Design and Simulation of a Ring Resonator using the FDTD Technique

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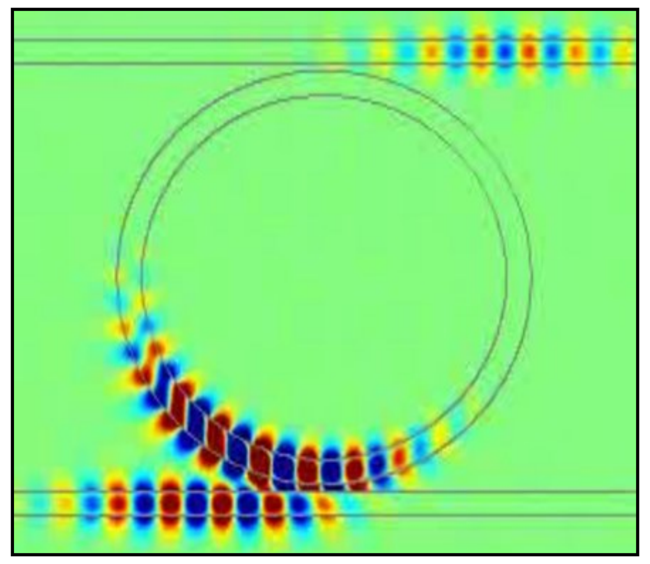
Introduction

- I explored the defining properties of ring resonators and the characteristics of an ideal device.
- Ring resonators are an optical filtering device that have a variety of practical applications such as:
  i. Mechanical, thermo-optic or electro-optic sensing
  ii. Wavelength filtering
  iii. Multiplexing



Simulation of a wave propagating through a ring resonator

- The main operating principles of ring resonators are total internal reflection and optical coupling.

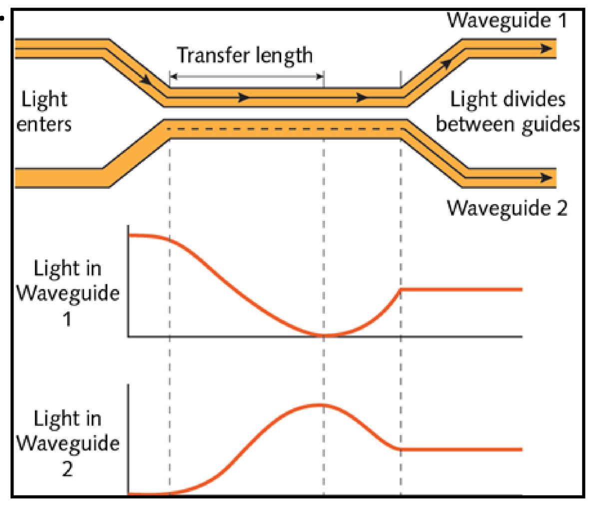
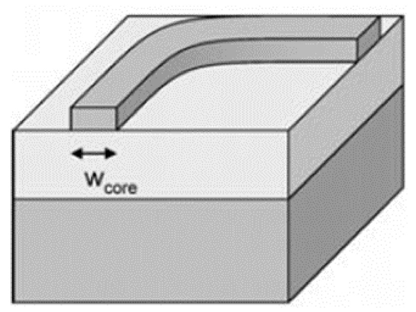
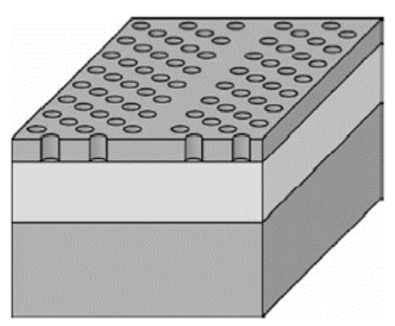


Illustration of optical coupling

- Ring resonators can be made from photonic crystal slabs or they can be Silicon on Insulator devices.
- Ring resonators made from a photonic crystal slab have a photonic band-gap guided mode. This is very prone to dispersion.
- Resonators made as Silicon-on-Insulator devices use photonic wire guided modes. They are much better at containing light to the cavity as they have a high refractive index contrast.



