Modelling of Pulse Propagation in Microresonator Devices

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Abstract

Effective method for the calculation of propagation of an optical signal in microresonator (MR) structures is presented. Propagation of rectangular pulses through MR is examined.

Introduction

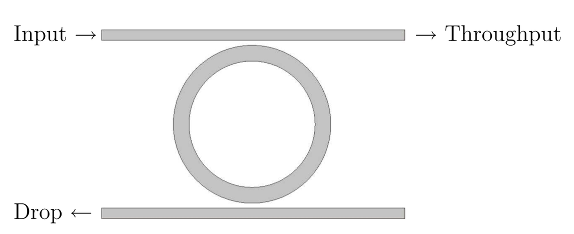
The propagation of an optical wave in MRs is usually modelled using the FDTD method. In the 3D case, this approach provides very realistic results. Time consumption for such calculation, however, makes this method often unusable for design needs even in the 2D approximation.

Another possibility is to use a system-based modelling [1] with the help of the FFT. But, for typical optical frequencies, an extremely large number of samples of the signal must be used.

In this poster, we present an efficient approach similar to the FFT one. The complication with huge number of needed signal samples is overcome by using the Fourier Transform of a periodical signal with a known spectrum. It is a well-known property of a modulated optical signal that its spectrum is formed by a (double-side) spectrum of the pulse envelope centered at the optical (carrier) frequency. Thus, in the frequency domain, only the spectrum of the *modulation* signal is treated. The resultant output time-dependent optical signal is obtained as a sum of the Fourier components in which the optical frequency is properly taken into account.

Numerical results

For the analysis, let us consider a MR structure with two ports, see figure right. The transfer functions of the output ports can be described as



$$F_{through} = \frac{t_1 - \alpha t_2^* (|t_1|^2 + |\kappa_1|^2) \exp(\mathrm{i}\Theta)}{1 - \alpha t_1^* t_2^* \exp(\mathrm{i}\Theta)}, \quad (1)$$

$$F_{drop} = \frac{\alpha_{12} \kappa_1^* \kappa_2 \exp(\mathrm{i}\Theta_{12})}{1 - \alpha t_1^* t_2^* \exp(\mathrm{i}\Theta)}. \quad (2)$$

Here t_i are the transmission coefficients of coupling elements, κ_i are the coupling coefficients. α and Θ are amplitude and phase transmissions per a MR round trip. α_{12} and Θ_{12} are portions of α and Θ related to the path length between input and drop port. Symbol * denotes the complex conjugation. The round trip time of microresonator is defined as

$$t_g = L \frac{N_g}{c_0} = \frac{\lambda_0^2}{c_0} \cdot \frac{1}{FSR}, \quad (3)$$

where L is the round-trip path length inside the MR, N_g is the group effective index, c_0 is the velocity of light, λ_0 is the vacuum wavelength, and FSR is the free spectral range.

For simplicity, let us consider a single rectangular pulse as an input signal. Two different cases are treated. For polymeric MR structure with $R = 50\,\mu$m, $t_g = 1.565$ ps and coupling coefficients $\kappa = 0.7$, propagation of pulses with lengths $T = 10$ ps and $T = 0.2$ ps is analyzed.

Propagation of a rectangular pulse with length $T = 10$ ps is treated first. The results are shown in Fig. 1.

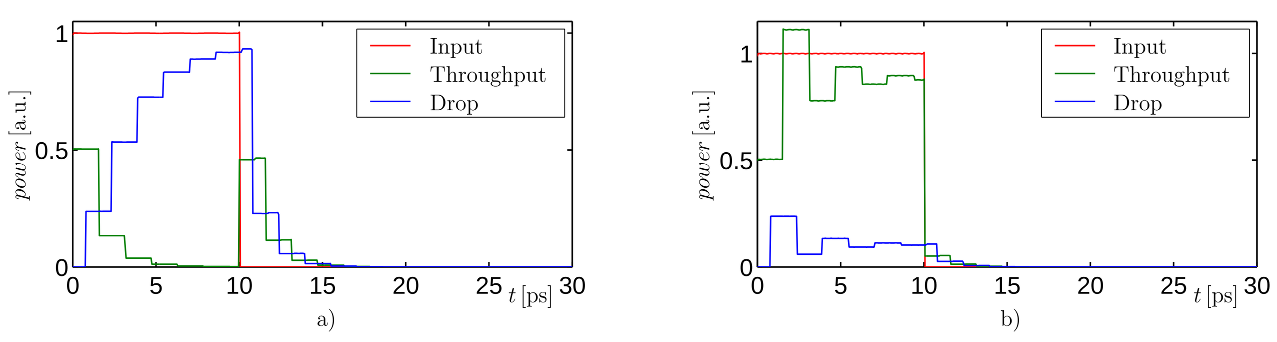


Fig. 1. The power of the input and output signals for $T = 10$ ps.

