INTERFERENCE OF LIGHT

(NEP Semester III - Chapter 5)

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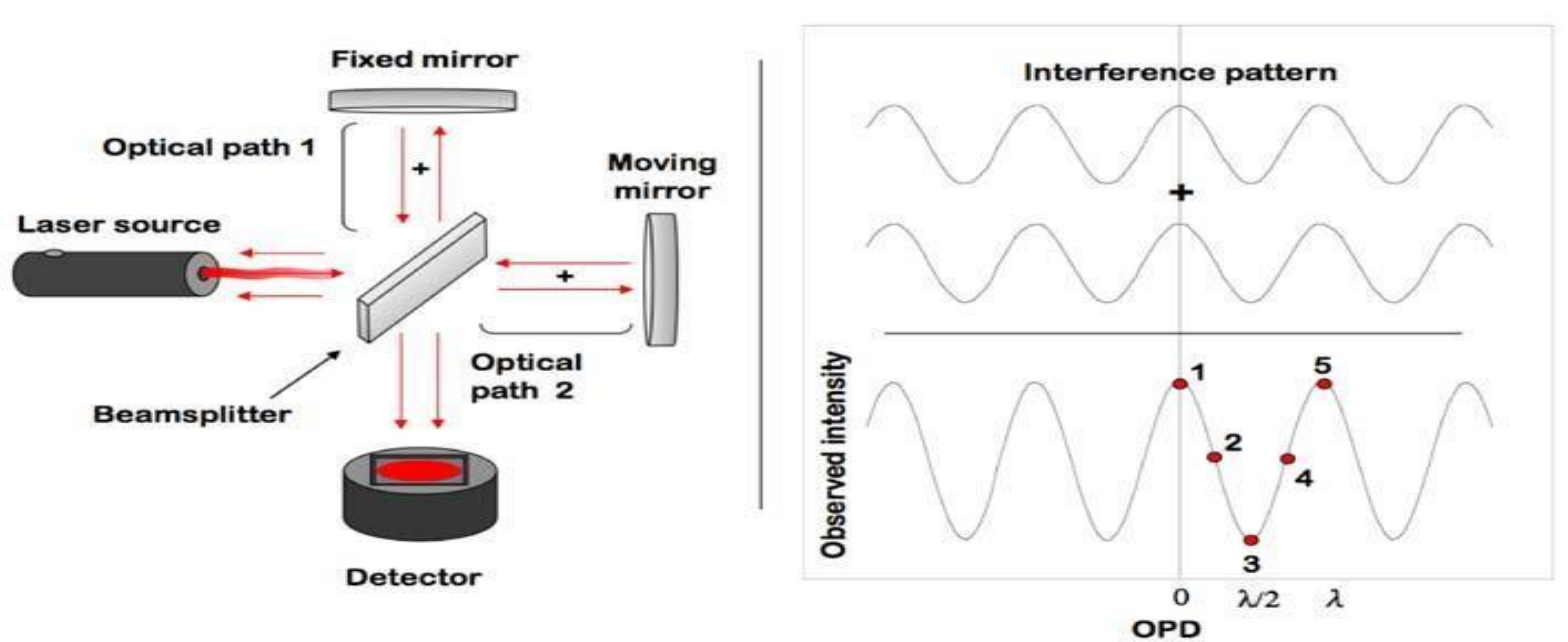
02.06.2021

Definition of Interferometry:

- Interferometry is a family of techniques in which waves, usually electromagnetic waves, are superimposed causing the phenomenon of interference in order to extract information.
- An interferometer is an optical device which utilizes the effect of interference.



Definition:

- Typically, it starts with some input beam, splits it into two separate beams with some kind of beam splitter (a partially transmissive mirror).
- Possibly exposes some of these beams to some external influences (e.g. some length changes or refractive index changes in a transparent medium).
- Recombines the beams on another beam splitter.
- The power or the spatial shape of the resulting beam can then be used e.g. for a measurement.

Physical Principles of Interferometers:

- There are also substantially different principles of using interferometers.
- For example, Michelson interferometers are used in very different ways, using different types of light sources and photo-detectors.
- When a light source with low optical bandwidth is used (perhaps even a single-frequency laser), the detector signal varies periodically when the difference in arm lengths (optical path length) is changed.
- Such a signal makes it possible to do measurements with a depth resolution well below the wavelength, but there is an ambiguity.

Physical Principles of Interferometers:

- For example, a monotonic increase or decrease of the arm length difference leads to the same variation of the detected signal.
- This problem may be solved by modulating the arm length difference e.g. with a vibrating mirror (or with an optical modulator) and by monitoring the resulting modulation on the detector in addition to the average signal power.
- Simultaneous operation of an interferometer with two wavelengths is another way of removing the ambiguity.