Photonic Wire Waveguide



Crystal Slab Waveguide

Analysis

- The main points of a ring resonator that we analyse are the input signal, the through port, the drop port and the add port.

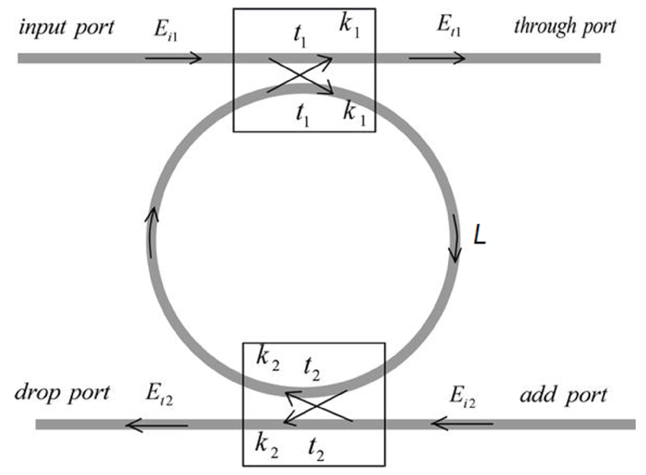


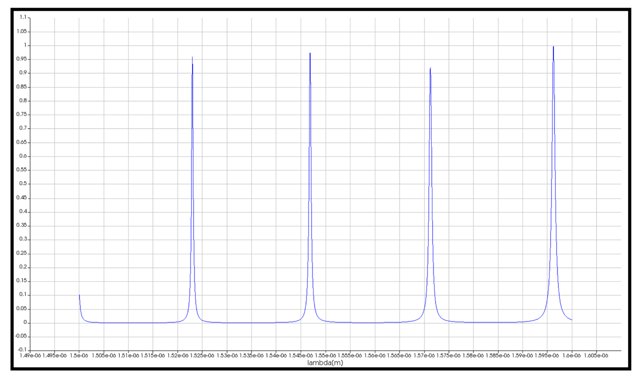
Illustration of the analysis points of a ring resonator

- The main equations that define the efficiency of a ring resonator are:

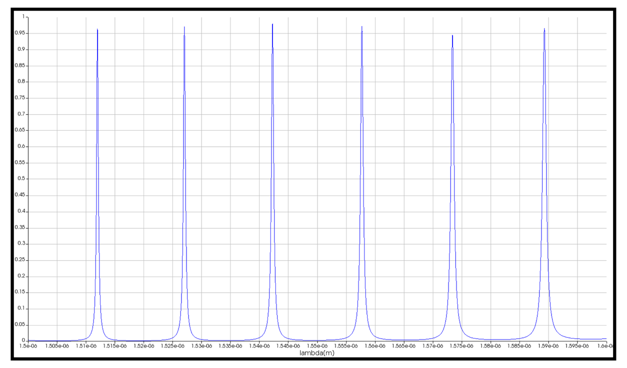
$$FSR = \frac{\lambda^2}{n_g L} \qquad Q = \frac{n_g L \pi}{\lambda} \frac{\mid T_{11} \mid}{1 - \mid T_{11}^2 \mid}$$

