Contents

Fabry-Perot Etalon (Lossy Dispersive)

The Fabry-Perot etalon has previously been covered. However, introduction of dispersive materials changes the expressions and add complexity to the refelction and transmisssion spectra.

Labels

Fabry-Perot etalon; Reflectance; Dispersive material; Lorentz-Drude model

Theory

For a material to have gain or loss the refractive index must be complex in nature ($\tilde{n} = n' - jn''$). Note that Optiwave uses the engineering sign convention which results in the use of the negative in the refractive index expression. The reflectance ($\mathcal{R}$) for the case of a lossy dispersive Fabry-Perot (FP) resonator filled with material n_2, with a background medium of n_1, and a length of L is calculated as [1]

$$\mathcal{R} = \frac{R\left(1 - 2e^{\alpha L}cos(\phi) + e^{2\alpha L}\right)}{1 - 2Re^{\alpha L}cos(\phi) + R^2 e^{2\alpha L}} \tag{1}$$

where $R = \frac{(n_2^{'}(\omega) - n_1)^2 + n_2^{''2}(\omega)}{(n_2^{'}(\omega) + n_1)^2 + n_2^{''2}(\omega)}$ is the reflectivity and the absorption coefficient is calculated as $\alpha = -\frac{4\pi n^{''}}{\lambda}$ [2-3]. The parameter $\phi = \frac{4\pi n^{'} L}{\lambda}$ represents the phase difference as a result of a round-trip between two successive outgoing waves.

Within OptiFDTD, a dispersive material $n(\omega)$ is achieved through fitting the permittivity with the Drude model along with a number of Lorentz resonances i.e. :

$$\varepsilon_r = 1 + \sum_{m=0}^{M} \frac{G_m \Omega_m^2}{\omega_m^2 + i\Gamma_m \omega - \omega^2} \tag{2}$$

where $\sum_{m=1}^{M} G_m = 1$. The coefficient G_m corresponds to oscillator strength. Ω_m, Γ_m and ω_m represent the plasma frequency, damping factor and the m-th resonance frequency, respectively. For further details, see the Lorentz-Drude article.

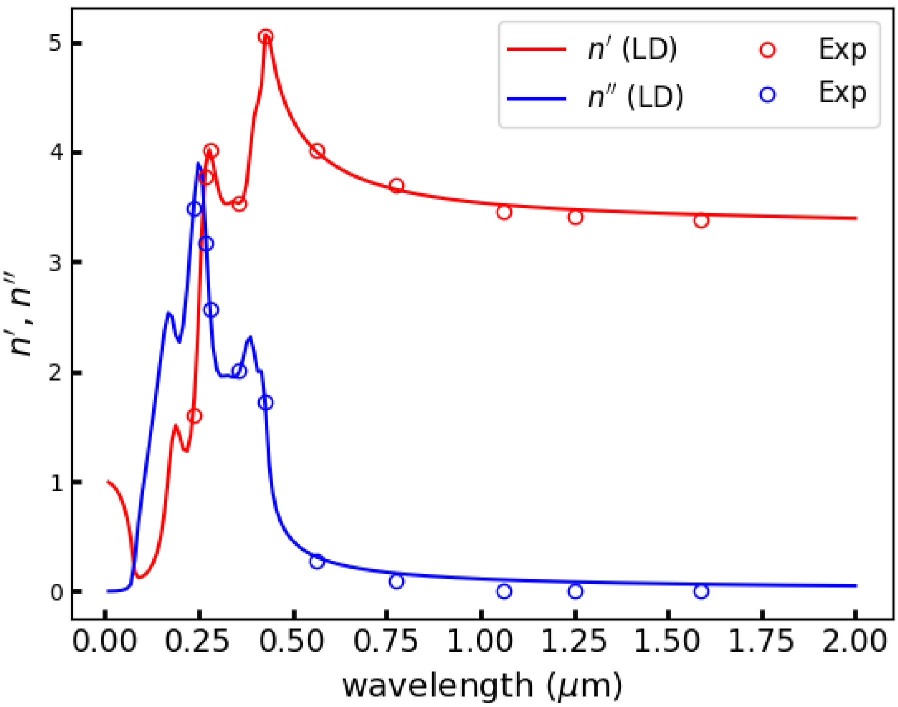

Figure 1: The real and imaginary parts of the refractive index of GaAs. The experimental data is taken from [4].

