Etalons

Etalons are most commonly used as line-narrowing elements in narrowband laser cavities or as bandwidth-limiting and coarse-tuning elements in broadband and picosecond lasers. Further applications are laser line profile monitoring, diagnosis.

The etalons described in this section are all of the planar Fabry-Perot type. Typical transmission characteristics for this type etalon are shown in Figure 1.58.

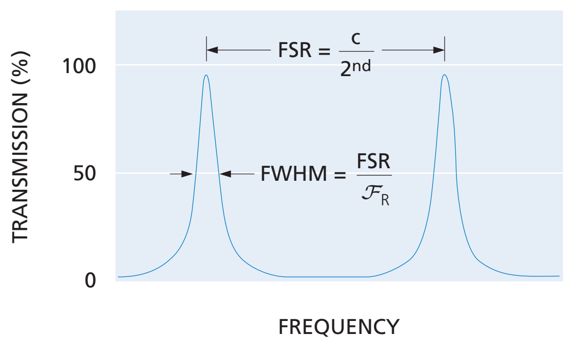

Figure 1.58 **Transmission characteristics of a Fabry-Perot etalon**

Air-Spaced Etalons consist of pairs of very flat plano-plano plates separated by optically contacted spacers. The inner surfaces of the plates are coated with partially reflecting coatings, the outer surfaces are coated with antireflection coatings.

Solid Etalons are made from a single plate with parallel sides. Partially reflecting coatings are then deposited on both sides. The cavity is formed by the plate thickness between the coatings.

Deposited Solid Etalons are a special type of solid etalon in which the cavity is formed by a deposited layer of coating material. The thickness of this deposited layer depends on the free spectral range required and can range from a few nanometers up to 15 micrometers. The cavity is sandwiched between the etalon reflector coatings and the whole assembly is supported on a fused-silica base plate.

Etalon plates need excellent surface flatness and plate parallelism. To avoid peak transmission losses due to scatter or absorption, the optical coatings also have to meet the highest standards.

For a plane wave incident on the etalon, the transmission of the etalon is given by:

$$T = \frac{I_{\text{trans}}}{I_{\text{inc}}} = \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2(\delta/2)} \qquad (1.112)$$

Here, R is the reflectance of each surface; δ is the phase shift

$$\delta = \frac{2\pi}{\lambda}\eta d\cos\theta \qquad (1.113)$$

where,

η is the refractive index (e.g., 1 for air-spaced etalons)

d is the etalon spacing or thickness

θ is the angle of incidence

The free spectral range (FSR) of the etalon is given by

$$\text{FSR} = \frac{c}{2\eta d} \text{ in Hz} \qquad (1.114)$$

$$= \frac{1}{2\eta d} \text{ in cm}^{-1}$$

$$= \frac{\lambda^2}{2\eta d} \text{ in nm}$$

The reflectivity finesse, $\mathcal{F}_R$ is given by

$$\mathcal{F}_R = \frac{\pi\sqrt{R}}{1-R} \qquad (1.115)$$

Figure 1.59 shows the reflectivity finesse as a function of the coating reflectivity.

The bandwidth (FWHM) is given by

$$\text{FWHM} = \frac{\text{FSR}}{\mathcal{F}_R} \qquad (1.116)$$

However, the above applies to theoretical etalons which are assumed to be perfect. In reality, even the best etalon will show defects that limit theoretically expected performance. Therefore, in a real etalon, the actual finesse will usually be lower than the reflectivity finesse.

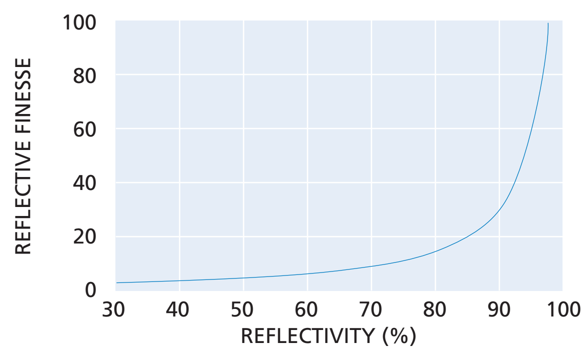

Figure 1.59 **Reflectivity finesse vs. coating reflectance of each surface**

$$\mathcal{F}_R = \frac{\pi\sqrt{R}}{1-R} \quad (1.117)$$

$$\mathcal{F}_S = \frac{M}{2}\frac{\lambda}{633\text{ nm}} \quad (1.118)$$

$$\mathcal{F}_\theta = \frac{\lambda}{d\tan^2\theta} \quad (1.119)$$

$$\mathcal{F}_D = \frac{\mathrm{CA}^2}{2d\lambda} \quad (1.120)$$

where $\mathcal{F}_R$ is the reflectivity finesse, $\mathcal{F}_s$ is the plate spherical deviation finesse coefficient, $\mathcal{F}_\theta$ is the incident beam divergence finesse coefficient, and $\mathcal{F}_d$ is the diffraction-limited finesse coefficient.

