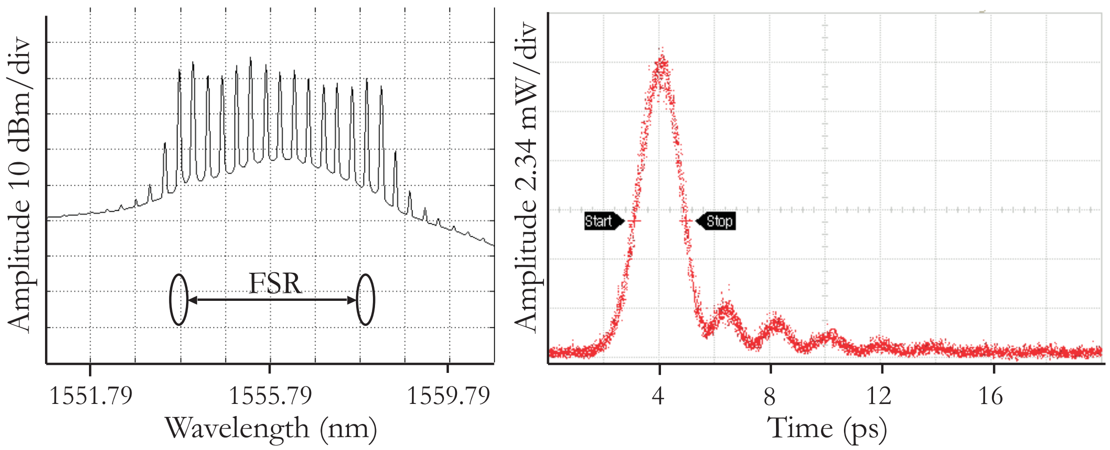

Figure 2: Measured wavelength spectrum and detected response of the drop port of the MR in 'OFF' condition.

radius of 50 μm and are described in detail in [3]. The MRs are themally tunable by means of a chromium heater on top of the MR, enabling to switch between 'ON' and 'OFF' resonance. The MRs were used to analyze their influence on the pulse train described above. The measured spectrum and recovered pulse, measured at the drop port, in the

’OFF’ state are shown in Figure 2. The pulse is altered into a pulse train with a separation according the roundtrips of the pulses. The distance between the pulses is 2.4 ps, a little more that the roundtrip time calculated above. This can be explained by the additional dispersion a pulse has due to the tight radius of the ring. Finite-Difference Time Domain (FDTD) simulations confirm this. The exponential slope of the envelope of the pulse train is a measure for the coupling constants and the loss inside the ring. However, since the incoming pulse has a tail broader than the roundtrip time, the pulses from the outgoing pulse train are not completely independent. This causes the envelope to rise and so it is not possible to determine the coupling ratio by this means.
This can better be seen when looking at the measurements in the ’ON’ state, shown in Figure 3. The wavelength components of the pulse now exhibit a longer delay, since the tails of the outgoing pulses interfere. This causes the individual pulses from the pulse train the melt together in one long pulse with higher intensity as is shown in the right picture of Figure 3. The spectrum confirms this as the FWHM is shortened as is to be expected from the pulse broadening in time. Also the wavelength response of the MR drop port in CW case, with a FSR of 4.2 nm, can be seen superposed on the pulsetrain spectrum.

