EE 485
Introduction to Photonics
Course Information

Class homepage
- http://faculty.washington.edu/lylin/EE485W04/

Time/Location: MW 9:30-11:20, Bloedel 392

Instructor: Lih Y. Lin (lin@ee.washington.edu)
- Office: M414 EE1
- Office hour: Wed. 11:30-12:30

Credits: 4 units

Main textbook: Saleh and Teich, Fundamentals of Photonics, Wiley-Interscience

Grading
- Homework assignment each week: 50%
  (Homework due one week after they are assigned. No late homework will be accepted.)
- Midterm exam: 20%
- Final exam: 30%
Course Description

Introduction to fundamental optics and optical phenomena. Main topics:

- Ray and Wave Optics
- Gaussian Beam Optics
- Fourier Optics and Diffraction
- Electromagnetic Optics
- Polarization
- Guided-wave and Fiber Optics
- Resonator Optics
- Statistical Properties of Light and Coherence
- Photons
History of Optics

- Geometrical optics (Ray optics)
  - Enunciated by Euclid in *Catoptrics*, 300 B.C.
- Early 1600: First telescope by Galileo Galilei
- Snell’s law — Law of refraction
  - Willebrord Snell, 1621
  - Pierre de Fermat: Principle of least time, 1657
- End of the 16th century: Formulation of theory on the nature of light as wave motion to explain reflection and refraction, by Christian Huygens
- 1704: *Corpuscular* nature of light (light as moving particles) to explain refraction, dispersion, diffraction, and polarization, by Issac Newton, that overshadowed Huygen’s contributions
- Early 1800: Thomas Young explains interference by describing light as consisted of waves
- Maxwell equation (1864) — Light as *electromagnetic waves*, by James Clerk Maxwell
- How about emission and absorption?
- Quantum theory — Light as *photons*
  - 1900: Max Plank introduced the *quantum* theory of light
  - 1905: Albert Einstein extended the idea and demonstrated that in the photoelectric effect, light behaves as particles with energies $\nu = h\nu$
  - 1925-1935: Development of quantum mechanics yielding explanation of the wave-particle duality of light
- 1950s: Communication and information theory
- 1960: First laser
Electromagnetic Spectrum

Optical frequencies
Postulates of Ray Optics

- Light travels in the form of “rays”.
- An optical medium is characterized by refractive index \( n \) \((n \geq 1)\). Speed of light in the medium = \( c_0/n \). Time to travel a distance \( d \) by light = \( nd/c_0 \). \( nd \) = optical path length.
- In an inhomogeneous medium, the refractive index \( n(r) \) is a function of the position \( r = (x,y,z) \).
  
  \[
  \text{Optical path length} = \int_{A}^{B} n(r) \, ds
  \]

- **Fermat’s principle**: Light rays travel along the path of least time.
- **Hero’s principle**: In a homogeneous medium \((n \neq n(x, y, z))\), the path of least time = the path of minimum distance. \( \rightarrow \) Light travel in straight lines.
Postulates of Ray Optics (continued)

- Law of reflection
  - The reflected ray lies in the plane of incidence
  - The angle of reflection equals the angle of incidence
  - (Proved by Hero’s principle)

- Law of refraction
  - The refracted ray lies in the plane of incidence
  - The angle of refraction $\theta_2$ is related to the angle of incidence $\theta_1$ by Snell’s law:
    \[
    n_1 \sin \theta_1 = n_2 \sin \theta_2
    \]
  - (Proved by Fermat’s principle)
Simple Optical Components — Mirrors

**Planar mirrors**

![Reflection from a planar mirror.](image)

**Parabolic mirrors**

![Focusing of light by a paraboloidal mirror.](image)

**Elliptical mirrors**

![Reflection from an elliptical mirror.](image)

**Spherical mirrors**

![Reflection of parallel rays from a concave spherical mirror.](image)
Paraxial Rays Reflected from Spherical Mirrors

Paraxial approximation: Rays travel close to optical axis, \( \sin(\theta) \sim \theta \) (in radians)

**Focal length of a spherical mirror:**

\[
f = \frac{-R}{2}
\]

**Imaging equation:**

\[
\frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{f}
\]
Simple Optical Components – Planar Boundaries

External refraction:
\[ n_1 < n_2, \quad \theta_1 > \theta_2 \]

Internal refraction:
\[ n_1 > n_2, \quad \theta_1 < \theta_2 \]

Total internal reflection:
\[ n_1 > n_2, \quad \theta_2 = 90^\circ \]

Critical angle

\[ \theta_c = \sin^{-1} \frac{n_2}{n_1} \]

Figure 1.2-8  Relation between the angles of refraction and incidence.

Figure 1.2-9  (a) Total internal reflection at a planar boundary. (b) The reflecting prism. If \( n_1 > \sqrt{2} \) and \( n_2 = 1 \) (air), then \( \theta_1 < 45^\circ \); since \( \theta_1 = 45^\circ \), the ray is totally reflected. (c) Rays are guided by total internal reflection from the internal surface of an optical fiber.
Simple Optical Components – Spherical Lenses

Thin lens, paraxial approximation

Focal length $f$

\[
\frac{1}{f} = (n-1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) = (n-1) \left( \frac{1}{R_1} + \frac{1}{|R_2|} \right)
\]

Imaging equation:

\[
\frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{f}
\]

Magnification:

\[
y_2 = -\frac{z_2}{z_1} y_1
\]
Matrix Optics

- A technique for tracing paraxial rays.
- The rays are assumed to travel only within a single plane.
- A ray is described by its position (y) and its angle (θ) with respect to the optical axis.
- The position and angle at the input and output planes of an optical system are related by two linear algebraic equations.
  - The optical system is described by a 2 x 2 matrix called the “ray-transfer matrix”.
- The ray-transfer matrix of a cascade of optical components (or systems) is a product of the ray-transfer matrices of the individual components (or systems).

![Diagram of a ray with y and θ coordinates](image)
The Ray-Transfer Matrix

Paraxial approximation, \( \sin(\theta) \sim \theta \)

\[
y_2 = Ay_1 + B\theta_1 \\
\theta_2 = Cy_1 + D\theta_1
\]

\[
\begin{bmatrix}
y_2 \\ \theta_2
\end{bmatrix} =
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
\begin{bmatrix}
y_1 \\ \theta_1
\end{bmatrix}
\equiv M
\begin{bmatrix}
y_1 \\ \theta_1
\end{bmatrix}
\]
Matrices of Simple Optical Component

Free-space propagation

\[ \mathbf{M} = \begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix} \]

Refraction at a planar boundary

\[ \mathbf{M} = \begin{bmatrix} 1 & 0 \\ 0 & \frac{n_1}{n_2} \end{bmatrix} \]

Refraction at a spherical boundary

\[ \mathbf{M} = \begin{bmatrix} 1 & 0 \\ -\frac{(n_2 - n_1)}{n_2R} & \frac{n_1}{n_2} \end{bmatrix} \]

Convex, \( R > 0 \); concave, \( R < 0 \)

Transmission through a thin lens

\[ \mathbf{M} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{bmatrix} \]

Convex, \( f > 0 \); concave, \( f < 0 \)

Reflection from a planar mirror

\[ \mathbf{M} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \]

Reflection from a spherical mirror

\[ \mathbf{M} = \begin{bmatrix} \frac{1}{2} & 0 \\ \frac{R}{2} & 1 \end{bmatrix} \]

Convex, \( R < 0 \); concave, \( R > 0 \)