Fig. a) shows the results for the case when the carrier optical wavelength is identical with a resonant wavelength of the MR, Fig. b) holds for the case when the carrier wavelength lies between neighbouring resonances. One can see that at resonance, the behavior of the drop port can be described as an integrator – the high frequency components are filtered out. This fact causes a distortion of the output signal. Conversely, the output signal in the throughput port has the character of a derivator and thus the changes of the input signal are transferred also into the throughput port. On the other hand, there are oscillations of the output signals when the carrier wavelength is out of resonance.

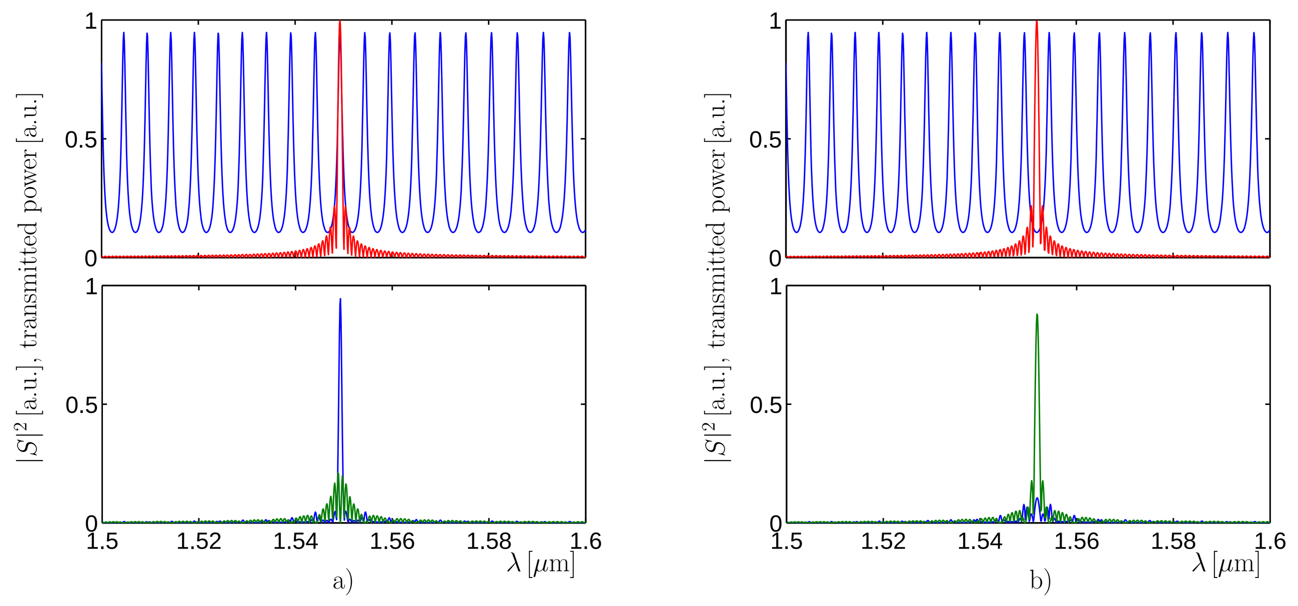


Fig. 2. Spectrum of the input signal and spectral characteristics of the drop port (top), spectra of the output signals (bottom). Pulse length is $T = 10$ ps.

An interesting problem of propagation of a pulse shorter than the MR round trip time was recently discussed , e.g., in [2]. The results for the pulse length $T = 0.2$ ps are depicted in Fig. 3.