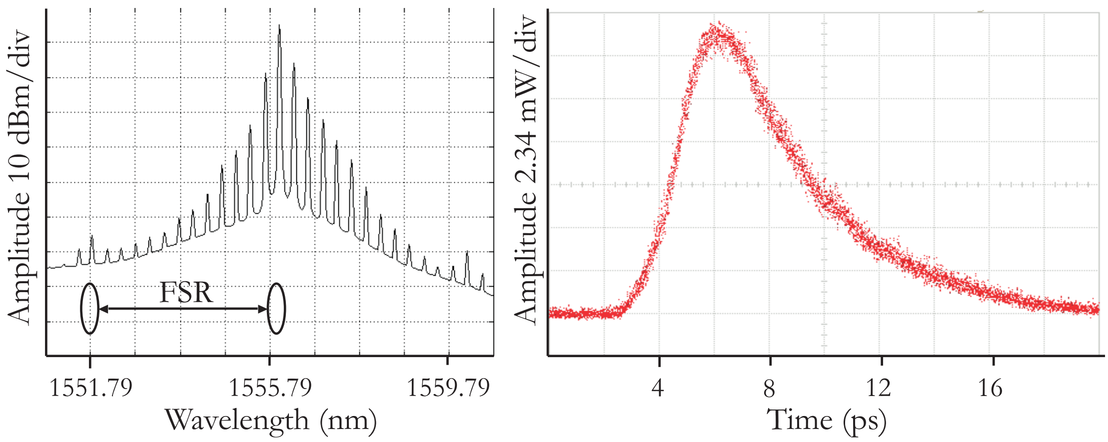

Figure 3: Measured wavelength spectrum and detected response in the drop port of the MR in ’ON’ condition.

fs pulses filtered by microring resonators

To see the behaviour of a pulse that has a FWHM in time that is much shorter than the roundtriptime of the ring, fs pulses where used to characterize the MR. The pulses have a FWHM of 200 fs and a repetition rate of 80 MHz and are generated by an Optical Parametric Oscillator from Spectra Physics. The racetrack MR has a radius of 100 μm and a coupling section of 40 μm and is laterally coupled to the waveguides. The Si_3N_4 waveguides with dimensions of 2.5 x 0.14 μm were placed on a SiO_2 buffer and an air top cladding. This ring has a roundtrip time of $\approx$4 ps. The measured spectrum of the drop and through port are shown in Figure 4. This Figure also shows the CW response of the through port of the ring. Both in the drop and through ports the pulse spectrum can be seen which is around 12 nm wide, superposed with the MR CW response of the appropriate port.

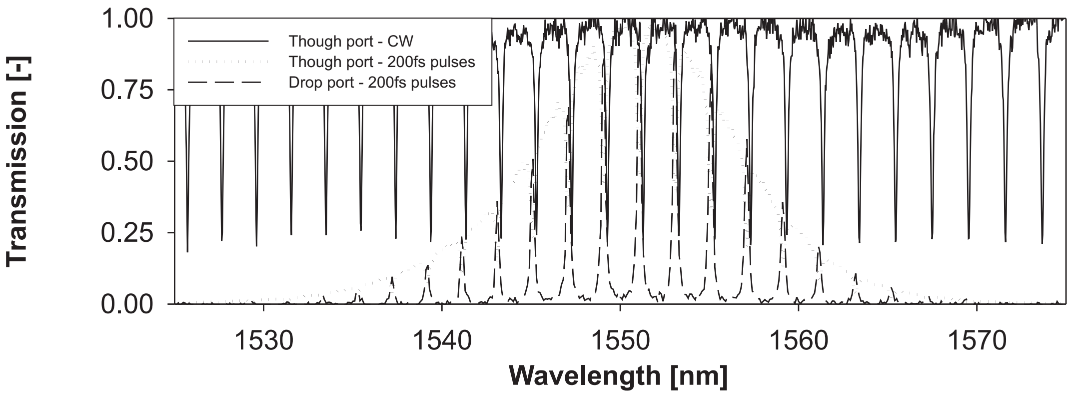

Figure 4: Measured wavelength spectrum after propagation of CW and 200 fs pulses through MR with roundtrip time of ≈4ps.

Conclusion

These measurements show some interesting behaviour of ps and sub-ps pulses in resonant filters (MR). These few measurements already show intriguing results, stimulating additional measurements and demonstrating the fundamental speed limitations for high speed filtering by microring resonators. When even shorter pulses can be used with a duration clearly shorter than the roundtrip time, better answers can be given to the behaviour of the pulses and additional phenomena like ballistic transport can be observed [5].

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