Contents

Fabry-Perot Etalon (Non-Dispersive)

A Fabry-Perot (FP) resonator is composed of a slab of material with high refractive index or a pair of parallel reflecting surfaces with some distance (L). The surfaces can either be mirrors or an interface between two regions of differing refractive index. The mechanism of resonance is based on the multiple beam interference as a result of successive reflections from the two parallel interfaces, see Fig. 1.

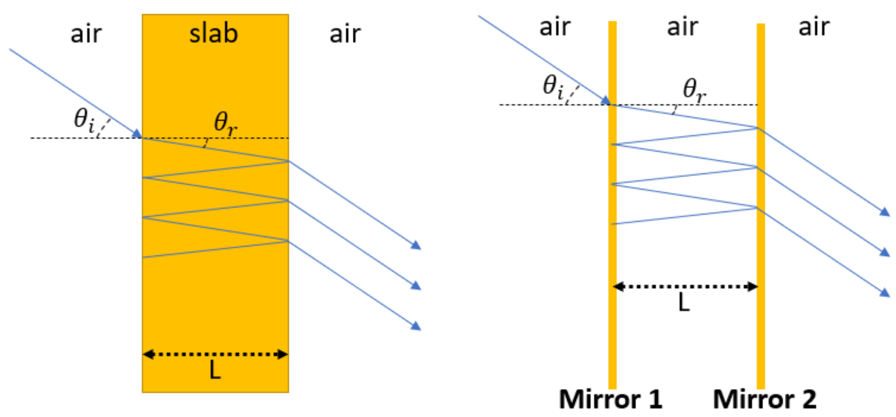

Figure 1: The basic schematics of Fabry-Perot resonators composed of a high-index slab (left) and a pair of parallel mirrors (right).

Labels

Fabry-Perot resonator; resonator; transmittance; reflectance.

Theory

The resulting transmitted (E_t) and reflected (E_r) electric fields from an FP resonator can be obtained as

$$\begin{aligned} E_t &= E_i t_1 t_2 \left(1 + r_2^2 e^{i\phi} + r_2^4 e^{i2\phi} + ...\right) && (1) \\ E_r &= E_i \left[r_1 + t_1 t_2 r_2 e^{i\phi} \left(1 + r_2^2 e^{i\phi} + r_2^4 e^{i2\phi} + ...\right)\right] && (2) \end{aligned}$$

where E_i is the incident electric field [1-2]. The coefficients r_1 (r_2) and $t_1(t_2)$ are the amplitude reflection and transmission coefficients from the medium $n_1(n_2)$ to $n_2(n_1)$, respectively. The parameter $\phi = \frac{4\pi n_2 L}{\lambda}$ is the phase difference as a result of a round-trip between two successive outgoing waves.

The reflectivity of each interface ($R = r_1 r_2$) for the normal angle of incidence is calculated as

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 \tag{3}$$

and the transmittance (the superposition all transmitted waves) (T) and reflectance (the superposition of all reflected waves) ($\mathcal{R}$) can be obtained as

$$\begin{aligned} T &= \frac{|E_t|^2}{|E_i|^2} = \frac{1}{1 + F\sin^2\left(\frac{\phi}{2}\right)} && (4) \\ \mathcal{R} &= \frac{|E_r|^2}{|E_i|^2} = F\frac{\sin^2\left(\frac{\phi}{2}\right)}{1 + \sin^2\left(\frac{\phi}{2}\right)} && (5) \\ F &= \frac{4R}{(1-R)^2} && (6) \end{aligned}$$

where F is the finesse parameter indicating how sharp a resonance seems in comparison with the spectral distance between two consecutive resonances (FSR) [1-2].