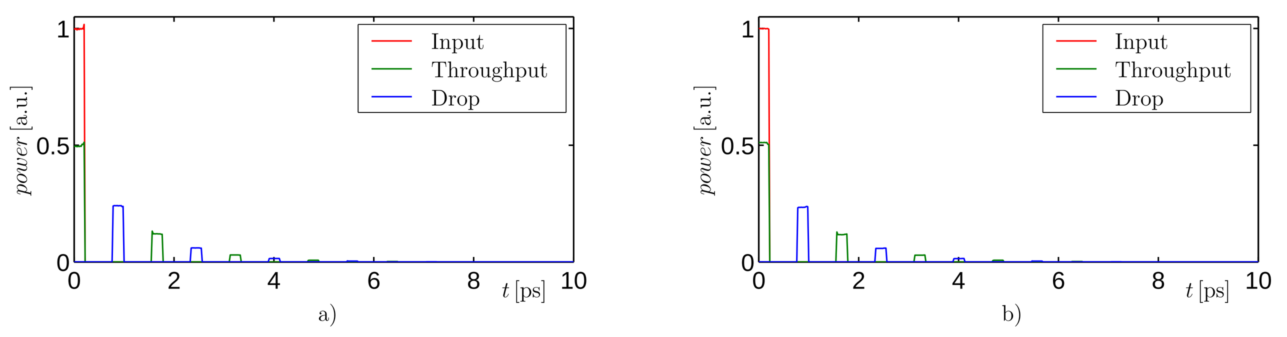


Fig. 3. The power of the input and output signals for $T = 0.2$ ps.

It is obvious that the input signal is only divided between the throughput port and the MR ring guide with the ratio of the coupling coefficients. In addition, the results are not influenced by the position of the center wavelength of the signal to a resonant wavelength of the MR.

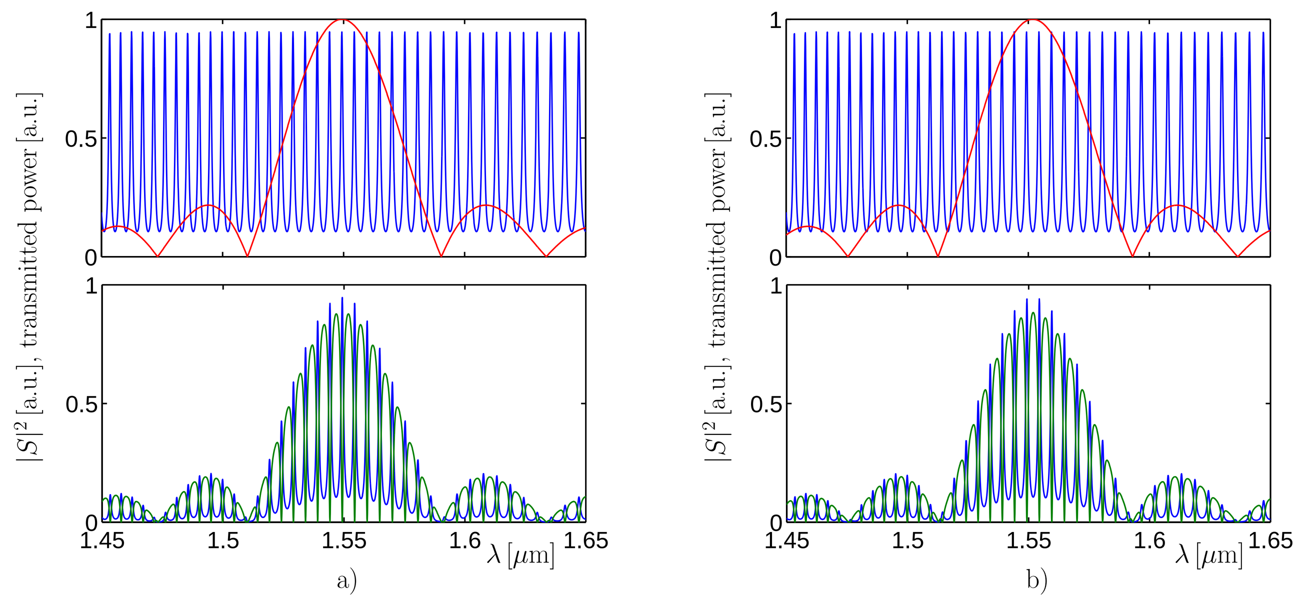


Fig. 4. Spectrum of the input signal and spectral characteristics of the drop port (top), spectra of the output signals (bottom). Pulse length is $T = 10$ ps.

Conclusions

Simple, powerful and efficient method for numerical analysis of time domain characteristics of microresonator devices was presented. Propagation of rectangular pulses through microresonators was studied with this method.

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References

[1] A. Yariv, Universal relations for coupling of optical power between microresonators and dielectric waveguides. *Electronics letters,* Vol. **36**, No. 4, pp. 321–322, 2000.

[2] A. Driessen et al., Microresonators as building blocks for VLSI photonics. The International School of Quantum Electronics, 39th course, Erice, Sicily, 2003.