Physical Principles of Interferometers:

- If the detector is a kind of camera (e.g. a CCD chip) and the surfaces monitored are fairly smooth, the phase profile (and thus the profile of optical path length) can be reconstructed by recording several images with different overall phase shifts (phase-shifting interferometry).
- A phase-unwrapping algorithm can be used to retrieve unambiguously surface maps extending over more than a wavelength.
- However, such methods may not work for rough surfaces or for surfaces with steep steps.

Physical Principles of Interferometers:

- A white light interferometer uses a broadband light source (e.g., a super-luminescent diode), so that interference fringes are observed only in a narrow range around the point of zero arm length difference.
- In that way, the above-mentioned ambiguity is effectively removed.
- A wavelength-tunable laser can be used to record the detector signal for different optical frequencies.
- From such signals, the arm length difference can be unambiguously retrieved.
- This works also with two-dimensional detectors (e.g. CCD cameras).

Physical Principles of Interferometers:

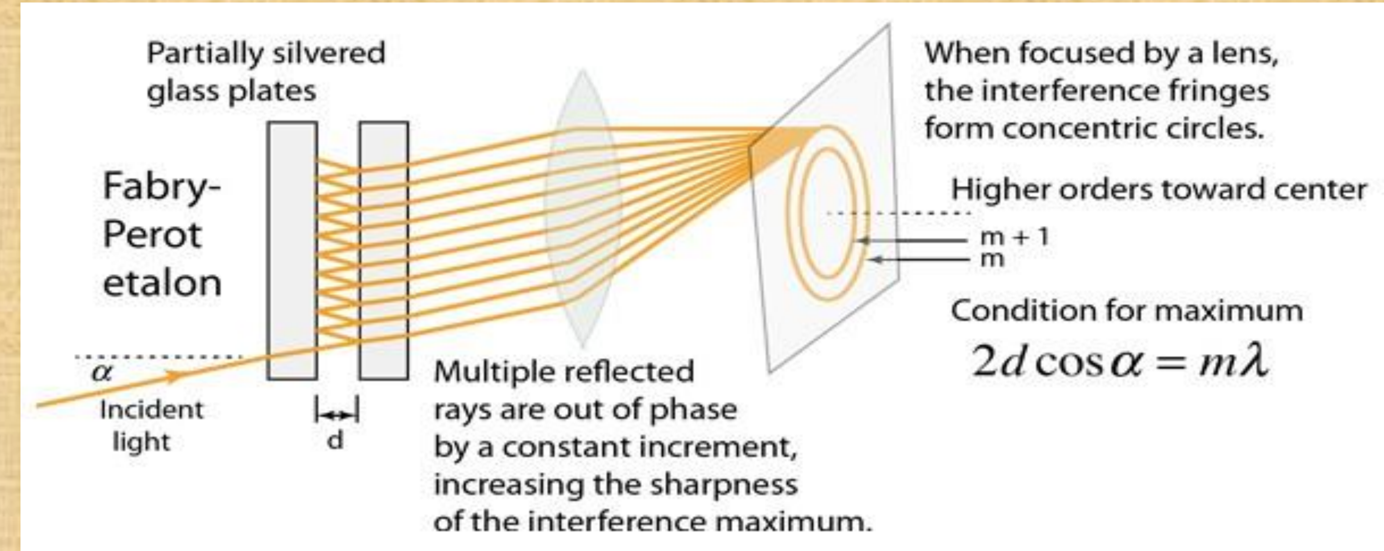
- If one of the mirrors is intentionally tilted, an interference fringe pattern is obtained.
- Any change in arm length difference will then move the fringe pattern.
- This method makes it possible to measure phase changes sensitively and also to measure position-dependent phase changes, e.g. in some optical elements.
- Another class of interferometric method is named as spectral interferometry.
- Here, interference in the spectral domain is exploited.
- The spectral modulation period is essentially determined by a time delay.

Fabry–Pérot Interferometer:

- A Fabry–Pérot interferometer consists of two parallel mirrors, allowing for multiple round trips of light. (A monolithic version of this can be a glass plate with reflective coatings on both sides.)
- For high mirror reflectivities, such a device can have very sharp resonances (a high finesse), i.e. exhibit a high transmission only for optical frequencies which closely match certain values.
- Based on these sharp features, distances (or changes of distances) can be measured with a resolution far better than the wavelength. Similarly, resonance frequencies can be defined very precisely.
- A modified version is the Fizeau interferometer, where the second mirror is totally reflective, and slightly tilted. The reflected light is used (e.g. with an angled beam splitter) e.g. for characterizing optical components.
- Another special kind of Fabry–Pérot interferometer, used for dispersion compensation, is the Gires–Tournois interferometer.

Fabry–Pérot Interferometer:

- This interferometer makes use of multiple reflections between two closely spaced partially silvered surfaces.
- Part of the light is transmitted each time the light reaches the second surface, resulting in multiple offset beams which can interfere with each other.
- The large number of interfering rays produce an interferometer with extremely high resolution, somewhat like the multiple slits of a diffraction grating increase its resolution.