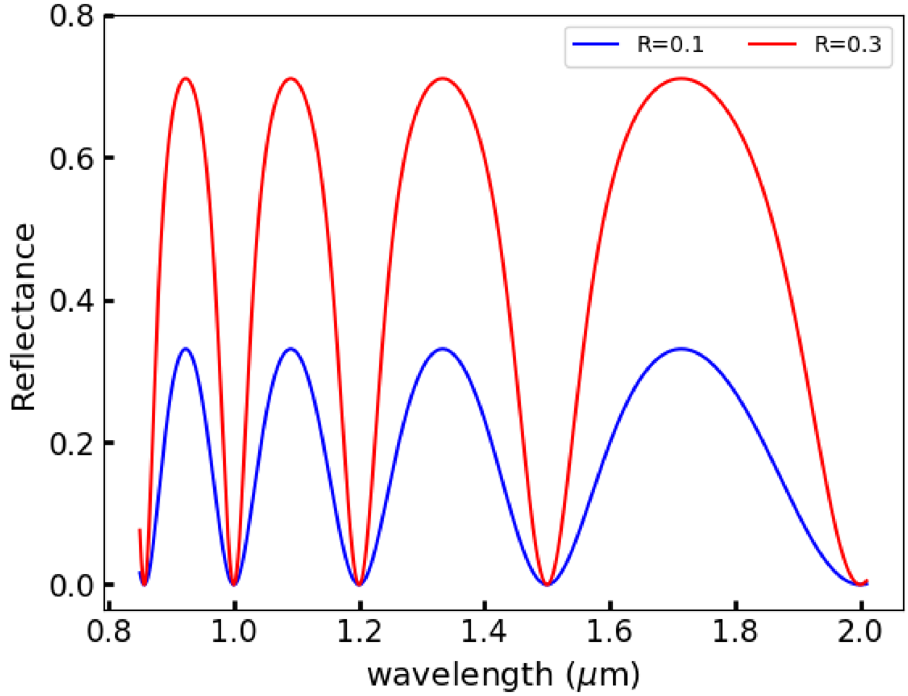

Figure 2: Reflectance spectrum of a Fabry-Perot resonator composed of a pair of parallel mirrors with different reflectivity coefficients and a separating distance L=3μm.

For the case of a lossless resonator, the conservation of energy implies the relation

$$\mathcal{R} + T = 1 \tag{7}$$

The reflectance spectrum of an FP etalon composed of a pair of parallel mirrors can be obtained analytically, see Fig. 2.

Design

The simulation is performed using a 2D design consisting of a waveguide centered in the domain.

Table 1: Wafer specifications and boundary conditions

Wafer properties	Value
Length along x (μ m)	1 μ m
Length along z (μ m)	16 μ m
Boundary conditions (z = 0 and z = 16 μ m	Anisotropic perfectly matched layer (APML)
Boundary conditions (x = 0 and z = 1 μ m	Periodic boundary condition (PBC)

The input plane was configured using a rectangular distribution as the optical source positioned at z=5.5 μm

Table 2: Details of the optical source employed in the simulation

Optical source features	Value
Wavelength (μm)	1.55
Half Width (μm)	0.5
Direction of propagation	z
Time domain shape	Sine-Modulated Gaussian Pulse

The mesh parameters (Δx and Δz) are chosen as 0.003 μm. The number of time-steps for a simulation is dependent on the length of an FP resonator. Testing confirmed that for the FP resonator under test (n=3 and L=3 μm) 35000 time-steps were adequate, see the article on convergence testing for further details [??]. The polarization is set to "TE" which is corresponding to components of E_y, H_x and H_z.

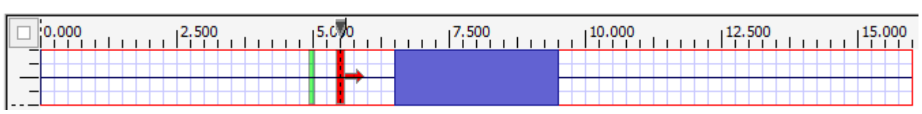

Figure 3: The layout for the simulation of an FP etalon using OptiFDTD.

Results

Figure 4 show the simulation results of an FP etalon composed of a slab with different reflectivity coefficient R and the length L=3 μm. The reflectivity coefficient R=0.1 and 0.3 correspond to the refractive index n=1.92 and 3.42, respectively. A good agreement between the simulation results and the analytical ones can be observed. Note that the FSR is not identical for different values of reflectivity (R) due to different phase-shifts caused by different refractive indices of the FP resonator.