Design

The permittivity of Gallium Arsenide (GaAs) can be described adequately by Lorentz-Drude model with six resonance frequencies and ε_∞ set to unity. The real ($n^{'}$) and imaginary ($n^{''}$) parts of the complex refractive index of GaAs are shown in Fig. 1.

The general layout for the simulation of a FP etalon is shown in Fig. 2. For other settings of the design e.g. dimensions of the simulation region, the boundary conditions and the input plane features see the article Fabry-Perot Etalon.

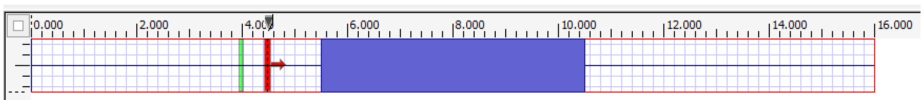

Figure 2: The layout for the simulation of a FP etalon using OptiFDTD.

Results

Figure 3 shows the reflectance spectra of lossy dispersive FP resonators made of GaAs with different lengths i.e. 2 μm, 3 μm and 5 μm. As can be seen, the reflectance for all three lengths of the FP resonator oscillates with increased attenuation for shorter wavelengths resulting from the dispersion in both the real part of the refractive index and propagation loss (α).

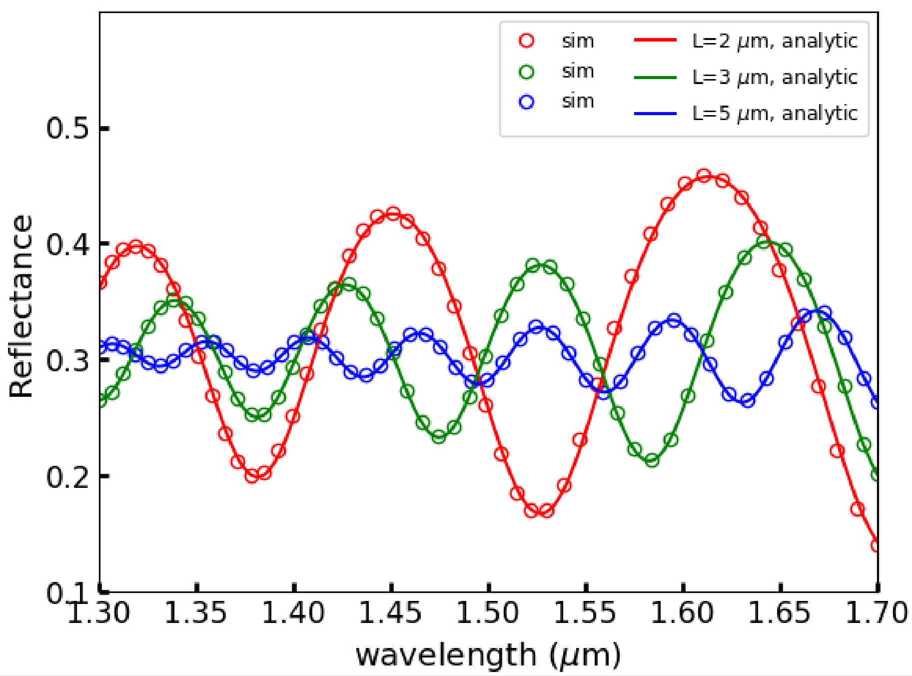

Figure 3: The reflectance spectra (normal incidence) of lossy dispersive FP etalons with three different lengths.

References

1. M. Fopx, *Optical Properties of Solids 2nd edition (Oxford Master Series in Pysics)*. New York, New York, USA: Oxford University Press, 2003.
2. A. Ghatak, *Optics 3rd edition*. New Delhi, India: Tata McGraw-Hill Education, 2005.
3. E. Hecht, *Optics 4th edition*. San Francisco, Ca, USA: Addison Wesley, 2002.
4. M. N. Polyanskiy, “Refractive index of GaAs (Gallium Arsenide) - Aspnes,” https://refractiveindex.info/?shelf=main&book=GaAs&page=Aspnes (accessed March 01, 2023).