$$L_{coupler} = \frac{\lambda}{\pi \Delta n} \sin^{-1}(\mid T_{12} \mid)$$

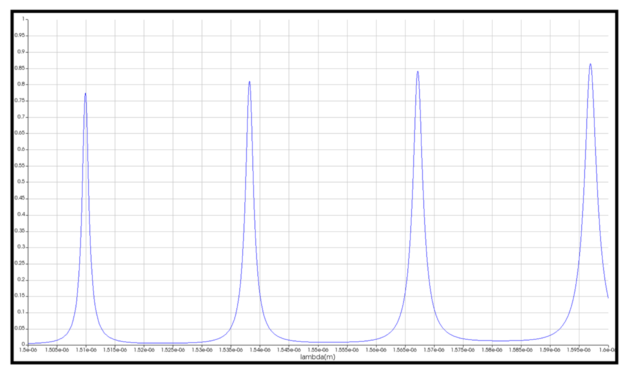
- FSR is the Free Spectral Range. It allows us to have access to a larger bandwidth of signals and drop single signals from a broadband of signals.
- Q-Factor of a photonic component is also known as the *quality factor.* This is the total number of trips that light can make inside a cavity before its intensity is reduced by a factor of e.
- The intrinsic properties of the ring resonator that affect the Free Spectral Range of the resonator are the circumference of the ring - L, coupling distances - T_{11} /T_{12} and the coupling length - $L_{Coupler}$.



