Backscatter in Waveguides and Circuits

File name: `2Rings_backscatter.apc`

Reference: F. Morichetti et al., "Roughness Induced Backscattering in Optical Silicon Waveguides," Phys. Rev. Lett. 104, 033902 (2010).
F. Morichetti et al., "Backscattering in silicon photonic waveguides and circuits", Proc. SPIE 7943, 79430J (2011).

In integrated optical waveguides the main responsible of waveguide attenuation is the scattering due to sidewall roughness. The scattered light is spread around the waveguide but a portion is coupled to the backward foundamental mode and can interfere with other pars of the circuits, induce a distortion of the spectral transfer function or increase the crosstalk. The electromagnetic analysis of a wave propagating along a waveguide with rough sidewalls it is a well-known cumbersome problem. In Aspic, the straight waveguide and the bent waveguide own a unique analytical model of the backscatter that allows to take into account the distributed backscatter at no extra computational cost. For the theoretical details the user can refer to the publications in the Reference.
The “Straight” and “Circular Bend” allow to specify the Backscatter Probability Spectral Density Function PSD in [dB/mm]. This parameter specifies the average power backscattered by 1 millimetre of waveguide, the distribution being Gaussian in intensity and white in frequency. An example of the spectral response of two waveguides 1 mm and 1 cm long with a backscatter PSD of -27 dB/mm, the typical value for the TE mode in a silicon wire waveguide, is shown in fig. 1.

Fig. 1 – Spectral transmission (above) and reflection (below) characteristics of waveguides 1 mm and 1 cm long with PSD of -27 dB/mm.

The ripple period depends on the length of the waveguide that produces a correlation among all the uncorrelated contributions. Note that the average backscatter power level is -27dB for the 1mm long waveguide and -17dB for the longer one. Also the phase and the group delay are affected by the distributed backscatter.

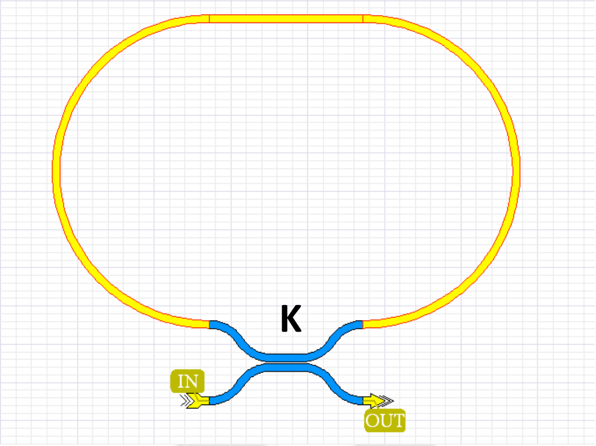

Fig. 2 – All-pass ring filter with Rough Circular and Straight Waveguide

Fig. 2 shows an example where the model of the distributed backreflections allows the correct simulation of the circuit behaviour. The circuit is a ring-based all-pass filter, where coupling coefficients K equal to 0.2 and 0.8 and roughness-induced backreflection of -30dB/mm has been considered inside the cavity. For an all-pass filter it is well known that, for small values of K, the light trapping at the resonant frequencies of the ring resonator can induce sharp transmission notches. The common explanation is that the light is radiated out during the propagation in the cavity, but roundtrip losses do not entirely justify the observed notches' depth.

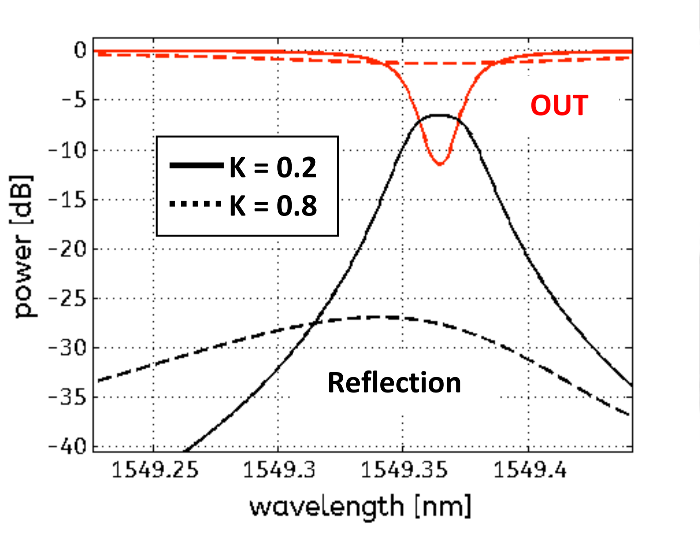

Fig. 3 – Spectral characteristic of the all-pass filter of Fig. 2. Red lines represent the power transmitted from port OUT, black lines the power reflected from port IN. Two different values of the coupling coefficient have been considered.