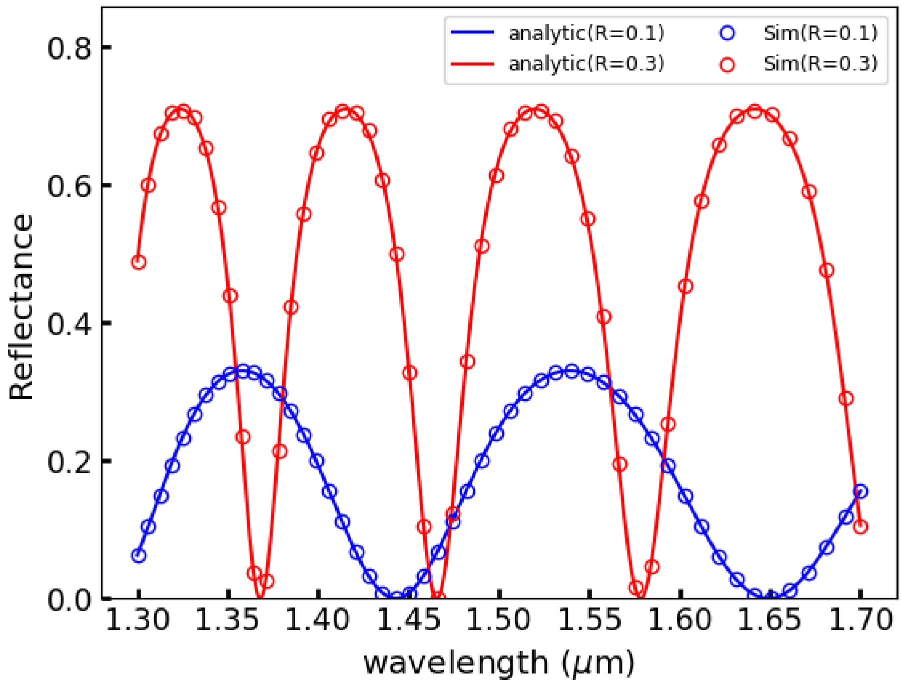

Figure 4: Reflectance spectrum of an FP etalon composed of a high-index slab for two different reflectivity coefficients, R=0.1 (n=1.92) and 0.3 (n=3.42).

The structure can be modeled for different lengths of the FP resonator and the resulting spectra can be seen in Fig. 5. Note that all reflectance spectra show a zero at λ=1.5 μm due to the even integer ratio n/λ=2 in Eq. 5.

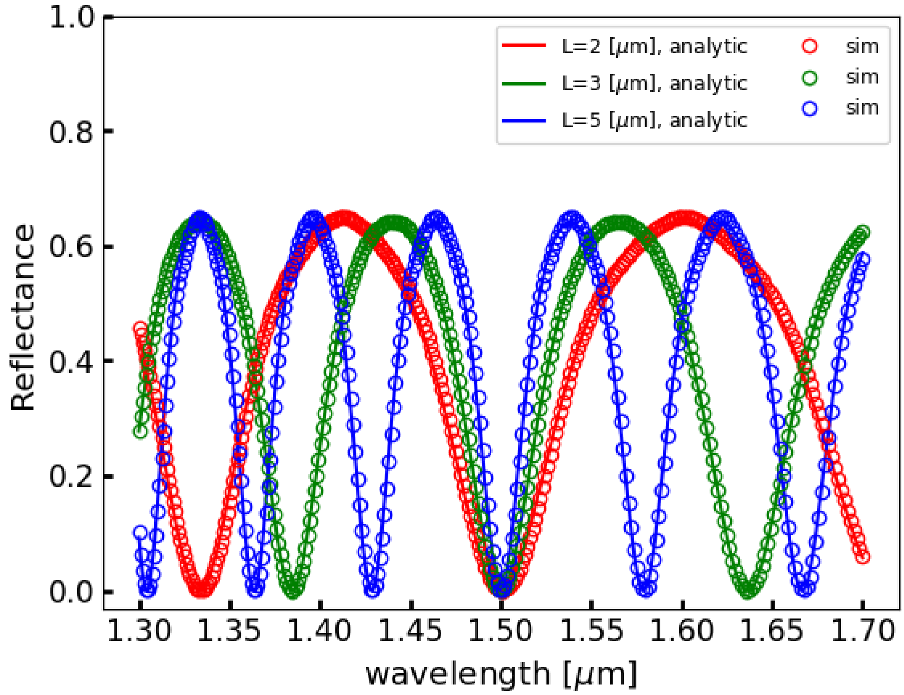

Figure 5: Reflectance spectrum of a Fabry-Perot resonator composed of a high-index slab (n=3) for three different resonator lengths, L=2 μm, 3 μm and 5 μm.

Convergence testing was completed on the results to ensure suitable mesh size (Δx and Δz) and number of time-steps were used.

References

1. A. Ghatak, *Optics 3rd edition.* New Delhi, India: Tata McGraw-Hill Education, 2005.
2. E. Hecht, *Optics 4th edition.* San Francisco, Ca, USA: Addison Wesley, 2002.