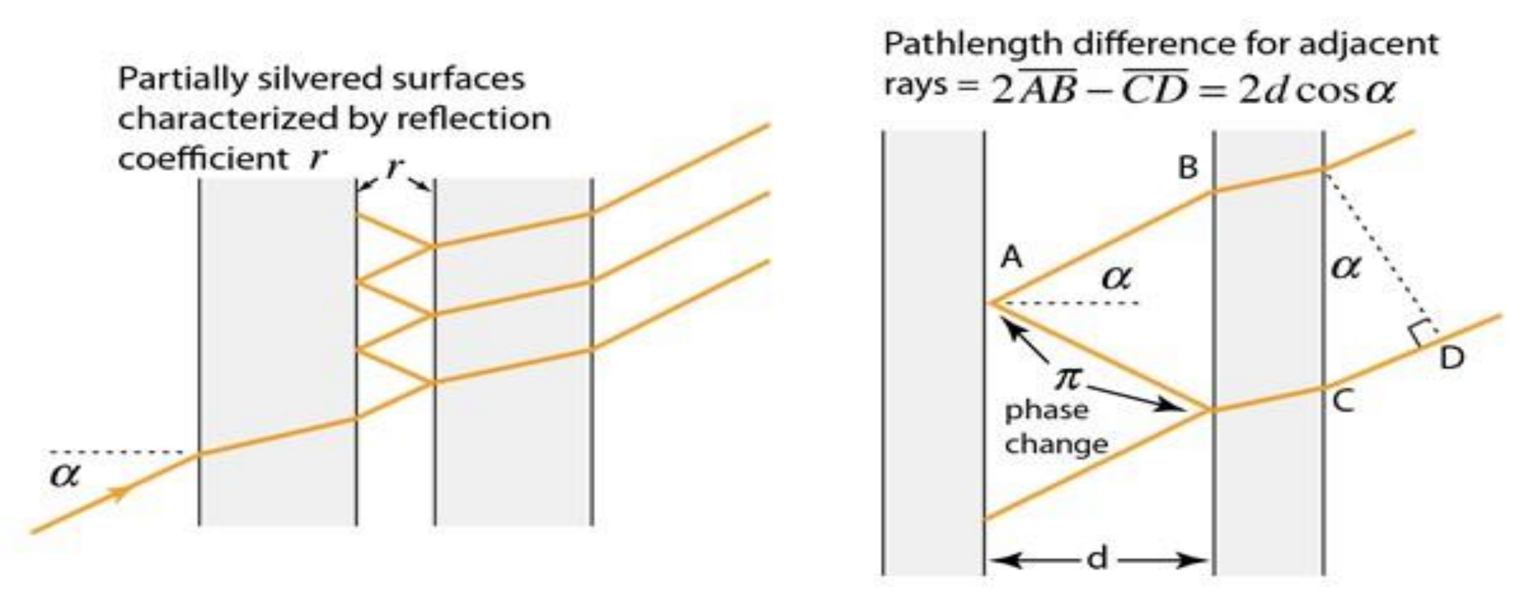
Fabry–Pérot Interferometer:

- The Fabry-Perot Interferometer makes use of multiple reflections which follow the interference condition for thin films.

- The net phase change is zero for two adjacent rays, so the condition

$2d\cos\alpha = m\lambda$

represents an intensity maximum.



Fabry–Pérot Interferometer: Resolution

- A high-resolution interferometer, the Fabry-Perot Interferometer has a resolvance of

$$\frac{\lambda}{\Delta\lambda} = \frac{m\pi\sqrt{r}}{1-r}$$

m = order of interference $\approx \frac{2d}{\lambda}$ for small angles.

r = reflectance of etalon surfaces.

- Which means that the least separation of two spectral lines is given by

$$\Delta\lambda = \frac{\lambda(1-r)}{m\pi\sqrt{r}}$$

- This separation means that the two wavelengths satisfy the Rayleigh criterion.
- The interferometer can also be characterized by its free spectral range, the change in wavelength necessary to shift the fringe system by one fringe:

$$\delta\lambda = \frac{\lambda^2}{2d}$$

Applications:

- Interferometers are used to measure length, distance, displacement with an accuracy & sensitivity of the order of wavelength of light.
- For measuring the wavelength e.g. of a laser beam (→ wavemeter), or for analyzing a beam in terms of wavelength components.
- For monitoring slight changes in an optical wavelength or frequency (typically using the transmission curve of a Fabry–Pérot interferometer) (frequency discriminators).
- For measuring rotations (with a Sagnac interferometer).
- For measuring slight deviations of an optical surface from perfect flatness (or from some other shape).

Applications:

- For measuring the linewidth of a laser (→ self-heterodyne linewidth measurement, frequency discriminator).
- For revealing tiny refractive index variations or induced index changes in a transparent medium.
- For measurements of the chromatic dispersion of optical components.
- As an optical filter.
- For the full characterization of ultrashort pulses via spectral interferometry.