Fig. 3 shows that the missing light is actually scattered back as consequence of the waveguide sidewall roughness and, for sufficiently low values of K, can even exceed the transmitted power, as in the case of the APF in Fig.2 with K=0.2. The multiple round trips in the resonator strongly correlate the backscattering, so that it does not exhibit a white-noise-like power spectral density as in a straight waveguide.

Fig. 4 shows a circuit, two coupled rings, realizing a bandpass filter with FSR=400GHz and bandwidth of 30 GHz. The filter has been designed with the Aspic Synthesis Toolbox and then the bent waveguides composing the rings have been substituted with Rough Circular Bends with a PSD of -27 dB.

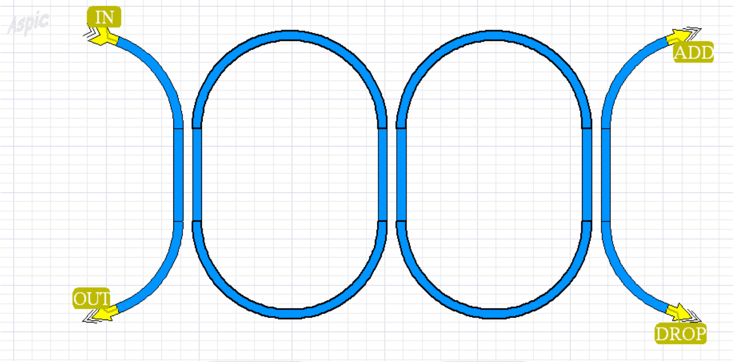

Fig. 4 – Coupled ring resonator filter

Fig. 5 reports the spectral transfer function of the filter at the four ports. As can be noticed the backscatter does not affect the Drop and Out characteristic (blue and red lines). This is a property of these filters as the backscattered light never interferes with the incoming one. The other two ports, instead, In and Add, should be isolated but an intense and spectrally oscillating light is present. Ten simulations are reported, corresponding to ten different realizations of the same identical filter. Note that, around the resonance, the backreflected signal can be as high as -15dB.
Even if the nominal parameters are identical, the roughness, and hence the backscatter, is different, exactly as in practice. The analysis is obtained by clicking the Sweep box in the Simulation Config windows and specifying the number of simulations to carry on.

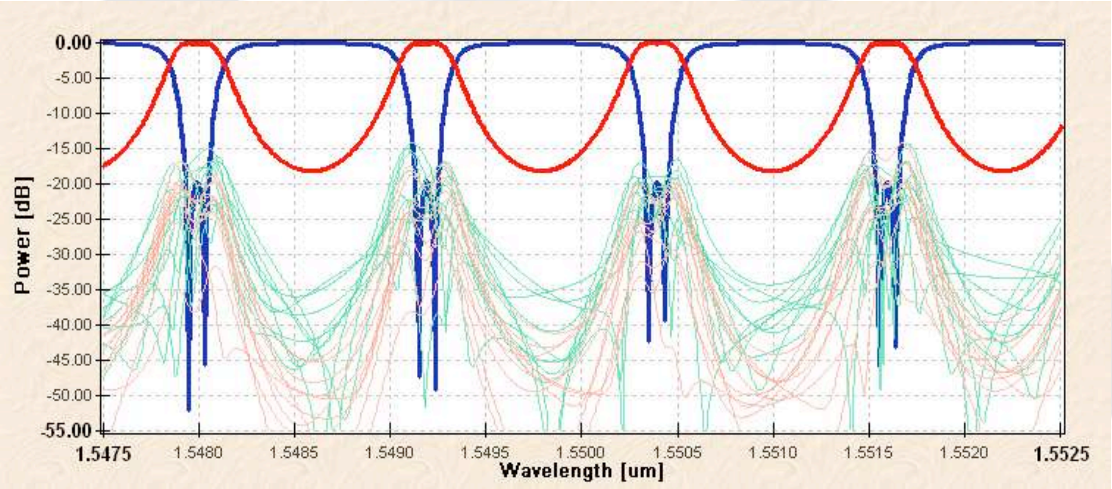

Fig. 5 – Spectral characteristic of the filter of Fig. 4. OUT and DROP port characteristics are shown in thick line, IN and ADD in thin lines.

The effect of the back scatter is even more detrimental in all the circuits that works in reflection as Bragg gratings, Michelson interferometers, all pass ring filters and so on.