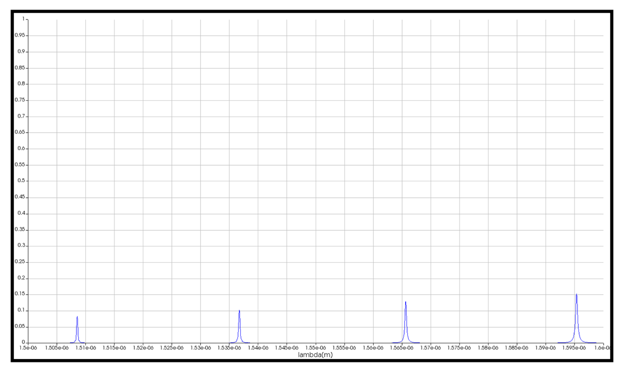
Drop signal : R = 3.7μm



Drop signal : R = 5.8μm

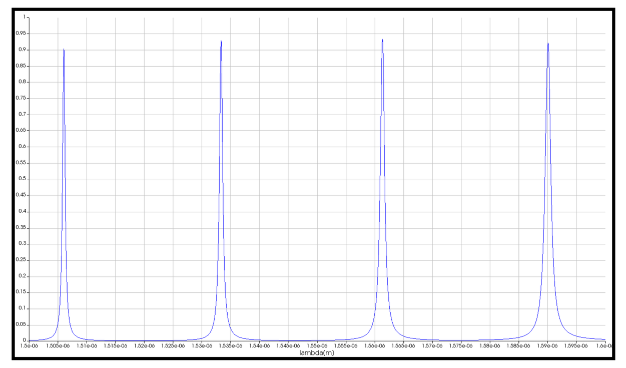


Drop signal : T_{11} = 0.03μm

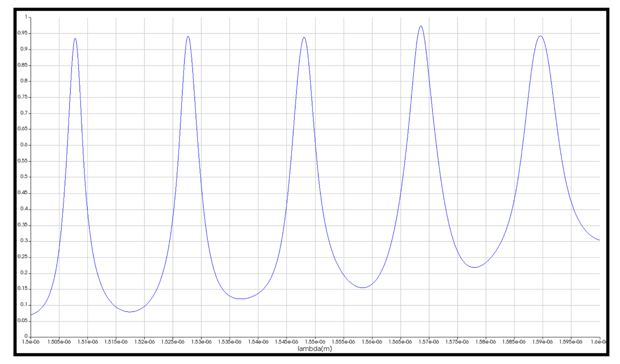


Drop signal : T_{11} = 0.3μm

Conclusions

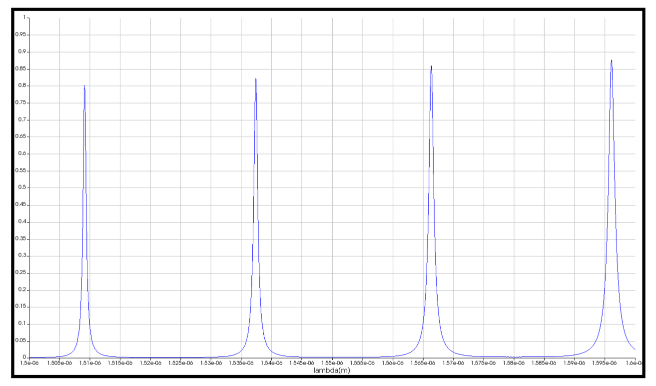


Drop signal : $L_{Coupler}$ = 0.3μm

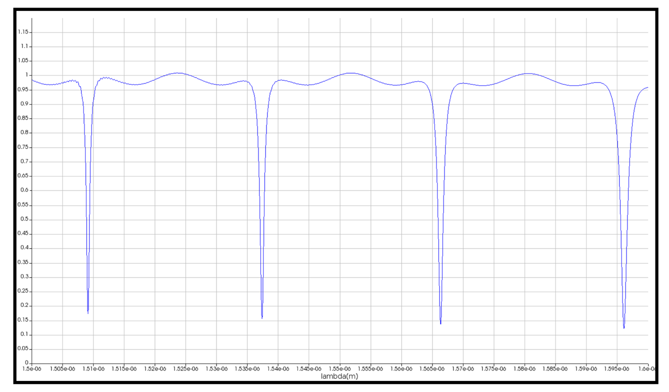


Drop signal : $L_{Coupler}$ = 3μm

- As we increase the ring length we increase the Free Spectral Range of the resonator. This increases the number of signal frequencies that are filtered.
- As we increase the coupling distance, less and less of the electromagnetic wave is coupled to the ring, so we effectively filter nothing. However, if we make it too small we obtain broad signal spikes. Approximately 0.1μm is ideal for a ring size of R = 3.1μm.
- As we increase the coupling length we reduce the intensity of the received signal peaks and broaden our signal peaks as well.

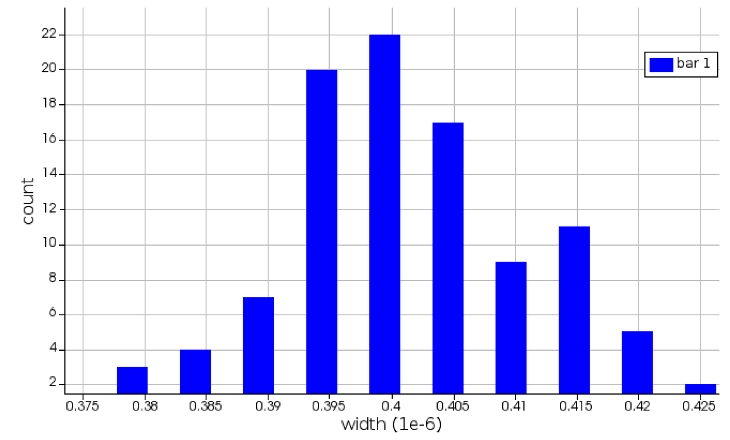


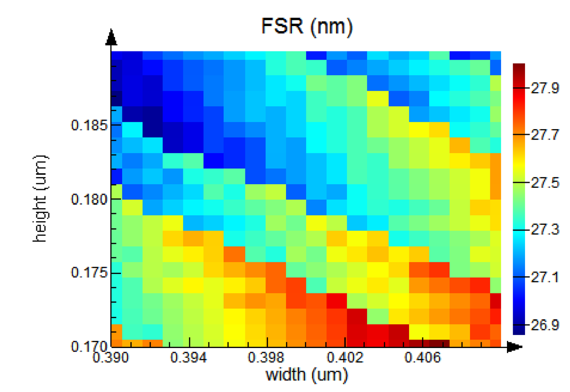
Drop signal of Ideal Resonator



Through signal of Ideal Resonator

- If we wish to maintain sharp transmission peaks and intensity levels then we must keep the coupling length to an absolute minimum. Thus $L_{coupler}$ should be 0.
- To maximise our Q-factor a value of T_{11} = 0.0956 is close enough for resonance without being too close that the peaks become too broad.
- For this value of T_{11} the optimum ring size for propagation resonance is a radius of 3.1μm.





Effect of Fabrication Tolerances on the FSR of an Ideal Resonator