The defects that contribute to this reduction are as shown in Figure 1.60 (graphical representations are exagerated for clarification).

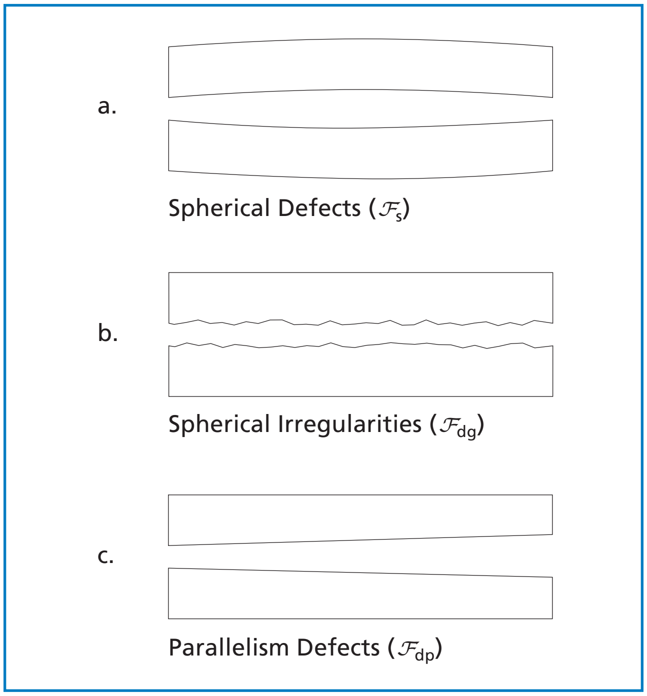

Figure 1.60 **Three types of defects contributing to the total defect finesse**

All three types of defects contribute to the total defect finesse $\mathcal{F}_d$:

$$\frac{1}{\mathcal{F}_d^{\,2}} = \frac{1}{\mathcal{F}_S^{\,2}} + \frac{1}{\mathcal{F}_{dg}^{\,2}} + \frac{1}{\mathcal{F}_{dp}^{\,2}} \quad (1.121)$$

The beam divergence also influences the actual finesse of an etalon.

Taking into account all these contributions, the effective finesse ($\mathcal{F}_e$) of an etalon (with $\mathcal{F}_R$ being the reflectivity finesse and $\mathcal{F}_\theta$ the divergence finesse) is:

$$\frac{1}{\mathcal{F}_e} = \sqrt{\frac{1}{\mathcal{F}_R^{\,2}} + \frac{1}{\mathcal{F}_D^{\,2}} + \frac{1}{\mathcal{F}_\theta^{\,2}} + \frac{1}{\mathcal{F}_S^{\,2}}} \quad (1.122)$$

The effective finesse a user sees when using the etalon depends not only on the absolute clear aperture, but also on the used aperture of the etalon, especially when a high finesse is required.

The examples below show how the effective finesse varies with plate flatness and clear aperture.

Example 1: Air-spaced etalon,

$R = 95\%$ ($\pm 1\%$) at 633 nm

CA = 25 mm

Used aperture = 20 mm

Spacer (air gap) = 1 mm

Spherical / parallelism defects = <λ/20

Plate rms = 0.80 nm

Beam divergence = 0.1 mRad

$\mathcal{F}_R = 61$, $\mathcal{F}_e = 10$

Example 2: Air-spaced etalon,

Same parameters as example 1 except:

Used aperture = 5 mm

$\mathcal{F}_R = 61$, $\mathcal{F}_e = 40$ (± 4)

Example 3: Air-spaced etalon,

Same parameters as example 1 except:

Spherical / parallelism defects = λ/100

Plate rms = 0.40 nm

Beam divergence: 0.1mRad

$\mathcal{F}_R = 61$, $\mathcal{F}_e = 40$ (± 8)

These examples illustrate that, for large-aperture applications, it is important to use very high-quality plates to ensure a high finesse and good transmission values.

TUNING AN ETALON

Etalons can be tuned over a limited range to alter their peak transmission wavelengths. These techniques are:

Angle tuning or tilting the etalon: As the angle of incidence is increased, the center wavelength of the etalon can be tuned down the spectrum.

Temperature tuning: Primarily used for solid etalons, temperature-tuning changes both the actual spacing of the reflective surfaces via expansion and the index of refraction of the material, which changes the optical spacing. The tuning result can be given by

$$\frac{\partial(\mathrm{FSR})}{\partial T} = -(\mathrm{FSR})\left[\frac{1}{\mathrm{n}}\frac{\partial \eta}{\partial T} + \frac{1}{d}\frac{\partial d}{\partial T}\right] \qquad (1.123)$$

Pressure tuning: Air-spaced etalons can be tuned by increasing the pressure in the cavity between the optics, thereby increasing the effective index of refraction, and thus the effective spacing.

The above examples illustrate how critical the optical surface flatness, plate parallelism and surface quality are to the overall performance of an etalon. At CVI Melles Griot we have developed sophisticated software that allows us to simulate all effects that influence the performance of an etalon. To order an etalon, FSR, finesse and used aperture are required.